# Dose Compliance Concentrations for Radionuclides (DCC)

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## DCC User's Guide

Contents



PDF of User's Guide.

**Welcome to the EPA's "Dose Compliance Concentrations for Radionuclides at Superfund Sites" (DCC) user's guide. Here you will find descriptions, equations and default exposure parameters used to calculate the dose-based DCCs. Additional guidance is also provided on sources of parameters and proper DCC use. It is suggested that users read the DCC 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 recommended approaches based on EPA's best thinking to date with respect to dose assessment for response actions at CERCLA sites. This document does not establish binding rules. Alternative approaches for dose 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 placed in the Administrative Record for the site. Accordingly, 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 ARAR DCC 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. This calculator is intended for use by risk assessors, health physicists and other qualified environmental protection specialists.**

**It should also be noted that calculating a DCC addresses neither human cancer risk 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, or air, and the WTC for uranium inside buildings. EPA's SDCC Calculator should be used to assess radionuclide dose for hard outside surfaces, and the BDCC Calculator for radionuclide dose inside buildings. EPA's PRG Calculator should be used to assess radionuclide cancer risk for soil, water, and air, BPRG Calculator for radionuclide cancer risk inside buildings, and the SPRG Calculator for radionuclide cancer risk 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 DCCs for radionuclides for several different exposure scenarios. The calculator is flexible and may be used to derive site-specific DCCs 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 subsurface conditions, and an assessment of each model's potential applicability to the soil screening process.**

## 1. Introduction

Radionuclide ARAR Dose Compliance Concentrations (DCCs) are dose concentrations derived from standardized equations that combine exposure information, assumptions, and dose conversion factors (DCFs).

The Dose Assessment Guidance is a tool that the U.S. Environmental Protection Agency developed to help standardize the evaluation and cleanup of radioactively contaminated sites at which a doses are being assessed. This guidance provides a methodology for radiation professionals to calculate dose-based, site-specific, dose compliance concentrations (DCCs) for radionuclides complying with a dose-based standard as an ARAR. This guidance supersedes the dose assessment methodology contained in the "Risk Assessment Guidance for Superfund Volume I Human Health Evaluation Manual (Part A) (EPA/540/1-89/002).

A number of different radiation standards may be used as Applicable or Relevant and Appropriate Requirements (ARARs) to establish cleanup levels at a site. Cleanup levels may be based on a number of Federal or State ARARs. Federal standards expressed in terms of dose that are potential ARARs at CERCLA sites include 40 CFR Part 190, "Environmental Radiation Protection Standards for Nuclear Power Operations," 40 CFR Part 191, "Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes," or 10 CFR Part 61, "Licensing Requirements for Land Disposal of Radioactive Waste," among others.

One set of radiation standards consists of a combination of whole body and critical organ dose annual limits, generally either (1) 25 mrem to the whole body, 75 mrem to the thyroid, and 25 mrem to any other critical organ besides the thyroid, or (2) 25 mrem/year to the whole body and 75 mrem/year to any critical organ (including the thyroid). A third set of standards consists of a single limit (e.g., 10 mrem/year). The type of dose limit used in the standard would be the same type of dose methodology used for purposes conducting dose assessment to demonstrate ARAR compliance.

The changes in the dose limits reflect an evolution over time in the approach to dose limitation and in the methods used to calculate doses. The first two radiation protection standards listed above (the 25/75/25 and 25/75 mrem annual dose limits) are based on the older, critical organ concept of dose limitation. This approach limits dose and long-term effects to a specific target tissue or organ (e.g., the thyroid), the most radiosensitive tissue or organ, or the tissue or organ receiving the highest dose. Under this approach, introduced in 1959 by the International Commission on Radiological Protection (ICRP) in its Publication 2, "Report of Committee II on Permissible Dose for Internal Radiation," (ICRP, 1959) the dose to an organ from internally-deposited radionuclides is calculated separately from the dose due to external exposure, and the whole body is essentially treated as one of the critical organs.

Standards were then based on the effective dose equivalent concept of dose limitation introduced in 1977 by the ICRP in its Publication 26, "Recommendations of the International Commission on Radiological Protection" (ICRP, 1977). The effective dose equivalent approach accounts for the differences in the cancer induction rates in organs and tissues subjected to equal doses of radiation and normalizes these doses and effects on a whole body basis. Under this approach, the effective dose equivalent dose is calculated as the weighted sum of the committed dose equivalents (from ingested and inhaled radionuclides) and the dose equivalent (for external exposure from photon-emitting radionuclides) to all organs and tissues. The weighting factors used in these calculations are organ-specific and correspond to the fractional contribution of each organ or tissue to the total risk of fatal cancers when the body is uniformly irradiated. Thus, the summation of all organ and tissue factors is equal to one.

ICRP has since updated the effective dose equivalent concept with the introduction of effective dose quantity in its Publication 60, "1990 recommendations of the International Commission on Radiological Protection" (ICRP, 1991). The effective dose quantity is similar to the effective dose equivalent approach while incorporating updated scientific information in the dose conversion factors. Effective dose quantity incorporates a greater number of organs and updated information on organ-specific risk, and age- specific dose coefficients for internal exposure which incorporate new physiologically-based biokinetic models.

ICRP Publication 107 (ICRP 2008) provides an electronic database of the physical data needed in calculations of radionuclide-specific protection and operational quantities. This database supersedes the data of ICRP 38 and will be used in future ICRP publications of dose coefficients for the intake of or exposure to radionuclides in the workplace and the environment.

The purpose of this document is provide guidance to EPA personnel for the calculation of release criteria based on regulations promulgated under various methods of dose calculation. This guidance will relate these dose limits to a single measure, cleanup concentration. This guidance will assist OSCs and RPMs in making decisions at these sites.

Users of this guidance should note that the use of this calculator to develop dose compliance concentrations for some dose-based ARARs does not affect the CERCLA requirement to comply with all other Federal and State ARARs at a site (e.g., 40 CFR 141.66, 40 CFR 192.12). ARARs are determined site-specifically. For a list of "Likely Federal Radiation Applicable or Relevant and Appropriate (ARARs)", see Attachment A of EPA's guidance "Establishment of Cleanup Levels for CERCLA sites with Radioactive Contamination." For additional guidance documents on compliance with ARARs at radioactively contaminated sites, go to the following webpage: http://www.epa.gov/superfund/resources/radiation/radarars.htm

This website combines current EPA DCFs with "standard" exposure factors to estimate contaminant concentrations in environmental media (soil and water) that are protective of humans(including sensitive groups) over a lifetime. Exceeding a DCC usually suggests that further evaluation of the potential doses is appropriate. The DCC concentrations presented on this website can be used to screen pollutants in environmental media, trigger further investigation, and provide initial cleanup goals, if applicable. DCCs 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. http://www.epa.gov/superfund/resources/radiation/radrisk.htm#train

# 2. Understanding the DCC Website

## 2.1 General Considerations

DCCs are isotope concentrations that correspond to certain levels of dose in air, soil, water and biota. Dose Coefficients (DCFs), for a given radionuclide represent the dose equivalent per unit intake (i.e. ingestion or inhalation) or external exposure of that radionuclide. In dose assessments these DCFs are used in calculations with radionuclide concentrations and exposure assumptions to estimate dose from exposure to radioactive contamination. The calculations may be rearranged to generate DCCs for a specified level of dose. DCFs may be specified for specific body organs or tissues of interest, or as a weighted sum of individual organ dose, termed the effective dose equivalent. These DCFs 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 dose to the receptor. Dose Coefficients 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 dose coefficients 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 dose coefficient value 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 dose coefficient 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 dose coefficient 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. (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 dose coefficient value for the form estimated to pose the maximum dose is reported in the Radionuclide Table in most cases.

Inhaled particulates are assumed to have an activity median aerodynamic diameter (AMAD) of 1 um, as recommended by the ICRP for consideration of environmental exposures in the absence specific information physical characteristics of the aerosol. Where appropriate, radionuclides 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 DCCs are generated with standard exposure route equations using EPA DCFs and exposure parameters. For the calculation of oral dose coefficients, area correction factors, and gamma shielding factors, a standard soil density of 1.6 g/cm$^3$ has been used.

## 2.2 DCC Output Options

The calculator offers three options for calculating DCCs. Previous versions of this calculator employed slope factors that included progeny ingrowth for 100 years and 1000 years; designated "+D" and "+E", respectively. The +D and +E slope factors are no longer included in the pick list. This section describes the potential applications of the three choices and recommends a default DCC calculation.

### 2.2.1 Assume Secular Equilibrium Throughout the Chain (no decay)

This is the preferred DCC calculation option and is marked as the default selection in the calculator. When a single isotope is selected, the calculator identifies all the daughters in the chain. The DCCs for each daughter are combined with the parent on a fractional basis. The fractional basis is determined by branching fractions where a progeny may decay into more than one isotope. The resulting DCC 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 DCC provided in the output would be the inverse sum of the reciprocal DCCs of the parent and all the progeny. Currently, all the soil DCC equation images are presented with a radioactive decay term to account for half-lives shorter than the exposure duration. Decay is not included in this DCC option as the assumption of secular equilibrium is that the parent is continually being renewed.

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

### 2.2.2 Provide Results for Progeny Throughout Chain

This option displays the DCCs calculated with half-life decay as identified in the DCC equation images. In addition to the selected isotope, all the individual progeny DCCs are displayed. This option presents the progeny so that when screening environmental data against DCCs, the risk assessor can identify any isotopes for which he has no data.

### 2.2.3 No Progeny Included

This option displays DCCs, with half-life decay as identified in the DCC equation images, for only the selected isotopes. No progeny DCCs are displayed or contribution combined into the DCC for the selected isotope.

## 2.3 Dose Conversion Factors (DCFs)

Users of this calculator tool should choose the DCFs (International Commission on Radiological Protection (ICRP) 30, 60 or 107) required by the ARAR. If DCFs are not specified within the regulation (for example, the Code of Federal Regulations for a federal standard that is being complied with as an ARAR), then users should generally choose ICRP 107 DCFs. This recommendation is consistent with the guidance contained in "Use of IRIS Values in Superfund Risk Assessment" (OSWER 9285.7-16) for EPA to evaluate dose based upon its best scientific judgment. For further discussion of the scientific differences between ICRP 30 and 60 methodologies, see "Dosimetric Significance of the ICRP's Updated Guidance and Models, 1989-2003, and Implications for U.S. Federal Guidance" (August 2003, ORNL/TM-2003/207). http://ordose.ornl.gov/documents/ornltm2003-207.pdf. For a discussion of the impacts of the ICRP 107 nuclear decay data, see Impact of the New nuclear Decay Data of ICRP Publication 107 on Inhalation Dose Coefficients for Workers.

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 dose coefficients for radionuclides in conventional units of picocuries (pCi). Ingestion and inhalation dose coefficients are central estimates in a linear model of the age-averaged, lifetime attributable radiation cancer incidence (fatal and nonfatal cancer) dose per unit of activity inhaled or ingested, expressed as mrem/pCi. External exposure dose coefficients are central estimates of lifetime attributable radiation dose for each year of exposure to external radiation from photon-emitting radionuclides distributed uniformly in a thick layer of soil, and are expressed as *mrem/year per pCi/gram soil*. External exposure dose coefficients can also be used which have units of *mrem/year per pCi/cm$^2$ soil*. When combined with site-specific media concentration data and appropriate exposure assumptions, dose coefficients can be used to estimate annual dose 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 dose coefficients for radionuclides differs from the guidance presented in RAGS Part F for development of inhalation unit risk (IUR) values for chemicals.

The DCFs from the Center for Radiation Protection Knowledge differ from the values presented in FGR 12 CD supplement. The DCFs were calculated using ORNL's DCAL software in the manner of Federal Guidance Report 12 and 13. For the calculation of oral dose coefficients, a standard soil density of 1.6 g/cm$^3$ 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.

### 2.3.1 ICRP 30

Unlike ICRP 2 which did not calculate DCFs per se, ICRP 30 does present DCFs which may be used to calculate either organ dose equivalent or effective dose equivalent for ingestion and inhalation. For each radionuclide, ICRP 30 provides values for the organ dose equivalent conversion factors, hT,50, and the effective dose equivalent conversion factor, hE,50 (calculated using the organ weighting factors $w_T$). These values are also presented in Federal Guidance Report No. 11. Organ DCFs are provided for those organs which have specific weighting factors, namely the gonads, breast, red marrow, lungs, thyroid, and bone surfaces. Organ DCFs are also given for the remainder, which includes the five remaining tissues which receive the next highest doses. These include the liver, kidneys, spleen, brain, small intestine, upper large intestine, lower large intestine, etc.

Organ dose equivalent conversion factors and effective dose equivalent conversion factors for all radionuclides selected for this analysis are provided in Attachment A, Table A.2 (inhalation) and Table A.3 (ingestion). These values, in units of mrem/pCi, have been taken from Tables 2.1 and 2.2 respectively of Federal Guidance Report No. 11.

### 2.3.2 ICRP 60

ICRP 60 also presents DCFs. This is the document on which most of the world's radiation standards are based. ICRP 60 is similar to ICRP 30 except that it is based on more recent findings. Basically, there were more cancers observed in the Japanese populations exposed to radiation in the bombings, and so risk estimates increased. There were also reevaluations of the radiation dose calculations. These values are also presented in Federal Guidance Report No. 13.

The spontaneous fission isotopes are not in FGR-13. They are released in ICRP 72. ICRP 72 is analogous to the FGR 13 CD that contains most of the same values. Cf-252, Cf-254, Cm-248, Cm-250 and Pu-244 are the isotopes that decay by spontaneous fission at greater than 0.1%.

The use of dose conversion factors of ICRP 60/72 is mandated in the European Union by European Council Directive 96/29 of May 13, 1996. If requested, NRC can grant a licensee an exemption to use the new dosimetric data of the ICRP; e.g. ICRP 68 for occupational exposures. In accordance with a June 8, 2007 Federal Register notice, DOE no longer requires a facility to get an exception and they are able to use ICRP 68 dosimetric data for occupational exposure. Non-regulatory studies (e.g., dose assessments) use the technically best available dose coefficients which are those of the recent ICRP Publications. In addition, the IAEA in its Safety Series has adopted the ICRP Publication 60 Recommendations and the subsequent dose coefficients. For example, the dose coefficients of ICRP Publication 68 are contained in the IAEA Safety Guide entitled "Assessment of Occupational Exposure Due to Intakes of Radionuclides" RS-G-1.2 issued in 1999.

### 2.3.3 ICRP 107

ICRP Publication 107 (ICRP 2008) provides an electronic database of the physical data needed in calculations of radionuclide-specific protection and operational quantities. This database supersedes the data of ICRP 38 and will be used in future ICRP publications of dose coefficients for the intake of or exposure to radionuclides in the workplace and the environment.

The database contains information on the half-lives, decay chains, and yields and energies of radiations emitted in nuclear transformations of 1252 radionuclides of 97 elements. The CD accompanying the publication provides electronic access to complete tables of the emitted radiations, as well as the beta and neutron spectra. The database has been constructed such that user-developed software can extract the data needed for further calculations of a radionuclide of interest. A Windows- based application is provided to display summary information on a user-specified radionuclide, as well as the general characterization of the nuclides contained in the database. In addition, the application provides a means by which the user can export the emissions of a specified radionuclide for use in subsequent calculations.

### 2.3.4 Federal Guidance Report 12

ICRP Publications 30 and 60 provide dose coefficients for the ingestion and inhalation intake of radionuclides. Dose coefficients for exposure to the radiations emitted by radionuclides present outside the body are given in Federal Guidance Report 12. That report addresses radionuclides uniformly distributed in air, in water, on the surface of the soil and within the volume of the soil. The published report is consistent with ICRP Publication 26 however the CD Supplement to Federal Guidance Report 13 provides values for the effective dose as defined in ICRP Publication 60.

### 2.3.5 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 DCCs. 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. 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.
3. 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.
4. RESRAD. User's Manual for RESRAD Version 6. Environmental Assessment Division, Argonne National Laboratory. July 2001. Spreadsheet of values.
5. 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.
6. ICRP 2008. Nuclear Decay Data for Dosimetric Calculations. International Commission on Radiological Protection Publication 107. Ann. ICRP 38 (3), 2008.
7. EPAKD. Understanding Variation in Partition Coefficient, Kd, Values. Volume II: Review of Geochemistry and Available Kd 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. and Volume III: Review of Geochemistry and Available Kd 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. Fish bioconcentration factor (BCF (L/kg). IAEA, EA, RESRAD. BCF is the ratio of the radionuclide concentration in the fish tissue (pCi/kg fresh weight) from all exposure pathways relative to that in water (pCi/L).
5. 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).
6. 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).
7. 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).
8. Sheep Milk transfer factor ($TF_{sheep\text{-}milk}$ (day/L). IAEA. $TF_{sheep\text{-}milk}$ is the volumetric activity density in sheep milk (pCi/L) divided by the daily intake of radionuclide (pCi/day).
9. 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).
10. Goat Milk transfer factor ($TF_{goat\text{-}milk}$ (day/L). IAEA. $TF_{goat\text{-}milk}$ is the volumetric activity density in goat milk (pCi/L) divided by the daily intake of radionuclide (pCi/day).
11. 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).
12. Soil to water partition coefficient ($K_d$ (mg/kg-soil per mg/L water or simplified = L/kg). EPAKD, IAEA, SSL, RESRAD, BAES. ($K_d$ is the ratio of the mass activity density (pCi/kg) of the specified solid phase (usually on a dry mass basis) to the volumetric activity density (Bq/L) of the specified liquid phase.
13. Soil to plant transfer factor-wet ($Bv_{wet}$ (pCi/g plant per pCi/g soil). IAEA, EA, NCRP, SSL, RESRAD, BAES. The values for cereal grain are used from IAEA. ($Bv_{wet}$ is the ratio of the activity concentration of radionuclide in the plant (pCi/kg wet mass) to that in the soil (pCi/kg dry mass). Note: Some $Bv_{wet}$ values were derived from $Bv_{dry}$ sources, assuming the ratio of dry mass to fresh mass was presented in the source documents.
    - For carbon, the only value in the hierarchy is found in RESRAD. This value is excluded as it over estimates root uptake. See section 2.5.4 for a detailed discussion of the carbon transfer factor derivation.
14. Soil to plant transfer factor-dry ($Bv_{dry}$ (pCi/g plant per pCi/g soil). IAEA, EA, NCRP, SSL, RESRAD, BAES. The values for cereal grain are used. ($Bv_{dry}$ is the ratio of the activity concentration of radionuclide in the plant (pCi/kg dry mass) to that in the soil (pCi/kg dry mass). Note: Some $Bv_{dry}$ values were derived from $Bv_{wet}$ sources, assuming the ratio of dry mass to fresh mass was presented in the source documents.
    - For carbon, the only value in the hierarchy is found in RESRAD. This value is excluded as it over estimates root uptake. See section 2.5.4 for a detailed discussion of the carbon transfer factor derivation.

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

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

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 22 individually calculated DCCs that make up the default produce DCC. Each individual DCC is determine based on produce specific data such as intake rate, soil to plant transfer factors ($Bv_{wet}$), and soil mass loading factor (MLF). These 22 individual DCCs are then summed by inverse reciprocal to determine a total produce DCC. The MLFs and intake rates used in the determination of the default biota DCCs are based on fresh weight. Intake rates, MLFs, and tranfer factors were updated in July 2016. A pdf of the Technical Memorandum, released for this update, can 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 DCC. 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 prepartion 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 our tool, such as soil to plant transfer factor, mass loading factor, contaminated fraction, and intake rates. Another source for intake rates 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.

| 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** | 82.9 | 84.7 | 72.2 | 73.7 | 43.0 | 43.9 | 37.4 | 38.2 |
| **Citrus** | 194.4 | 309.4 | 194.1 | 309.4 | 100.6 | 160.4 | 100.6 | 160.4 |
| **Berries other than Strawberries** | 23.9 | 35.4 | 23.9 | 35.4 | 12.4 | 18.3 | 12.4 | 18.3 |
| **Peaches** | 99.3 | 103.1 | 111.4 | 115.7 | 51.5 | 53.5 | 57.7 | 60.0 |
| **Pears** | 76.9 | 59.9 | 66.7 | 51.9 | 39.9 | 31.1 | 34.6 | 26.9 |
| **Strawberries** | 25.3 | 40.5 | 25.3 | 40.5 | 13.1 | 21.0 | 13.1 | 21.0 |
| **Asparagas** | 12.0 | 39.3 | 12.0 | 39.3 | 8.2 | 26.8 | 8.2 | 26.8 |
| **Beets** | 3.9 | 33.9 | 3.9 | 33.9 | 2.7 | 23.2 | 2.7 | 23.2 |
| **Broccoli** | 14.4 | 35.3 | 13.1 | 32.0 | 9.9 | 24.1 | 8.9 | 21.9 |
| **Cabbage** | 11.5 | 85.7 | 12.3 | 92.1 | 7.8 | 58.6 | 8.4 | 62.9 |
| **Carrots** | 13.3 | 24.4 | 14.9 | 27.3 | 9.1 | 16.6 | 10.2 | 18.7 |
| **Corn** | 32.7 | 82.0 | 23.8 | 59.8 | 22.3 | 56.0 | 16.3 | 40.9 |
| **Cucumbers** | 16.9 | 54.9 | 25.4 | 82.4 | 11.5 | 37.5 | 17.3 | 56.3 |
| **Lettuce** | 4.2 | 37.5 | 4.2 | 37.5 | 2.9 | 25.6 | 2.9 | 25.6 |
| **Lima Beans** | 6.5 | 33.8 | 6.5 | 33.8 | 4.5 | 23.1 | 4.5 | 23.1 |
| **Okra** | 5.3 | 30.2 | 5.3 | 30.2 | 3.6 | 20.7 | 3.6 | 20.7 |
| **Onions** | 7.2 | 27.2 | 5.8 | 21.8 | 4.9 | 18.6 | 4.0 | 14.9 |
| **Peas** | 28.7 | 31.7 | 32.1 | 35.4 | 19.6 | 21.7 | 21.9 | 24.2 |
| **Pumpkins** | 45.2 | 64.8 | 45.2 | 64.8 | 30.9 | 44.2 | 30.9 | 44.2 |
| **Snap Beans** | 27.5 | 54.2 | 27.3 | 53.9 | 18.8 | 37.0 | 18.7 | 36.8 |
| **Tomatoes** | 34.9 | 94.2 | 29.7 | 80.3 | 23.8 | 64.4 | 20.3 | 54.8 |
| **White Potatoes** | 57.3 | 141.8 | 51.7 | 127.8 | 39.1 | 96.9 | 35.3 | 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** | 34.8 | 88.5 | 28.8 | 73.2 |
| **Cereal Grain** | 46.0 | 91.9 | 38.0 | 76.0 |

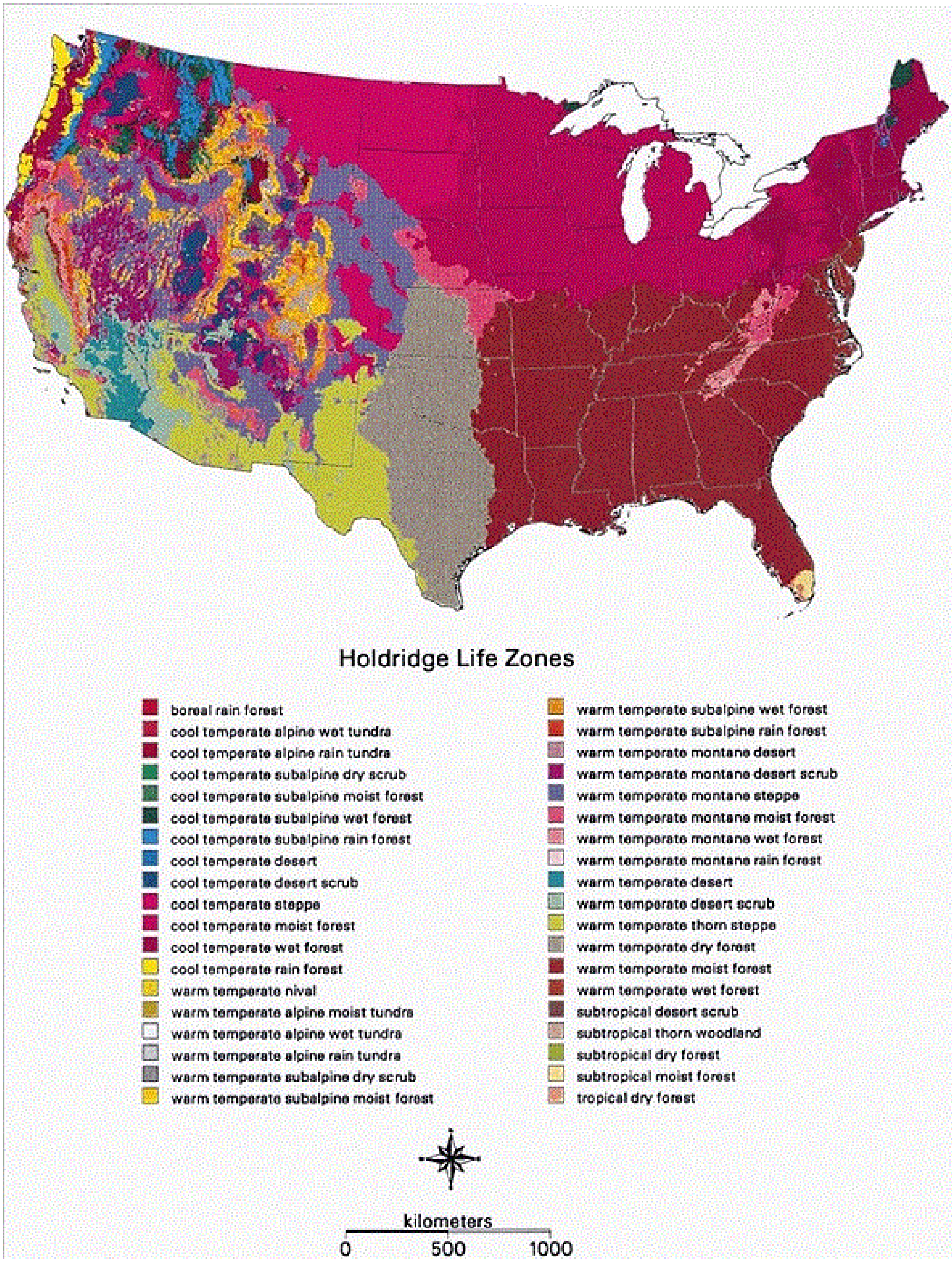
To determine which produce are commonly cultivated in the area around the site, users should contact their county extension office. The National Pesticide Information Center has an interactive map that allows users to choose their state and county; then connects them to their county extension office.

#### 2.5.1.2 Soil to Plant Transfer Factors ($Bv_{wet}$)

The new soil to plant transfer factors ($Bv_{wet}$) 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 24 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 22 produce 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 22 produce are based on fresh weight. For rice, IAEA did not specify a particular climate zone and, therefore, the rice transfer factors have been applied to all three climate zones.

### Climate Zones

The following map shows how the climate zones are distributed across the United States.




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

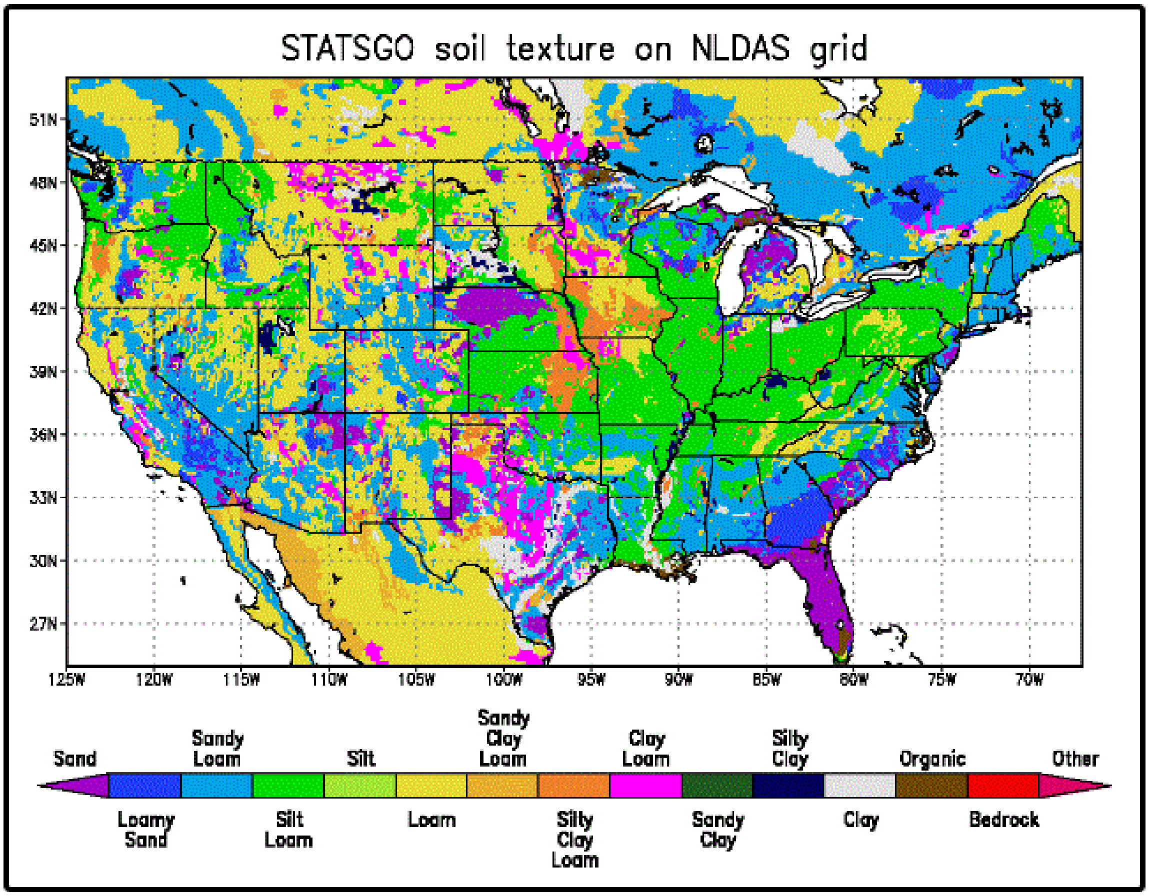
### Soil Types

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

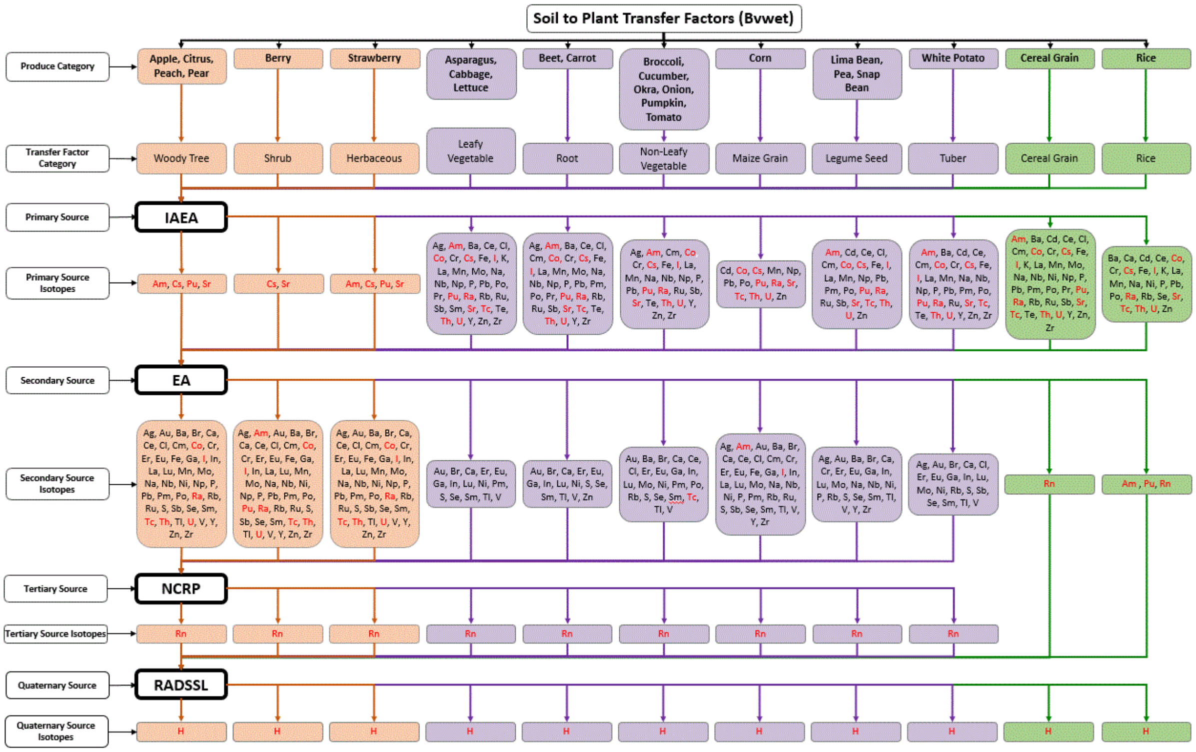
### Produce Types

The following table illustrates which soil to plant transfer factor categories from IAEA are used for each produce type in the DCC calculator. The individual produce output only lists the category name from IAEA, however, a value from a secondary source may be being 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 |
| **Asparagas** | 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** | Non-Leafy Vegetable | 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 |
| **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 |

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




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

- 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 DCC 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 is 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 tranfer factor for turkey or goose, then user-provided mode should be used.

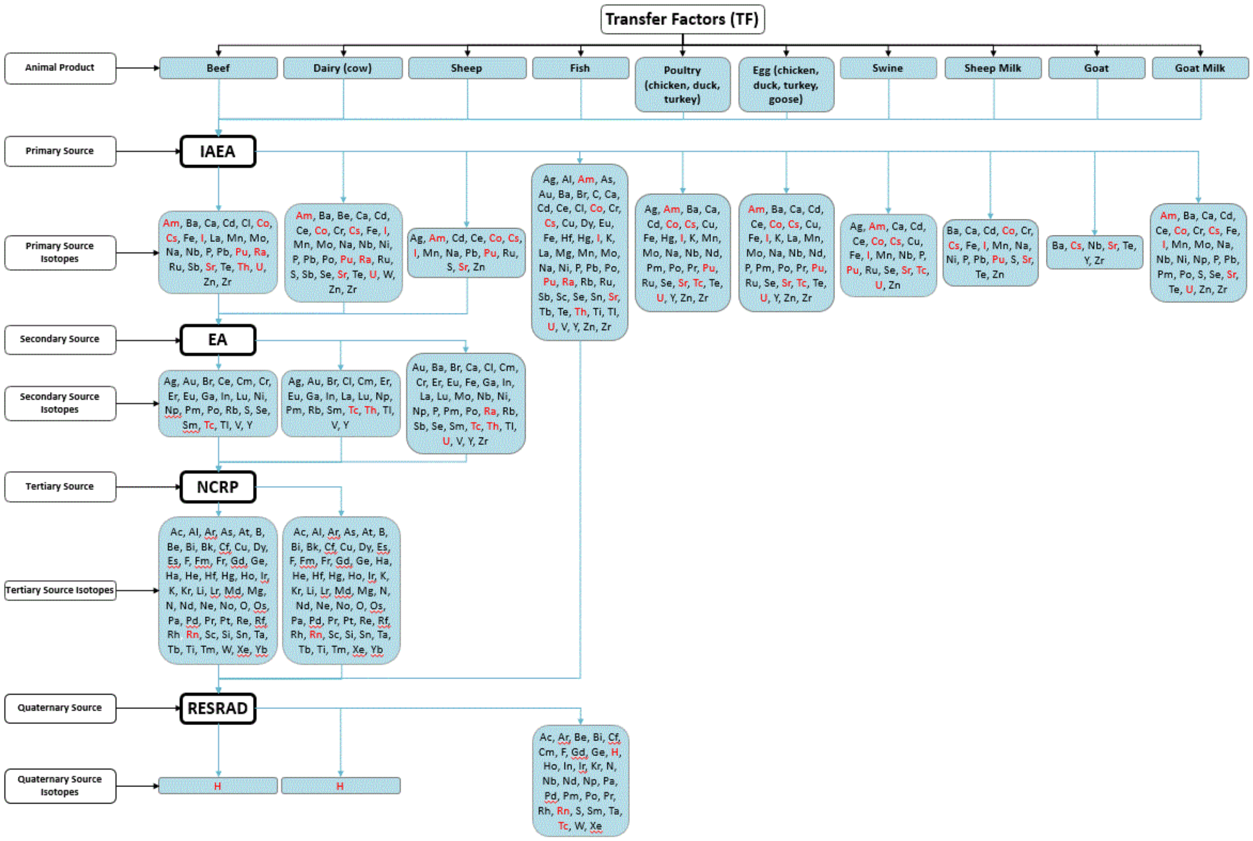
| Table 2.5.2-A | Intake Rate for Farmer Child (g/day) (FW) | Intake Rate for Farmer Adult (g/day) (FW) | Intake Rate for Farmer Child (g/day) (CPW) | Intake Rate for Farmer Adult (g/day) (CPW) |
|---|---|---|---|---|
| **Dairy - Cow** | 994.7 | 676.4 | 994.7 | 676.4 |
| **Beef** | 62.8 | 165.3 | 31.1 | 81.7 |
| **Swine** | 33.7 | 92.5 | 16.6 | 45.7 |
| **Poultry** | 46.9 | 107.4 | 23.2 | 53.1 |
| **Egg** | 31.7 | 59.6 | 31.7 | 59.6 |
| **Fish** | 57.4 | 831.8 | 35.2 | 509.9 |

Site-specific mode will also offer 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, 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, RESRAD and BAES sources do not contribute to our current output. They are retained in the user guide for informational purposes.




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

- 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 DCC calculator.

## 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. This file is engineered for 2 sided printing.

| Table 2.5.3-A | Mass Loading Facotr (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) |
| **Asparagas** | 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) |
| **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** | 1.59E-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+004 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 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% 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 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 DCCs in Context of Superfund Modeling Framework

This DCC calculator focuses on the application of a generic and simple site-specific approaches that are part of a larger framework for calculating concentration levels for complying with dose based ARARs. Generic DCCs for a 1 mrem standard are provided by viewing either the tables in the Download Area section of this calculator or by running the DCC Search section of this calculator with the "Get Default ARAR Concentrations" option. Part 3 of the Soil Screening Guidance for Radionuclides: Technical Background Document provides more information about 5 more detailed soil to groundwater models that are part of the same framework.

Generic DCCs are calculated from the same equations presented in the site-specific portion of the calculator, but are based on a number of default assumptions chosen to be protective of human health for most site conditions. Generic DCCs, which should be scaled to the same dose level as the standard being complied (e.g., multiplied by a factor of ten for a 10 mrem/year standard) can be used in place of site-specific DCC levels; however, in general, they are expected to be more conservative than site-specific levels. The site manager should weigh the cost of collecting the data necessary to develop site-specific DCCs with the potential for deriving a higher DCC 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 in 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 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". 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, then justification for doing so should be developed. The justification should include specific supporting data and information in the administrative record. The justification would normally include the model runs, using both the recommended EPA DCC model and the alternative model. Users are cautioned that they should have a thorough understanding of both the DCC 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 DCC 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 DCC calculators for the remedial program to establish the dose-based concentrations to ensure consistency with CERCLA, the NCP, and EPA's Superfund guidance for remedial sites. Prior to using another model for dose 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, 17, and 18 of Radiation Risk Assessment At CERCLA Sites: Q & A (EPA 540-R-012-13, May 2014).

## 2.7 Understanding Dose Output on the DCC Website

The DCC calculator provides an option to select dose output. In the calculator, select yes if dose output is desired. Selecting dose output requires the calculator to be run in "Site Specific" mode. The "Soil to Groundwater" medium does not have dose output and will become disabled when dose output is selected. The dose 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 Dose Output

This portion of the risk assessment process is generally referred to as "Dose Characterization". This step incorporates the outcome of the exposure and toxicity assessments to calculate the dose resulting from potential exposure to radionuclides via the pathways and routes of exposure determined appropriate for the source area.

The process used to calculate dose in this calculator does not follow the traditional method of first calculating a CDI (Chronic Daily Intake). Rather, dose is derived using a simple method that relies on the linear nature of the relationship between concentration and dose. Using the equation below, a DCC, the dose limit used to calculate the DCC, and a concentration entered by the user are all that is required to calculate dose.

$DL / DCC = Dose / C$

The linear equation above is then rearranged to solve for dose:

$Dose = (C \times DL) / DCC$

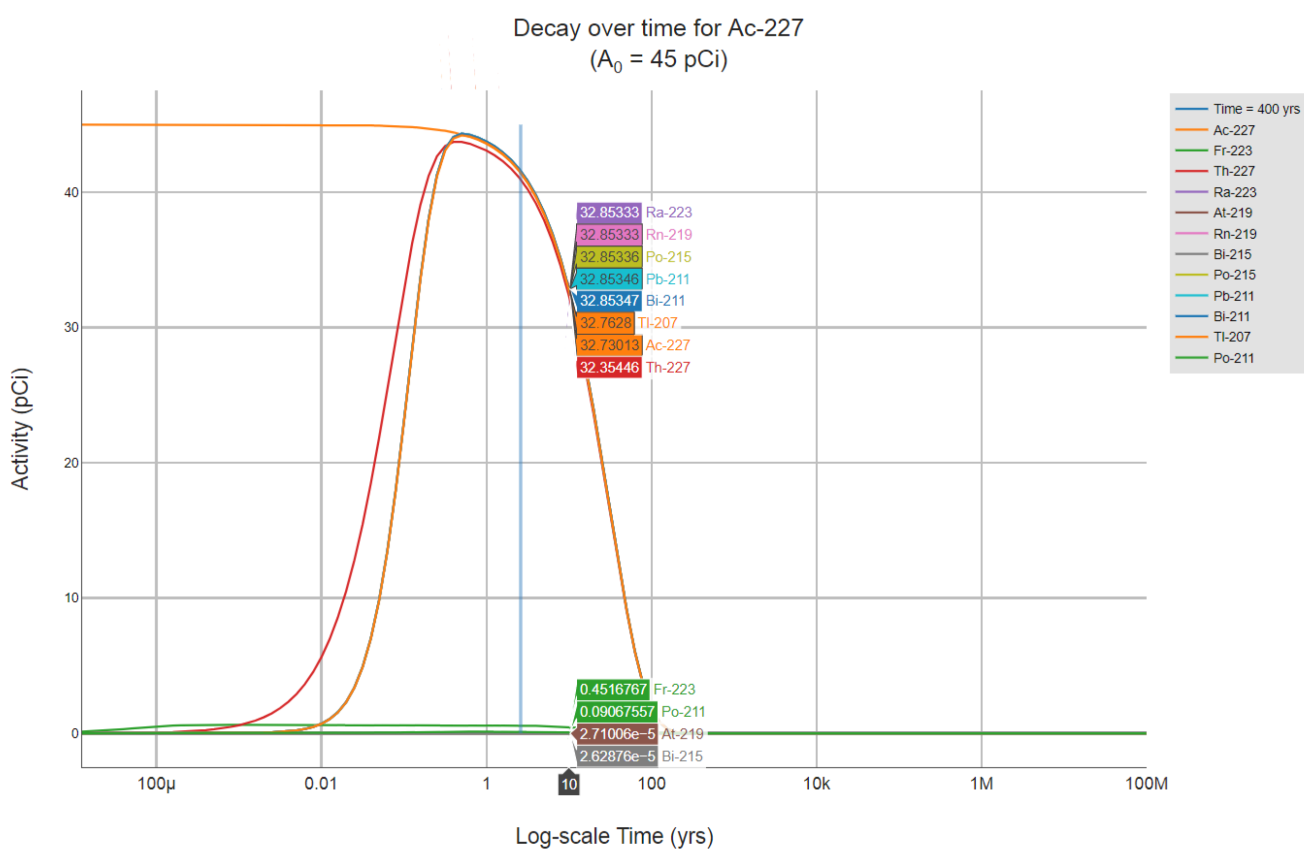
where:

Dose = The energy absorbed from radiation by a person (mrem/year);
C = Concentration entered by the user in site-specific mode [pCi/g ; pCi/$cm^2$ ; pCi/$m^3$ ; pCi/L]
DL = Dose Limit provided by the user in site-specific mode [mrem/year]
DCC = Dose Compliance Concentration, determined by the values entered by the user in site-specific mode [pCi/g ; pCi/$cm^2$ ; pCi/$m^3$ ; pCi/L]

### 2.7.2 General Considerations for Entering Site Data

As presented in the previous section, the dose output is dependent on the DCC calculated. Section 2.2 discusses the DCC output options. To summarize section 2.2, the DCC options are either secular equilibrium or not. 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 dose 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 DCC calculator to calculate dose using the second and third DCC Output options.




## 3. Using the DCC Table

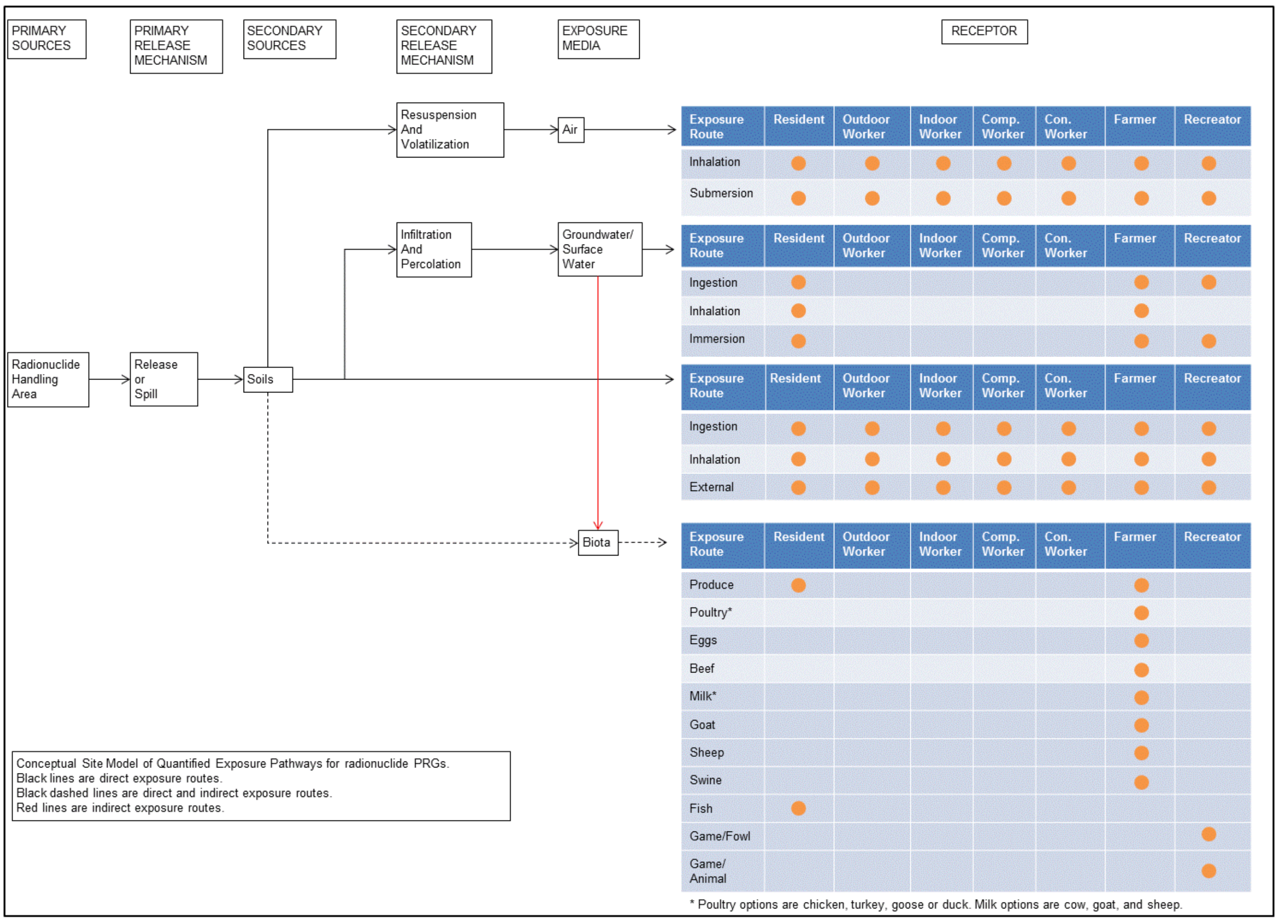
The tables in the DCC Download Area provide generic concentrations in the absence of site-specific dose assessments. Screening concentrations can be used for:

- Prioritizing multiple sites within a facility or exposure units
- Setting dose-based detection limits for contaminants of potential concern (COPCs)
- Focusing future dose assessment efforts

### 3.1 Developing a Conceptual Site Model

When using DCCs, the exposure pathways of concern and site conditions must match those taken into account by the screening levels. 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 conceptual site model for the land uses presented in this calculator is presented below.




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 covered by the DCC levels (i.e., resident and worker)?
- Are there other likely human exposure pathways that were not considered in development of the DCC levels?
- Are there unusual site conditions (e.g. large areas of contamination, high fugitive dust levels, potential for indoor air contamination)?

The DCCs 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 DCCs 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, (OSWER 9285.6-07P). 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 dose-based tool, the potential exists for misapplication. In most cases, this results from not understanding the intended use of the DCCs. In order to prevent misuse of the DCCs, the following should be avoided:

- Applying DCC levels to a site without adequately developing a conceptual site model that identifies relevant exposure pathways and exposure scenarios.

- Use of DCC levels as cleanup levels without the consideration of other relevant criteria such as ARARs,
- Use of DCC levels as cleanup levels without verifying numbers with a health physicist/risk assessor.
- Use of outdated DCC levels tables that have been superseded by more recent publications.
- Not considering the effects from the presence of multiple isotopes.
- Not considering the individual model limitations as described in section 4 (e.g., inhalation of tapwater only considers C-14, H-3, Ra-224, Ra-226, Rn-220, and Rn-222).

# 4. Land Use Descriptions, Equations, and Technical Documentation

The DCCs consider human exposure from contact with contaminated soils and water. The equations and technical discussion are aimed at developing compliance levels for dose-based ARARs. 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 DCC 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 2002. 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.

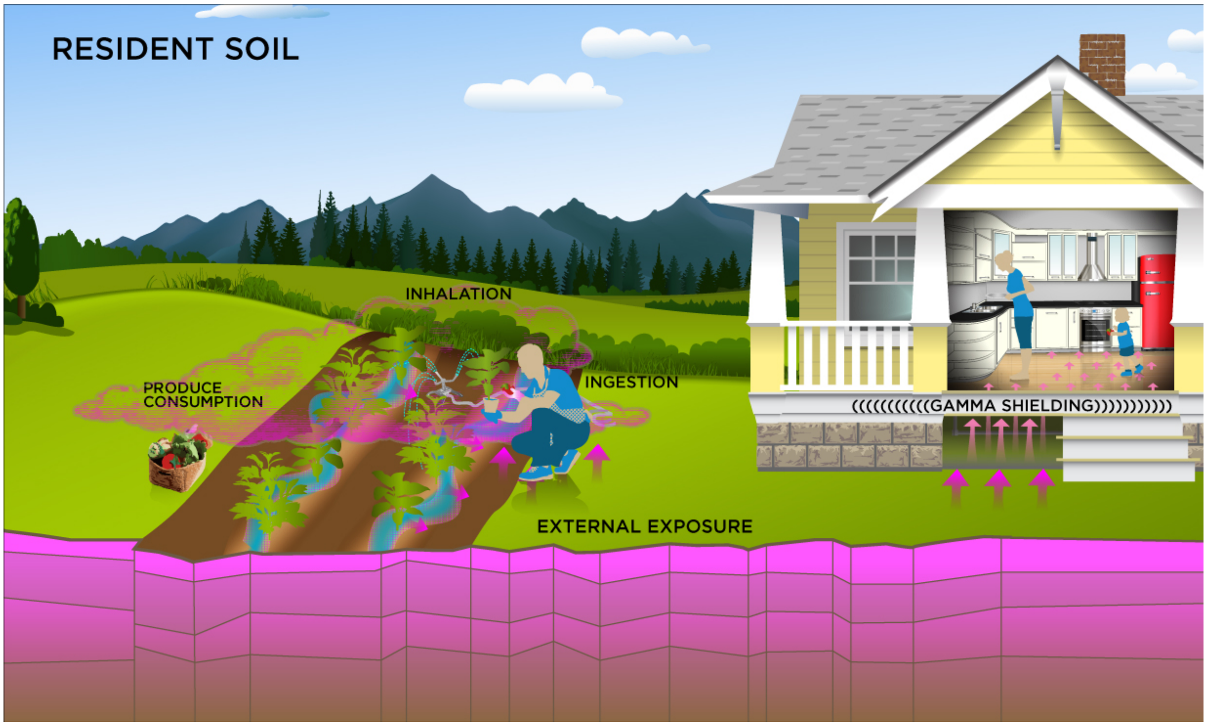
Users should note that if a route of exposure (e.g., ingesting fish from the pond in the farmer soil exposure scenario) is considered to be unreasonable at their site, both currently and in the future, they may eliminate the route in the site-specific option by entering zero for the ingestion rate of that route (e.g., replacing default fish ingestion rates in farmer soil scenario of 156.6 and 32.8 g/day with 0.0).

## 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 making 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, 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.

#### Graphical Representation




## Equations

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

- incidental ingestion of soil,

$$DCC_{res\text{-}soil\text{-}ing}(\text{pCi/g}) = \frac{DL\left(\frac{\text{mrem}}{\text{year}}\right) \times t_{res}(\text{year}) \times \lambda\left(\frac{1}{\text{year}}\right)}{\left(1-e^{-\lambda t_{res}}\right) \times DCF_{o}\left(\frac{\text{mrem}}{\text{pCi}}\right) \times IFS_{res\text{-}adj}\left(\frac{43{,}050\ \text{mg}}{\text{year}}\right) \times \left(\frac{\text{g}}{1000\ \text{mg}}\right)}$$

where:

$$IFS_{res\text{-}adj}\left(\frac{43{,}050\ \text{mg}}{\text{year}}\right) = \left(\begin{array}{l}\left(EF_{res\text{-}c}\left(\frac{350\ \text{days}}{\text{year}}\right) \times IRS_{res\text{-}c}\left(\frac{200\ \text{mg}}{\text{day}}\right) \times AAF_{res\text{-}c}(0.23)\right) + \\ \left(EF_{res\text{-}a}\left(\frac{350\ \text{days}}{\text{year}}\right) \times IRS_{res\text{-}a}\left(\frac{100\ \text{mg}}{\text{day}}\right) \times AAF_{res\text{-}a}(0.77)\right)\end{array}\right)$$

where:

$$AAF_{res\text{-}c}(0.23) = \left(\frac{ED_{res\text{-}c}(6\ \text{years})}{ED_{res}(26\ \text{years})}\right) \text{ and: } AAF_{res\text{-}a}(0.77) = \left(\frac{ED_{res\text{-}a}(20\ \text{years})}{ED_{res}(26\ \text{years})}\right)$$

- inhalation of particulates emitted from soil,

$$DCC_{res\text{-}soil\text{-}inh}(\text{pCi/g}) = \frac{DL\left(\frac{\text{mrem}}{\text{year}}\right) \times t_{res}(\text{year}) \times \lambda\left(\frac{1}{\text{year}}\right)}{\left(1-e^{-\lambda t_{res}}\right) \times DCF_{i}\left(\frac{\text{mrem}}{\text{pCi}}\right) \times IFA_{res\text{-}adj}\left(\frac{6{,}195\ \text{m}^3}{\text{year}}\right) \times \frac{1}{PEF\left(\frac{\text{m}^3}{\text{kg}}\right)} \times \left(\frac{1000\ \text{g}}{\text{kg}}\right)}$$

where:

$$IFA_{res\text{-}adj}\left(\frac{6{,}195\ \text{m}^3}{\text{year}}\right) = \left(\begin{array}{l}\left(EF_{res\text{-}c}\left(\frac{350\ \text{days}}{\text{year}}\right) \times ET_{res\text{-}c}\left(\frac{24\ \text{hours}}{\text{day}}\right) \times \left(\frac{1\ \text{day}}{24\ \text{hours}}\right) \times IRA_{res\text{-}c}\left(\frac{10\ \text{m}^3}{\text{day}}\right) \times AAF_{res\text{-}c}(0.23)\right) + \\ \left(EF_{res\text{-}a}\left(\frac{350\ \text{days}}{\text{year}}\right) \times ET_{res\text{-}a}\left(\frac{24\ \text{hours}}{\text{day}}\right) \times \left(\frac{1\ \text{day}}{24\ \text{hours}}\right) \times IRA_{res\text{-}a}\left(\frac{20\ \text{m}^3}{\text{day}}\right) \times AAF_{res\text{-}a}(0.77)\right)\end{array}\right)$$

where:

$$AAF_{res\text{-}c}(0.23) = \left(\frac{ED_{res\text{-}c}(6\ \text{years})}{ED_{res}(26\ \text{years})}\right) \text{ and: } AAF_{res\text{-}a}(0.77) = \left(\frac{ED_{res\text{-}a}(20\ \text{years})}{ED_{res}(26\ \text{years})}\right)$$

- external exposure to ionizing radiation, and

$$DCC_{res\text{-}soil\text{-}ext}(pCi/g) = \frac{DL\left(\frac{mrem}{year}\right) \times t_{res}(year) \times \lambda\left(\frac{1}{year}\right)}{\left(1-e^{-\lambda t_{res}}\right) \times DCF_{ext\text{-}sv}\left(\frac{mrem/year}{pCi/g}\right) \times EF_{res}\left(\frac{350\ days}{year}\right) \times \left(\frac{1\ year}{365\ days}\right) \times ACF_{ext\text{-}sv} \times \left[\left(ET_{res\text{-}o}\left(\frac{1.752\ hours}{day}\right) \times \left(\frac{1\ day}{24\ hours}\right) \times GSF_{ext\text{-}sv}(1.0)\right) + \left(ET_{res\text{-}i}\left(\frac{16.416\ hours}{day}\right) \times \left(\frac{1\ day}{24\ hours}\right) \times GSF_{i\text{-}total}\right)\right]}$$

- consumption of produce (fruits and vegetables) - back-calculated to soil. Sections 9 and 13 of the 2011 Exposure Factors Handbook were used to derive the intakes for home-grown produce.

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

where:
n = total number of produce items included

and:

$$DCC_{res\text{-}soil\text{-}produce\text{-}ing}(pCi/g) = \frac{DCC_{res\text{-}produce\text{-}ing}(pCi/g)}{\left(R_{upv} + R_{es}\right)} \times \left(\frac{t_{res}(year) \times \lambda\left(\frac{1}{year}\right)}{\left(1-e^{-\lambda t_{res}}\right)}\right)$$

where:

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

The consumption of produce exposure route drives the DCCs 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 DCC 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.

where:

$$DCC_{res\text{-}produce\text{-}ing}(pCi/g) = \frac{DL\left(\frac{mrem}{year}\right)}{DCF_o\left(\frac{mrem}{pCi}\right) \times IF_{res\text{-}adj}\left(\frac{g}{year}\right) \times CF_{res\text{-}produce}(1)}$$

where:

$$IF_{res\text{-}adj}\left(\frac{g}{year}\right) = \left(\begin{array}{l}\left(EF_{res\text{-}c}\left(\frac{350\ days}{year}\right) \times IR_{res\text{-}c}\left(\frac{g}{day}\right) \times AAF_{res\text{-}c}(0.23)\right) + \\ \left(EF_{res\text{-}a}\left(\frac{350\ days}{year}\right) \times IR_{res\text{-}a}\left(\frac{g}{day}\right) \times AAF_{res\text{-}a}(0.77)\right)\end{array}\right)$$

and:

$$AAF_{res\text{-}c}(0.23) = \left(\frac{ED_{res\text{-}c}(6\ years)}{ED_{res}(26\ years)}\right)\ \text{and: } AAF_{res\text{-}a}(0.77) = \left(\frac{ED_{res\text{-}a}(20\ years)}{ED_{res}(26\ years)}\right)$$

- total

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

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, body weights, and exposure duration for children from 1 to 6 years old and others from 7 to 26 years old. The equation is presented below. 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.

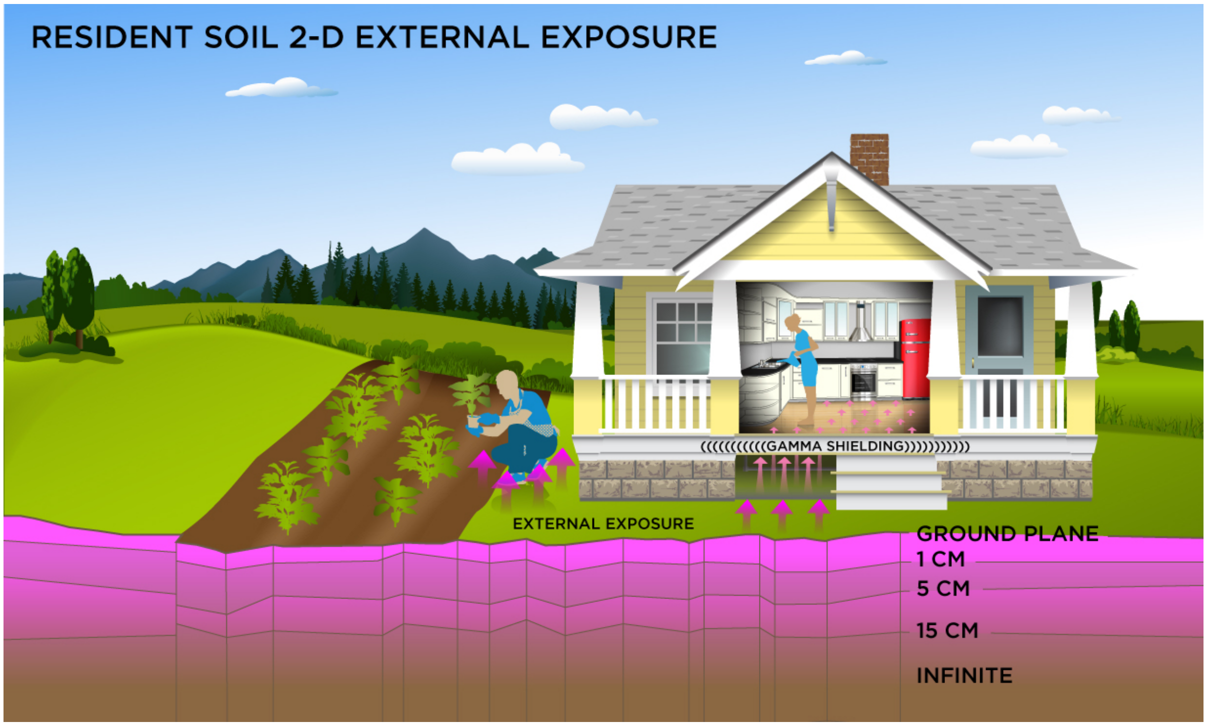
Definitions of the input variables are in Table 1.

## 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 making 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**




**Equations**

- Direct External Exposure to contamination at infinite depth

$$DCC_{res\text{-}soil\text{-}sv}(\text{pCi/g}) = \frac{DL\left(\frac{\text{mrem}}{\text{year}}\right) \times t_{res}(\text{year}) \times \lambda\left(\frac{1}{\text{year}}\right)}{\left(1-e^{-\lambda t_{res}}\right) \times DCF_{ext\text{-}sv}\left(\frac{\text{mrem/yr}}{\text{pCi/g}}\right) \times EF_{res}\left(\frac{350\text{ days}}{\text{year}}\right) \times \left(\frac{1\text{ year}}{365\text{ days}}\right) \times ACF_{ext\text{-}sv} \times \left[\left(ET_{res\text{-}o}\left(\frac{1.752\text{ hours}}{\text{day}}\right) \times \left(\frac{1\text{ day}}{24\text{ hours}}\right) \times GSF_{ext\text{-}sv}(1.0)\right) + \left(ET_{res\text{-}i}\left(\frac{16.416\text{ hours}}{\text{day}}\right) \times \left(\frac{1\text{ day}}{24\text{ hour}}\right) \times GSF_{i\text{-}total}\right)\right]}$$

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

- Direct External Exposure to contamination 1 cm thick

$$DCC_{res\text{-}soil\text{-}1cm}(\text{pCi/g}) = \frac{DL\left(\frac{\text{mrem}}{\text{year}}\right) \times t_{res}(\text{year}) \times \lambda\left(\frac{1}{\text{year}}\right)}{\left(1-e^{-\lambda t_{res}}\right) \times DCF_{ext\text{-}1cm}\left(\frac{\text{mrem/yr}}{\text{pCi/g}}\right) \times EF_{res}\left(\frac{350\text{ days}}{\text{year}}\right) \times \left(\frac{1\text{ year}}{365\text{ days}}\right) \times ACF_{ext\text{-}1cm} \times \left[\left(ET_{res\text{-}o}\left(\frac{1.752\text{ hours}}{\text{day}}\right) \times \left(\frac{1\text{ day}}{24\text{ hours}}\right) \times GSF_{ext\text{-}1cm}(1.0)\right) + \left(ET_{res\text{-}i}\left(\frac{16.416\text{ hours}}{\text{day}}\right) \times \left(\frac{1\text{ day}}{24\text{ hour}}\right) \times GSF_{i\text{-}total}\right)\right]}$$

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

- Direct External Exposure to contamination 5 cm thick

$$DCC_{res\text{-}soil\text{-}5cm}(\text{pCi/g}) = \frac{DL\left(\frac{\text{mrem}}{\text{year}}\right) \times t_{res}(\text{year}) \times \lambda\left(\frac{1}{\text{year}}\right)}{\left(1-e^{-\lambda t_{res}}\right) \times DCF_{ext\text{-}5cm}\left(\frac{\text{mrem/yr}}{\text{pCi/g}}\right) \times EF_{res}\left(\frac{350\text{ days}}{\text{year}}\right) \times \left(\frac{1\text{ year}}{365\text{ days}}\right) \times ACF_{ext\text{-}5cm} \times \left[\left(ET_{res\text{-}o}\left(\frac{1.752\text{ hours}}{\text{day}}\right) \times \left(\frac{1\text{ day}}{24\text{ hours}}\right) \times GSF_{ext\text{-}5cm}(1.0)\right) + \left(ET_{res\text{-}i}\left(\frac{16.416\text{ hours}}{\text{day}}\right) \times \left(\frac{1\text{ day}}{24\text{ hour}}\right) \times GSF_{i\text{-}total}\right)\right]}$$

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

- Direct External Exposure to contamination 15 cm thick

$$DCC_{res\text{-}soil\text{-}15cm}(pCi/g) = \frac{DL\left(\frac{mrem}{year}\right) \times t_{res}(year) \times \lambda\left(\frac{1}{year}\right)}{\left(1-e^{-\lambda t_{res}}\right) \times DCF_{ext\text{-}15cm}\left(\frac{mrem/yr}{pCi/g}\right) \times EF_{res}\left(\frac{350\ days}{year}\right) \times \left(\frac{1\ year}{365\ days}\right) \times ACF_{ext\text{-}15cm} \times \left[\left(ET_{res\text{-}o}\left(\frac{1.752\ hours}{day}\right) \times \left(\frac{1\ day}{24\ hours}\right) \times GSF_{ext\text{-}15cm}(1.0)\right) + \left(ET_{res\text{-}i}\left(\frac{16.416\ hours}{day}\right) \times \left(\frac{1\ day}{24\ hour}\right) \times GSF_{i\text{-}total}\right)\right]}$$

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

- Direct External Exposure to surface contamination

$$DCC_{res\text{-}soil\text{-}gp}(pCi/cm^2) = \frac{DL\left(\frac{mrem}{year}\right) \times t_{res}(year) \times \lambda\left(\frac{1}{year}\right)}{\left(1-e^{-\lambda t_{res}}\right) \times DCF_{ext\text{-}gp}\left(\frac{mrem/yr}{pCi/cm^2}\right) \times EF_{res}\left(\frac{350\ days}{year}\right) \times \left(\frac{1\ year}{365\ days}\right) \times ACF_{ext\text{-}gp} \times \left[\left(ET_{res\text{-}o}\left(\frac{1.752\ hours}{day}\right) \times \left(\frac{1\ day}{24\ hours}\right) \times GSF_{ext\text{-}gp}(1.0)\right) + \left(ET_{res\text{-}i}\left(\frac{16.416\ hours}{day}\right) \times \left(\frac{1\ day}{24\ hour}\right) \times GSF_{i\text{-}total}\right)\right]}$$

The resulting units for this recommended DCC are in $pCi/cm^2$. The units are based on area because the DCF used is the ground plane for external exposure.

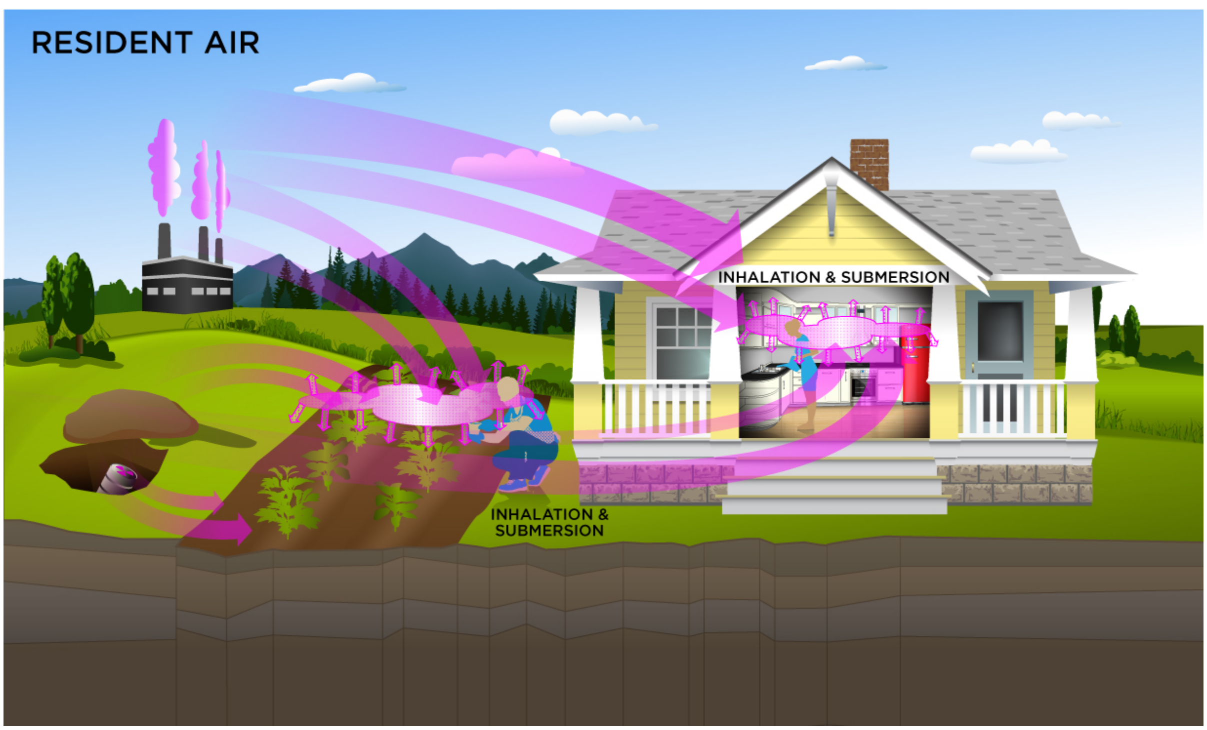
Definitions of the input variables are in Table 1.

### 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 making 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.

Two ambient air exposure conditions are offered for this scenario. The first scenario includes a half-life decay function and the second scenario does not. In situations where the contaminant in the air is not being replenished (e.g., an accidental one-time air release from a factory), equations for the first scenario 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), equations for the second scenario should be used.

#### Graphical Representation




#### Equations

The resident ambient air land use equation, presented here, contains the following exposure routes with half-life decay:

- inhalation and

$$DCC_{res\text{-}air\text{-}inh\text{-}decay}\left(pCi/m^3\right) = \frac{DL\left(\frac{mrem}{year}\right)\times t_{res}\,(year)\times\lambda\left(\frac{1}{year}\right)}{(1-e^{-\lambda t_{res}})\times DCF_i\left(\frac{mrem}{pCi}\right)\times IFA_{res\text{-}adj}\left(\frac{6{,}195\ m^3}{year}\right)}$$

where:

$$IFA_{res\text{-}adj}\left(\frac{6{,}195\ m^3}{year}\right) = \left(\begin{array}{l}\left(EF_{res\text{-}c}\left(\frac{350\ days}{year}\right)\times ET_{res\text{-}c}\left(\frac{24\ hours}{day}\right)\times\left(\frac{1\ day}{24 hours}\right)\times IRA_{res\text{-}c}\left(\frac{10\ m^3}{day}\right)\times AAF_{res\text{-}c}\,(0.23)\right)+\\ \left(EF_{res\text{-}a}\left(\frac{350\ days}{year}\right)\times ET_{res\text{-}a}\left(\frac{24\ hours}{day}\right)\times\left(\frac{1\ day}{24\ hours}\right)\times IRA_{res\text{-}a}\left(\frac{20\ m^3}{day}\right)\times AAF_{res\text{-}a}\,(0.77)\right)\end{array}\right)$$

where:

$$AAF_{res\text{-}c}(0.23) = \left(\frac{ED_{res\text{-}c}(6\ years)}{ED_{res}(26\ years)}\right)\ \text{and: } AAF_{res\text{-}a}(0.77) = \left(\frac{ED_{res\text{-}a}(20\ years)}{ED_{res}(26\ years)}\right)$$

- external exposure to ionizing radiation

$$DCC_{res\text{-}air\text{-}sub\text{-}decay}\left(pCi/m^3\right) = \frac{DL\left(\frac{mrem}{year}\right)\times t_{res}\,(year)\times\lambda\left(\frac{1}{year}\right)}{(1-e^{-\lambda t_{res}})\times DCF_{sub}\left(\frac{mrem/year}{pCi/m^3}\right)\times EF_{res}\left(\frac{350\ days}{year}\right)\times\left(\frac{1\ year}{365\ days}\right)\times ET_{res}\left(\frac{24\ hours}{day}\right)\times\left(\frac{1\ day}{24\ hours}\right)\times GSF_a\,(1.0)}$$

- total

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

The resident ambient air land use equation, presented here, contains the following exposure routes without half-life decay:

- inhalation and

$$DCC_{res\text{-}air\text{-}inh\text{-}nodecay}\left(pCi/m^3\right) = \frac{DL\left(\frac{mrem}{year}\right)}{DCF_i\left(\frac{mrem}{pCi}\right)\times IFA_{res\text{-}adj}\left(\frac{6{,}195\ m^3}{year}\right)}$$

where:

$$IFA_{res\text{-}adj}\left(\frac{6{,}195\ m^3}{year}\right) = \left(\begin{array}{l}\left(EF_{res\text{-}c}\left(\frac{350\ days}{year}\right)\times ET_{res\text{-}c}\left(\frac{24\ hours}{day}\right)\times\left(\frac{1\ day}{24\ hours}\right)\times IRA_{res\text{-}c}\left(\frac{10\ m^3}{day}\right)\times AAF_{res\text{-}c}\,(0.23)\right)+\\ \left(EF_{res\text{-}a}\left(\frac{350\ days}{year}\right)\times ET_{res\text{-}a}\left(\frac{24\ hours}{day}\right)\times\left(\frac{1\ day}{24\ hours}\right)\times IRA_{res\text{-}a}\left(\frac{20\ m^3}{day}\right)\times AAF_{res\text{-}a}\,(0.77)\right)\end{array}\right)$$

where:

$$AAF_{res\text{-}c}(0.23) = \left(\frac{ED_{res\text{-}c}(6\ years)}{ED_{res}(26\ years)}\right)\ \text{and: } AAF_{res\text{-}a}(0.77) = \left(\frac{ED_{res\text{-}a}(20\ years)}{ED_{res}(26\ years)}\right)$$

- external exposure to ionizing radiation

$$DCC_{res\text{-}air\text{-}sub\text{-}nodecay}\left(pCi/m^3\right) = \frac{DL\left(\frac{mrem}{year}\right)}{DCF_{sub}\left(\frac{mrem/year}{pCi/m^3}\right)\times EF_{res}\left(\frac{350\ days}{year}\right)\times\left(\frac{1\ year}{365\ days}\right)\times ET_{res}\left(\frac{24\ hours}{day}\right)\times\left(\frac{1\ day}{24\ hours}\right)\times GSF_a\,(1.0)}$$

- total

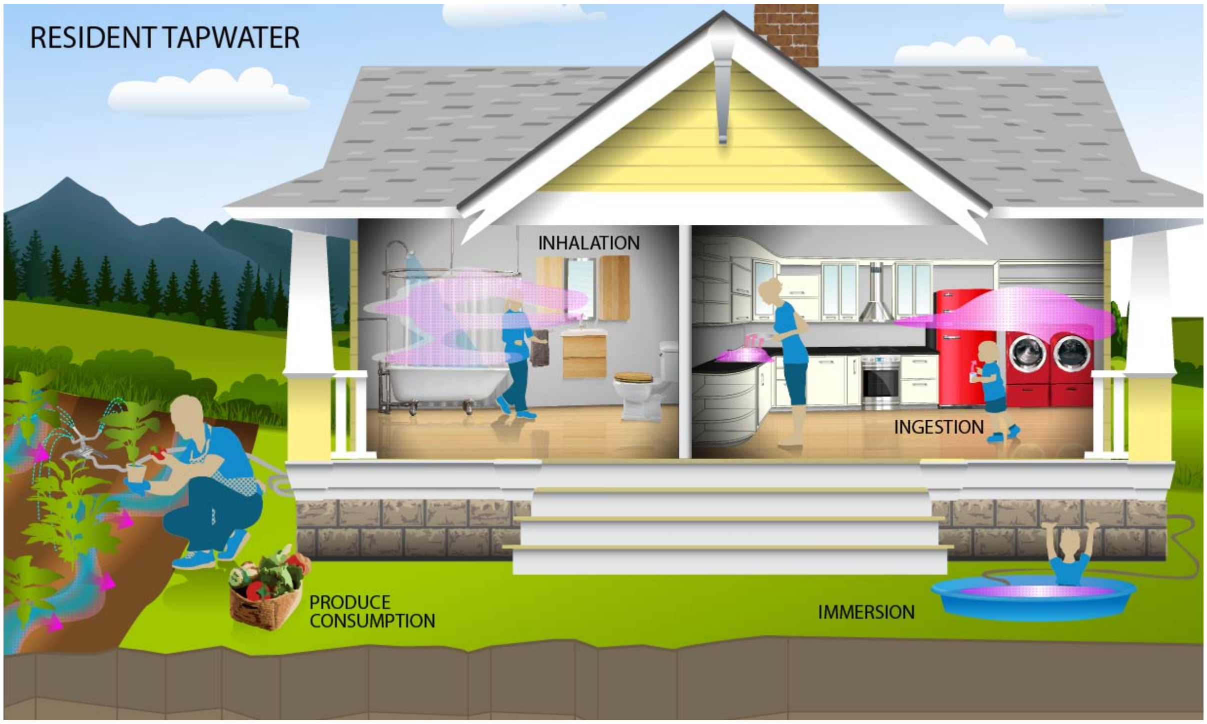
$$DCC_{res\text{-}air\text{-}tot\text{-}nodecay}\left(pCi/m^3\right) = \frac{1}{\frac{1}{DCC_{res\text{-}air\text{-}inh\text{-}nodecay}}+\frac{1}{DCC_{res\text{-}air\text{-}sub\text{-}nodecay}}}$$

Definitions of the input variables are in Table 1.

## 4.1.4 Resident Tapwater

This receptor is exposed to radionuclides that are delivered into a residence. Ingestion of drinking water is an appropriate pathway for all radionuclides. Activities such as showering, laundering, and dish washing also contribute to inhalation. The inhalation exposure route is only calculated for C-14, H-3, Ra-224, and Ra-226 which volatilize. External exposure to immersion in tapwater and exposure to produce irrigated with contaminated tapwater are also considered.

### Graphical Representation




## Equations

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

- ingestion of tapwater,

$$DCC_{water\text{-}ing}\left(pCi/L\right) = \frac{DL\left(\frac{mrem}{year}\right)}{DCF_o\left(\frac{mrem}{pCi}\right)\times IFW_{res\text{-}adj}\left(\frac{737\ L}{year}\right)}$$

where:

$$IFW_{res\text{-}adj}\left(\frac{737\ L}{year}\right) = \left(\begin{array}{l}\left(EF_{res\text{-}c}\left(\frac{350\ days}{year}\right)\times IRW_{res\text{-}c}\left(\frac{0.78\ L}{day}\right)\times AAF_{res\text{-}c}(0.23)\right)+\\ \left(EF_{res\text{-}a}\left(\frac{350\ days}{year}\right)\times IRW_{res\text{-}a}\left(\frac{2.5\ L}{day}\right)\times AAF_{res\text{-}a}(0.77)\right)\end{array}\right)$$

where:

$$AAF_{res\text{-}c}(0.23) = \left(\frac{ED_{res\text{-}c}(6\ years)}{ED_{res}(26\ years)}\right)\ \text{and: } AAF_{res\text{-}a}(0.77) = \left(\frac{ED_{res\text{-}a}(20\ years)}{ED_{res}(26\ years)}\right)$$

- inhalation, (The inhalation exposure route is only calculated for C-14, H-3, Ra-224, and Ra-226). Also, volatilization in the equation comes from household uses of water (e.g., showering, laundering, dish washing)

$$DCC_{water\text{-}inh}\left(pCi/L\right) = \frac{DL\left(\frac{mrem}{year}\right)}{DCF_i\left(\frac{mrem}{pCi}\right)\times IFA_{res\text{-}adj}\left(\frac{6{,}195\ m^3}{year}\right)\times K\left(\frac{0.5\ L}{m^3}\right)}$$

where:

$$IFA_{res\text{-}adj}\left(\frac{6{,}195\ m^3}{year}\right) = \left(\begin{array}{l}\left(EF_{res\text{-}c}\left(\frac{350\ days}{year}\right)\times ET_{res\text{-}c}\left(\frac{24\ hours}{day}\right)\times\left(\frac{1\ day}{24\ hours}\right)\times IRA_{res\text{-}c}\left(\frac{10\ m^3}{day}\right)\times AAF_{res\text{-}c}(0.23)\right)+\\ \left(EF_{res\text{-}a}\left(\frac{350\ days}{year}\right)\times ET_{res\text{-}a}\left(\frac{24\ hours}{day}\right)\times\left(\frac{1\ day}{24\ hours}\right)\times IRA_{res\text{-}a}\left(\frac{20\ m^3}{day}\right)\times AAF_{res\text{-}a}(0.77)\right)\end{array}\right)$$

where:

$$AAF_{res\text{-}c}(0.23) = \left(\frac{ED_{res\text{-}c}(6\ years)}{ED_{res}(26\ years)}\right)\ \text{and: } AAF_{res\text{-}a}(0.77) = \left(\frac{ED_{res\text{-}a}(20\ years)}{ED_{res}(26\ years)}\right)$$

- immersion,

$$DCC_{water\text{-}imm}(pCi/L) = \frac{DL\left(\frac{mrem}{year}\right)}{DCF_{imm}\left(\frac{mrem/year}{pCi/L}\right)\times\left(\frac{1\ year}{8760\ hours}\right)\times DFA_{res\text{-}adj}\left(\frac{235\ hours}{year}\right)}$$

where:

$$DFA_{res\text{-}adj}\left(\frac{235\ hours}{year}\right) = \left(\begin{array}{l}\left(EF_{res\text{-}c}\left(\frac{350\ days}{year}\right)\times EV_{res\text{-}c}\left(\frac{1\ event}{day}\right)\times ET_{event\text{-}res\text{-}c}\left(\frac{0.54\ hours}{event}\right)\times AAF_{res\text{-}c}(0.23)\right)+\\ \left(EF_{res\text{-}a}\left(\frac{350\ days}{year}\right)\times EV_{res\text{-}a}\left(\frac{1\ event}{day}\right)\times ET_{event\text{-}res\text{-}a}\left(\frac{0.71\ hours}{event}\right)\times AAF_{res\text{-}a}(0.77)\right)\end{array}\right)$$

where:

$$AAF_{res\text{-}c}(0.23) = \left(\frac{ED_{res\text{-}c}(6\ years)}{ED_{res}(26\ years)}\right)\ \text{and: } AAF_{res\text{-}a}(0.77) = \left(\frac{ED_{res\text{-}a}(20\ years)}{ED_{res}(26\ years)}\right)$$

- consumption of produce (fruits and vegetables) - back-calculated to tapwater, Sections 9 and 13 of the 2011 Exposure Factors Handbook were used to derive the intakes for home-grown produce.

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

where:

n = total number of produce items included

and:

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

where:

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

and:

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

where:

$$DCC_{res\text{-}produce\text{-}ing}(pCi/g) = \frac{DL\left(\frac{mrem}{year}\right)}{DCF_o\left(\frac{mrem}{pCi}\right)\times IF_{res\text{-}adj}\left(\frac{g}{year}\right)\times CF_{res\text{-}produce}(1)}$$

where:

$$IF_{res\text{-}adj}\left(\frac{g}{year}\right) = \left(\begin{array}{l}\left(EF_{res\text{-}c}\left(\frac{350\ days}{year}\right)\times IR_{res\text{-}c}\left(\frac{g}{day}\right)\times AAF_{res\text{-}c}(0.23)\right)+\\ \left(EF_{res\text{-}a}\left(\frac{350\ days}{year}\right)\times IR_{res\text{-}a}\left(\frac{g}{day}\right)\times AAF_{res\text{-}a}(0.77)\right)\end{array}\right)$$

and:

$$AAF_{res\text{-}c}(0.23) = \left(\frac{ED_{res\text{-}c}(6\ years)}{ED_{res}(26\ years)}\right)\ \text{and: } AAF_{res\text{-}a}(0.77) = \left(\frac{ED_{res\text{-}a}(20\ years)}{ED_{res}(26\ years)}\right)$$

- total

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

Definitions of the input variables are in Table 1.

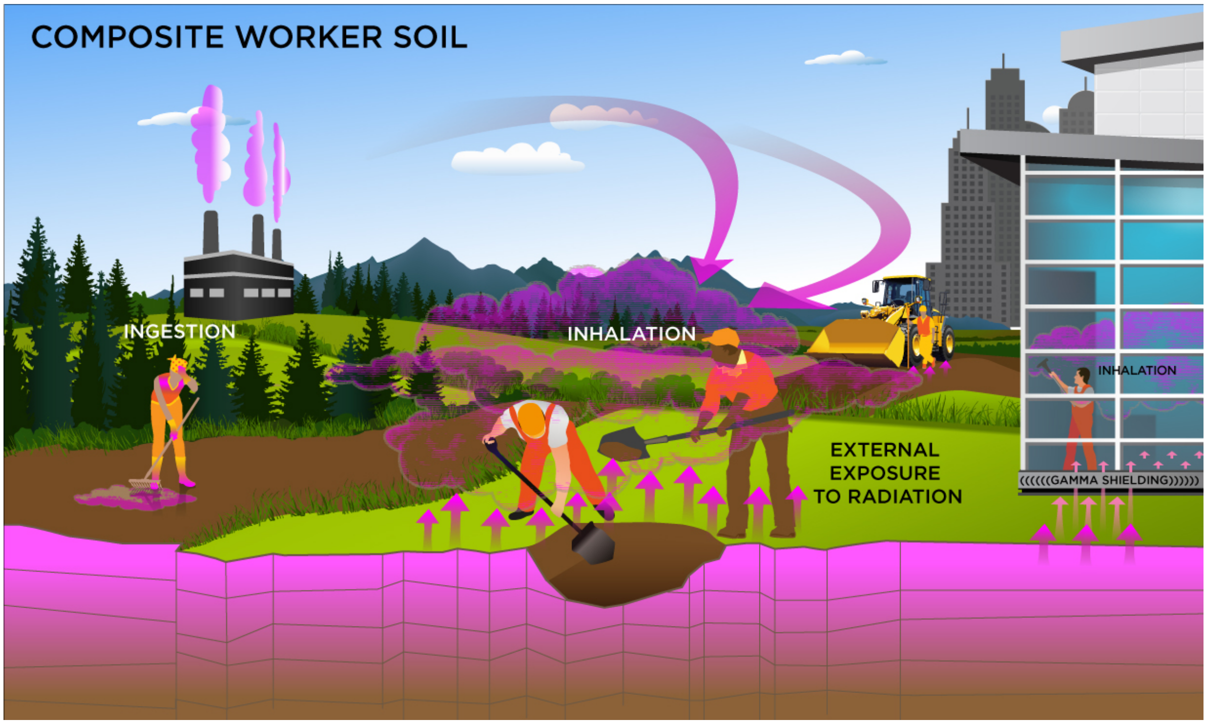
## 4.2 Composite Worker

### 4.2.1 Composite Worker Soil

This is a long-term receptor exposed during the work day who is a full time employee working on-site and 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, 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 for developing industrial default screening levels that are presented in the Download Area.

### Graphical Representation




### Equations

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

- incidental ingestion of soil,

$$DCC_{w\text{-}soil\text{-}ing}(pCi/g) = \frac{DL\left(\frac{mrem}{year}\right) \times t_w\,(year) \times \lambda\left(\frac{1}{year}\right)}{\left(1-e^{-\lambda t_w}\right) \times DCF_{oa}\left(\frac{mrem}{pCi}\right) \times EF_w\left(\frac{250\ days}{year}\right) \times IRS_w\left(\frac{100\ mg}{day}\right) \times \left(\frac{g}{1000\ mg}\right)}$$

- inhalation of particulates emitted from soil,

$$DCC_{w\text{-}soil\text{-}inh}(pCi/g) = \frac{DL\left(\frac{mrem}{year}\right) \times t_w\,(year) \times \lambda\left(\frac{1}{year}\right)}{\left(1-e^{-\lambda t_w}\right) \times DCF_i\left(\frac{mrem}{pCi}\right) \times EF_w\left(\frac{250\ days}{year}\right) \times ET_w\left(\frac{8\ hours}{day}\right) \times \left(\frac{1\ day}{24\ hours}\right) \times IRA_w\left(\frac{60\ m^3}{day}\right) \times \frac{1}{PEF\left(\frac{m^3}{kg}\right)} \times \left(\frac{1000\ g}{kg}\right)}$$

- external exposure to ionizing radiation, and

$$DCC_{w\text{-}soil\text{-}ext}(pCi/g) = \frac{DL\left(\frac{mrem}{year}\right) \times t_w\,(year) \times \lambda\left(\frac{1}{year}\right)}{\left(1-e^{-\lambda t_w}\right) \times DCF_{ext\text{-}sv}\left(\frac{mrem/year}{pCi/g}\right) \times EF_w\left(\frac{250\ days}{year}\right) \times \left(\frac{1\ year}{365\ days}\right) \times ET_w\left(\frac{8\ hours}{day}\right) \times \left(\frac{1\ day}{24\ hours}\right) \times GSF_o\,(1.0) \times ACF_{ext\text{-}sv}}$$

- total

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

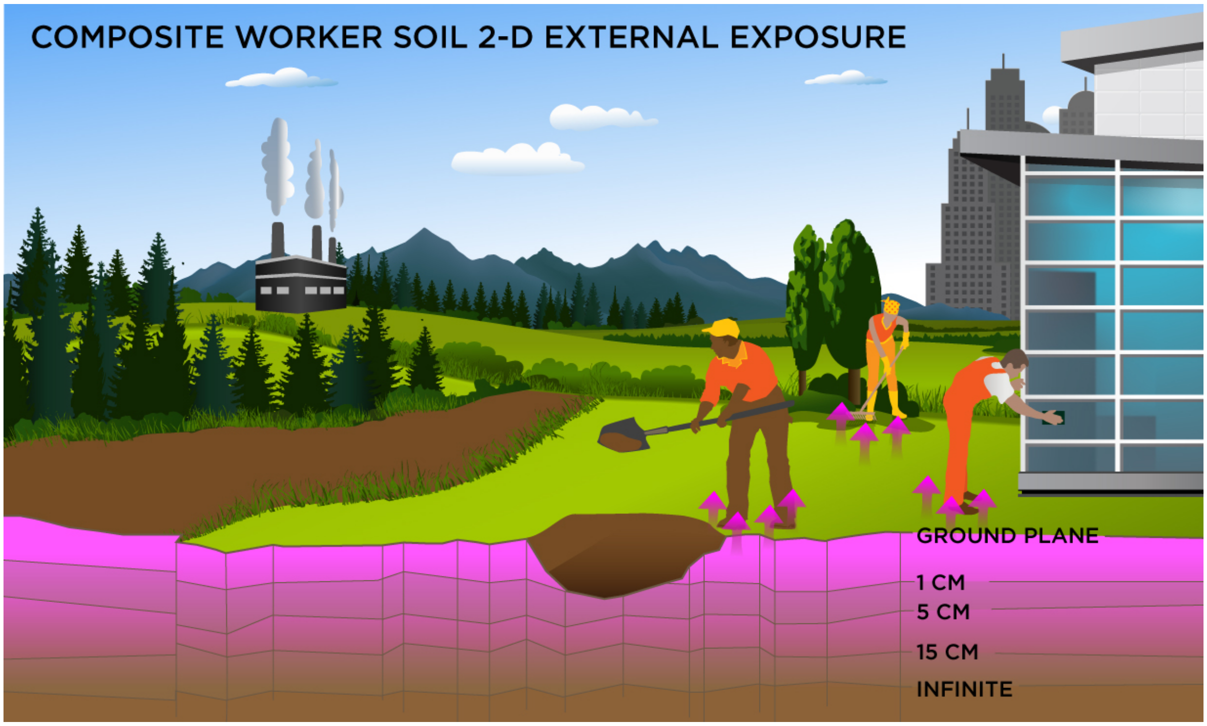
Definitions of the input variables are in Table 1.

## 4.2.2 Composite Worker Soil 2-D External Exposure

This is a long-term receptor exposed during the work day who is a full time employee working on-site and 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




## Equations

- Direct External Exposure to contamination at infinite depth

$$DCC_{w\text{-}soil\text{-}sv}(pCi/g) = \frac{DL\left(\frac{mrem}{year}\right)\times t_w(year)\times\lambda\left(\frac{1}{year}\right)}{\left(1-e^{-\lambda t_w}\right)\times DCF_{ext\text{-}sv}\left(\frac{mrem/year}{pCi/g}\right)\times EF_w\left(\frac{250\ days}{year}\right)\times\left(\frac{1\ year}{365\ days}\right)\times ET_w\left(\frac{8\ hours}{day}\right)\times\left(\frac{1\ day}{24\ hours}\right)\times GSF_{ext\text{-}sv}(1.0)\times ACF_{ext\text{-}sv}}$$

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

- Direct External Exposure to contamination 1 cm thick

$$DCC_{w\text{-}soil\text{-}1cm}(pCi/g) = \frac{DL\left(\frac{mrem}{year}\right)\times t_w(year)\times\lambda\left(\frac{1}{year}\right)}{\left(1-e^{-\lambda t_w}\right)\times DCF_{ext\text{-}1cm}\left(\frac{mrem/year}{pCi/g}\right)\times EF_w\left(\frac{250\ days}{year}\right)\times\left(\frac{1\ year}{365\ days}\right)\times ET_w\left(\frac{8\ hours}{day}\right)\times\left(\frac{1\ day}{24\ hours}\right)\times GSF_{ext\text{-}1cm}(1.0)\times ACF_{ext\text{-}1cm}}$$

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

- Direct External Exposure to contamination 5 cm thick

$$DCC_{w\text{-}soil\text{-}5cm}(pCi/g) = \frac{DL\left(\frac{mrem}{year}\right)\times t_w(year)\times\lambda\left(\frac{1}{year}\right)}{\left(1-e^{-\lambda t_w}\right)\times DCF_{ext\text{-}5cm}\left(\frac{mrem/year}{pCi/g}\right)\times EF_w\left(\frac{250\ days}{year}\right)\times\left(\frac{1\ year}{365\ days}\right)\times ET_w\left(\frac{8\ hours}{day}\right)\times\left(\frac{1\ day}{24\ hours}\right)\times GSF_{ext\text{-}5cm}(1.0)\times ACF_{ext\text{-}5cm}}$$

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

- Direct External Exposure to contamination 15 cm thick

$$DCC_{w\text{-}soil\text{-}15cm}(pCi/g) = \frac{DL\left(\frac{mrem}{year}\right)\times t_w(year)\times\lambda\left(\frac{1}{year}\right)}{\left(1-e^{-\lambda t_w}\right)\times DCF_{ext\text{-}15cm}\left(\frac{mrem/year}{pCi/g}\right)\times EF_w\left(\frac{250\ days}{year}\right)\times\left(\frac{1\ year}{365\ days}\right)\times ET_w\left(\frac{8\ hours}{day}\right)\times\left(\frac{1\ day}{24\ hours}\right)\times GSF_{ext\text{-}15cm}(1.0)\times ACF_{ext\text{-}15cm}}$$

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

- Direct External Exposure to surface contamination

$$DCC_{w\text{-}soil\text{-}gp}(pCi/cm^2) = \frac{DL\left(\frac{mrem}{year}\right)\times t_w(year)\times\lambda\left(\frac{1}{year}\right)}{\left(1-e^{-\lambda t_w}\right)\times DCF_{ext\text{-}gp}\left(\frac{mrem/year}{pCi/cm^2}\right)\times EF_w\left(\frac{250\ days}{year}\right)\times\left(\frac{1\ year}{365\ days}\right)\times ET_w\left(\frac{8\ hours}{day}\right)\times\left(\frac{1\ day}{24\ hours}\right)\times GSF_{ext\text{-}gp}(1.0)\times ACF_{ext\text{-}gp}}$$

The resulting units for this recommended DCC are in $pCi/cm^2$. The units are based on area because the DCF used is the ground plane for external exposure.

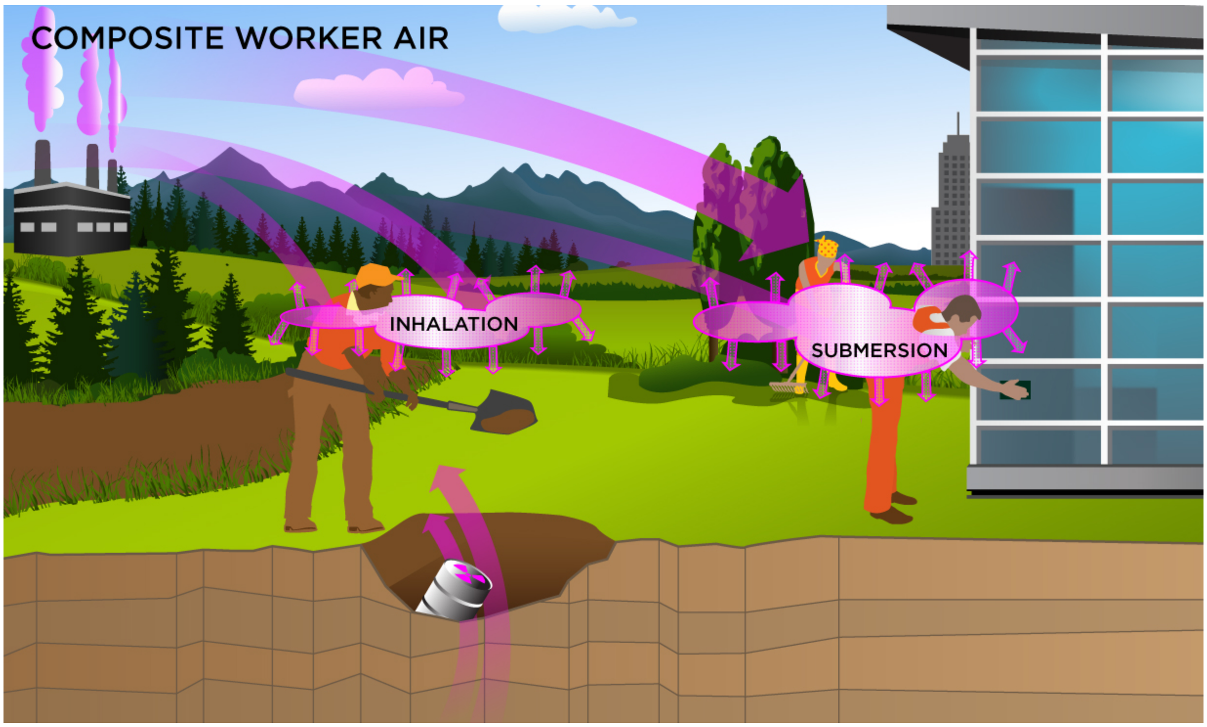
Definitions of the input variables are in Table 1.

## 4.2.3 Composite Worker Air

This is a long-term receptor exposed during the work day who is a full time employee working on-site and 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.

Two ambient air exposure conditions are offered for this scenario. The first scenario includes a half-life decay function and the second scenario does not. In situations where the contaminant in the air is not being replenished (e.g., an accidental one-time air release from a factory), equations for the first scenario 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), equations for the second scenario should be used.

### Graphical Representation




### Equations

The composite worker ambient air land use equations, presented here, contain the following exposure routes with half-life decay:

- inhalation and

$$DCC_{w\text{-}air\text{-}inh\text{-}decay}\left(pCi/m^3\right) = \frac{DL\left(\frac{mrem}{year}\right) \times t_w\,(year) \times \lambda\left(\frac{1}{year}\right)}{(1-e^{-\lambda t_w}) \times DCF_i\left(\frac{mrem}{pCi}\right) \times EF_w\left(\frac{250\ days}{year}\right) \times ET_w\left(\frac{8\ hours}{day}\right) \times \left(\frac{1\ day}{24\ hours}\right) \times IRA_w\left(\frac{60\ m^3}{day}\right)}$$

- external exposure to ionizing radiation

$$DCC_{w\text{-}air\text{-}sub\text{-}decay}\left(pCi/m^3\right) = \frac{DL\left(\frac{mrem}{year}\right) \times t_w\,(year) \times \lambda\left(\frac{1}{year}\right)}{(1-e^{-\lambda t_w}) \times DCF_{sub}\left(\frac{mrem/year}{pCi/m^3}\right) \times EF_w\left(\frac{250\ days}{year}\right) \times \left(\frac{1\ year}{365\ days}\right) \times ET_w\left(\frac{8\ hours}{day}\right) \times \left(\frac{1\ day}{24\ hours}\right) \times GSF_a\,(1.0)}$$

- total

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

The composite worker ambient air land use equation, presented here, contains the following exposure routes without half-life decay:

- inhalation and

$$DCC_{w\text{-}air\text{-}inh\text{-}nodecay}\left(pCi/m^3\right) = \frac{DL\left(\frac{mrem}{year}\right)}{DCF_i\left(\frac{mrem}{pCi}\right) \times EF_w\left(\frac{250\ days}{year}\right) \times ET_w\left(\frac{8\ hours}{day}\right) \times \left(\frac{1\ day}{24\ hours}\right) \times IRA_w\left(\frac{60\ m^3}{day}\right)}$$

- external exposure to ionizing radiation

$$DCC_{w\text{-}air\text{-}sub\text{-}nodecay}\left(pCi/m^3\right) = \frac{DL\left(\frac{mrem}{year}\right)}{DCF_{sub}\left(\frac{mrem/year}{pCi/m^3}\right) \times EF_w\left(\frac{250\ days}{year}\right) \times \left(\frac{1\ year}{365\ days}\right) \times ET_w\left(\frac{8\ hours}{day}\right) \times \left(\frac{1\ day}{24\ hours}\right) \times GSF_a\ (1.0)}$$

- total

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

Definitions of the input variables are in Table 1.

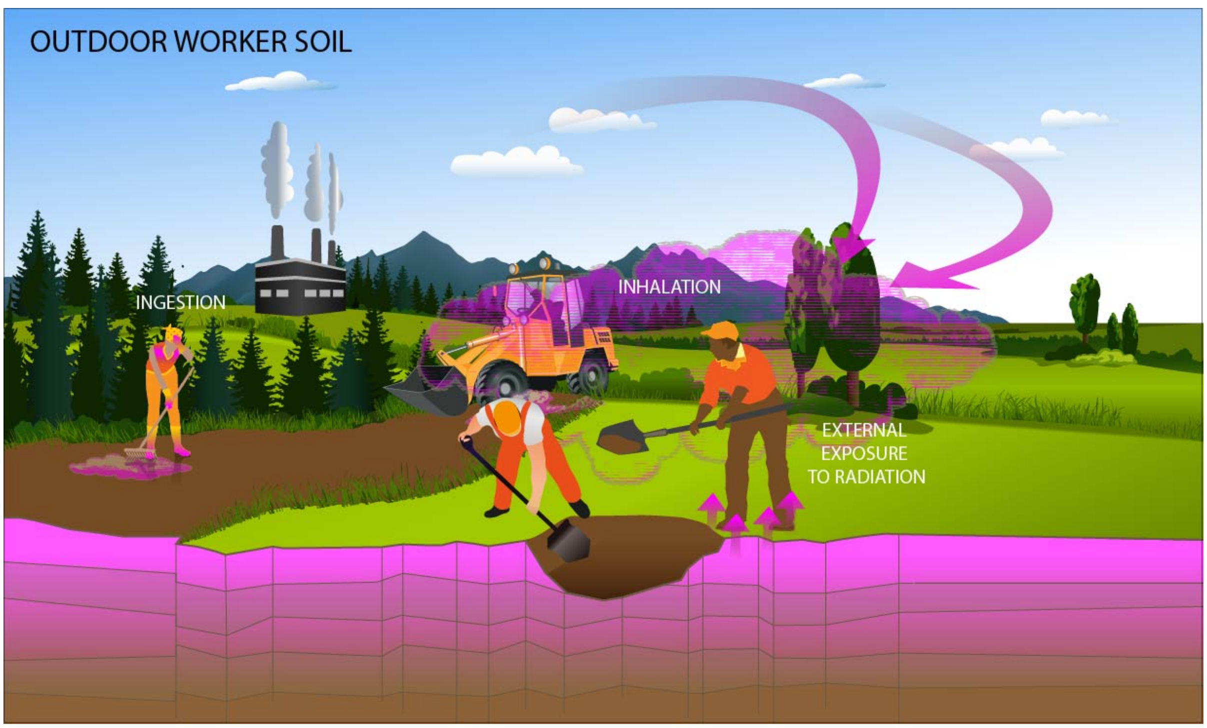
## 4.3 Outdoor Worker

### 4.3.1 Outdoor Worker Soil

This is a long-term receptor exposed during the work day who is a full time employee working on-site and 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, 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 DCC Download Area but DCCs can be created by using the Calculator to modify the exposure parameters for the composite worker to match the equations that follow.

#### Graphical Representation




#### Equations

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

- incidental ingestion of soil,

$$DCC_{ow\text{-}soil\text{-}ing}(pCi/g) = \frac{DL\left(\frac{mrem}{year}\right) \times t_{ow}\,(year) \times \lambda\left(\frac{1}{year}\right)}{\left(1\text{-}e^{-\lambda t_{ow}}\right) \times DCF_{oa}\left(\frac{mrem}{pCi}\right) \times EF_{ow}\left(\frac{225\ days}{year}\right) \times IRS_{ow}\left(\frac{100\ mg}{day}\right) \times \left(\frac{g}{1000\ mg}\right)}$$

- inhalation of particulates emitted from soil,

$$DCC_{ow\text{-}soil\text{-}inh}(pCi/g)=\frac{DL\left(\frac{mrem}{year}\right)\times t_{ow}(year)\times\lambda\left(\frac{1}{year}\right)}{\left(1-e^{-\lambda t_{ow}}\right)\times DCF_i\left(\frac{risk}{pCi}\right)\times EF_{ow}\left(\frac{225\ days}{year}\right)\times ET_{ow}\left(\frac{8\ hours}{day}\right)\times\left(\frac{1\ day}{24\ hours}\right)\times IRA_{ow}\left(\frac{60\ m^3}{day}\right)\times\frac{1}{PEF\left(\frac{m^3}{kg}\right)}\times\left(\frac{1000\ g}{kg}\right)}$$

- external exposure to ionizing radiation, and

$$DCC_{ow\text{-}soil\text{-}ext}(pCi/g)=\frac{DL\left(\frac{mrem}{year}\right)\times t_{ow}(year)\times\lambda\left(\frac{1}{year}\right)}{\left(1-e^{-\lambda t_{ow}}\right)\times DCF_{ext\text{-}sv}\left(\frac{mrem/year}{pCi/g}\right)\times EF_{ow}\left(\frac{225\ days}{year}\right)\times\left(\frac{1\ year}{365\ days}\right)\times ET_{ow}\left(\frac{8\ hours}{day}\right)\times\left(\frac{1\ day}{24\ hours}\right)\times GSF_{ext\text{-}sv}(1.0)\times ACF_{ext\text{-}sv}}$$

- total

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

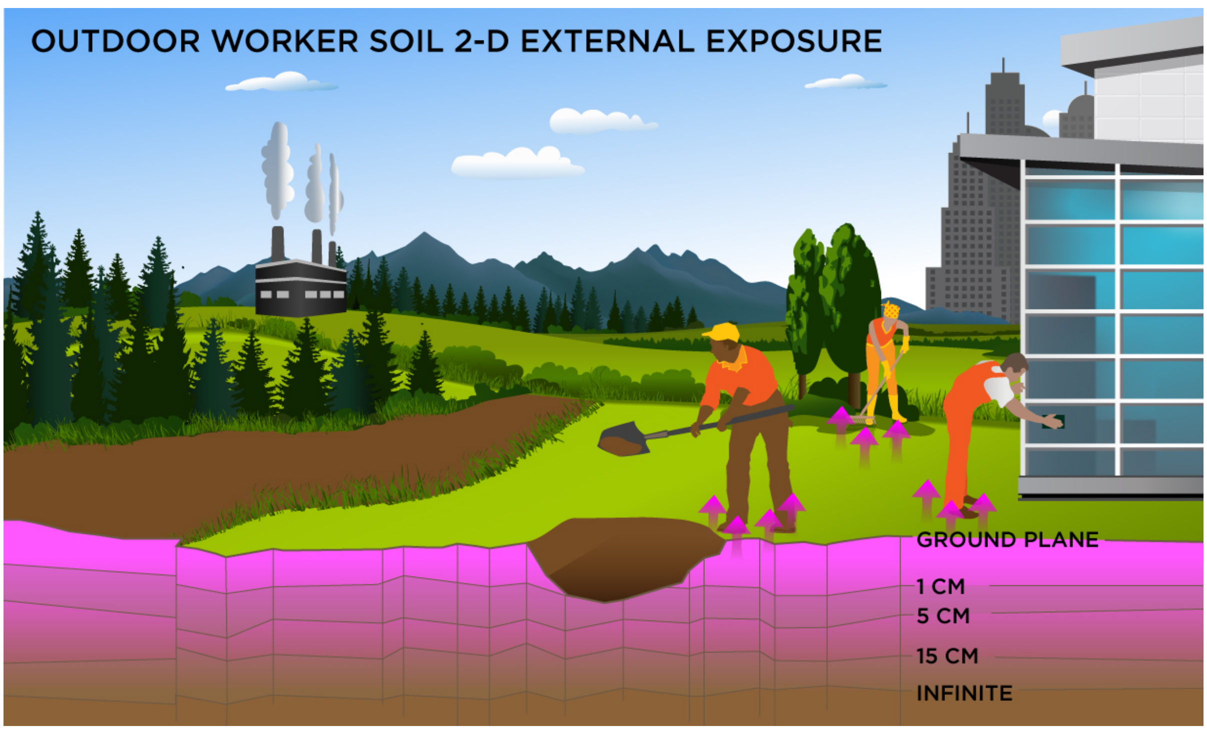
Definitions of the input variables are in Table 1.

## 4.3.2 Outdoor Worker Soil 2-D External Exposure

This is a long-term receptor exposed during the work day who is a full time employee working on-site and 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




### Equations

- Direct External Exposure to contamination at infinite depth

$$DCC_{ow\text{-}soil\text{-}sv}(pCi/g)=\frac{DL\left(\frac{mrem}{year}\right)\times t_{ow}(year)\times\lambda\left(\frac{1}{year}\right)}{\left(1-e^{-\lambda t_{ow}}\right)\times DCF_{ext\text{-}sv}\left(\frac{mrem/year}{pCi/g}\right)\times EF_{ow}\left(\frac{225\ days}{year}\right)\times\left(\frac{1\ year}{365\ days}\right)\times ET_{ow}\left(\frac{8\ hours}{day}\right)\times\left(\frac{1\ day}{24\ hours}\right)\times GSF_{ext\text{-}sv}(1.0)\times ACF_{ext\text{-}sv}}$$

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

- Direct External Exposure to contamination 1 cm thick

$$DCC_{ow\text{-}soil\text{-}1cm}(pCi/g) = \frac{DL\left(\frac{mrem}{year}\right)\times t_{ow}(year)\times\lambda\left(\frac{1}{year}\right)}{\left(1-e^{-\lambda t_{ow}}\right)\times DCF_{ext\text{-}1cm}\left(\frac{mrem/year}{pCi/g}\right)\times EF_{ow}\left(\frac{225\ days}{year}\right)\times\left(\frac{1\ year}{365\ days}\right)\times ET_{ow}\left(\frac{8\ hours}{day}\right)\times\left(\frac{1\ day}{24\ hours}\right)\times GSF_{ext\text{-}1cm}(1.0)\times ACF_{ext\text{-}1cm}}$$

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

- Direct External Exposure to contamination 5 cm thick

$$DCC_{ow\text{-}soil\text{-}5cm}(pCi/g) = \frac{DL\left(\frac{mrem}{year}\right)\times t_{ow}(year)\times\lambda\left(\frac{1}{year}\right)}{\left(1-e^{-\lambda t_{ow}}\right)\times DCF_{ext\text{-}5cm}\left(\frac{mrem/year}{pCi/g}\right)\times EF_{ow}\left(\frac{225\ days}{year}\right)\times\left(\frac{1\ year}{365\ days}\right)\times ET_{ow}\left(\frac{8\ hours}{day}\right)\times\left(\frac{1\ day}{24\ hours}\right)\times GSF_{ext\text{-}5cm}(1.0)\times ACF_{ext\text{-}5cm}}$$

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

- Direct External Exposure to contamination 15 cm thick

$$DCC_{ow\text{-}soil\text{-}15cm}(pCi/g) = \frac{DL\left(\frac{mrem}{year}\right)\times t_{ow}(year)\times\lambda\left(\frac{1}{year}\right)}{\left(1-e^{-\lambda t_{ow}}\right)\times DCF_{ext\text{-}15cm}\left(\frac{mrem/year}{pCi/g}\right)\times EF_{ow}\left(\frac{225\ day}{year}\right)\times\left(\frac{1\ year}{365\ days}\right)\times ET_{ow}\left(\frac{8\ hours}{day}\right)\times\left(\frac{1\ day}{24\ hours}\right)\times GSF_{ext\text{-}15cm}(1.0)\times ACF_{ext\text{-}15cm}}$$

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

- Direct External Exposure to surface contamination

$$DCC_{ow\text{-}soil\text{-}gp}(pCi/cm^2) = \frac{DL\left(\frac{mrem}{year}\right)\times t_{ow}(year)\times\lambda\left(\frac{1}{year}\right)}{\left(1-e^{-\lambda t_{ow}}\right)\times DCF_{ext\text{-}gp}\left(\frac{mrem/year}{pCi/cm^2}\right)\times EF_{ow}\left(\frac{225\ days}{year}\right)\times\left(\frac{1\ year}{365\ days}\right)\times ET_{ow}\left(\frac{8\ hours}{day}\right)\times\left(\frac{1\ day}{24\ hours}\right)\times GSF_{ext\text{-}gp}(1.0)\times ACF_{ext\text{-}gp}}$$

The resulting units for this recommended DCC are in $pCi/cm^2$. The units are based on area because the DCF used is the ground plane for external exposure.

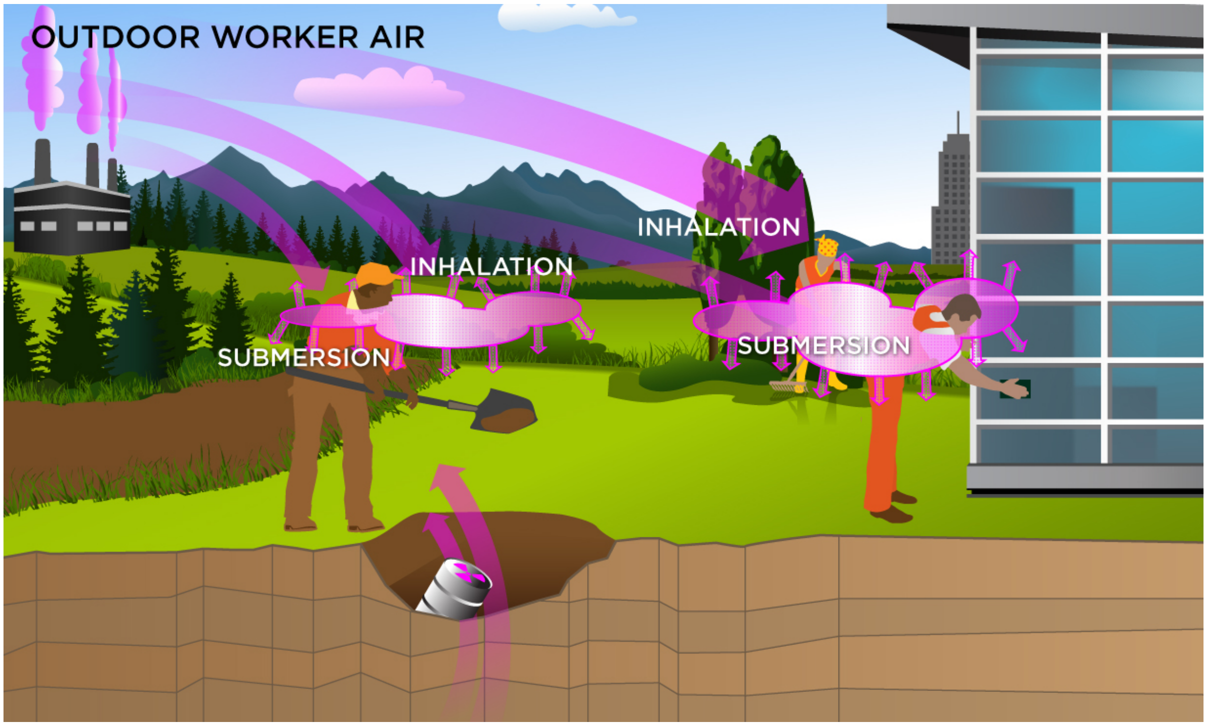
Definitions of the input variables are in Table 1.

### 4.3.3 Outdoor Worker Air

This is a long-term receptor exposed during the work day who is a full time employee working on-site and 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.

Two ambient air exposure conditions are offered for this scenario. The first scenario includes a half-life decay function and the second scenario does not. In situations where the contaminant in the air is not being replenished (e.g., an accidental one-time air release from a factory), equations for the first scenario 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), equations for the second scenario should be used.

#### Graphical Representation




## Equations

The outdoor worker ambient air land use equation, presented here, contains the following exposure routes with half-life decay:

- inhalation and

$$DCC_{ow\text{-}air\text{-}inh\text{-}decay}\left(pCi/m^3\right) = \frac{DL\left(\frac{mrem}{year}\right)\times t_{ow}\left(year\right)\times\lambda\left(\frac{1}{year}\right)}{(1\text{-}e^{-\lambda t_{ow}})\times DCF_i\left(\frac{mrem}{pCi}\right)\times EF_{ow}\left(\frac{225\ days}{year}\right)\times ET_{ow}\left(\frac{8\ hours}{day}\right)\times\left(\frac{1\ day}{24\ hours}\right)\times IRA_{ow}\left(\frac{60\ m^3}{day}\right)}$$

- external exposure to ionizing radiation

$$DCC_{ow\text{-}air\text{-}sub\text{-}decay}\left(pCi/m^3\right) = \frac{DL\left(\frac{mrem}{year}\right)\times t_{ow}\left(year\right)\times\lambda\left(\frac{1}{year}\right)}{(1\text{-}e^{-\lambda t_{ow}})\times DCF_{sub}\left(\frac{mrem/year}{pCi/m^3}\right)\times EF_{ow}\left(\frac{250\ days}{year}\right)\times\left(\frac{1\ year}{365\ day}\right)\times ET_{ow}\left(\frac{8\ hours}{day}\right)\times\left(\frac{1\ day}{24\ hours}\right)\times GSF_a\,(1.0)}$$

- total

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

The outdoor worker ambient air land use equation, presented here, contains the following exposure routes without half-life decay:

- inhalation and

$$DCC_{ow\text{-}air\text{-}inh\text{-}nodecay}\left(pCi/m^3\right) = \frac{DL\left(\frac{mrem}{year}\right)}{DCF_i\left(\frac{mrem}{pCi}\right)\times EF_{ow}\left(\frac{225\ days}{year}\right)\times ET_{ow}\left(\frac{8\ hours}{day}\right)\times\left(\frac{1\ day}{24\ hours}\right)\times IRA_{ow}\left(\frac{60\ m^3}{day}\right)}$$

- external exposure to ionizing radiation

$$DCC_{ow\text{-}air\text{-}sub\text{-}nodecay}\left(pCi/m^3\right) = \frac{DL\left(\frac{mrem}{year}\right)}{DCF_{sub}\left(\frac{mrem/year}{pCi/m^3}\right)\times EF_{ow}\left(\frac{250\ days}{year}\right)\times\left(\frac{1\ year}{365\ day}\right)\times ET_{ow}\left(\frac{8\ hours}{day}\right)\times\left(\frac{1\ day}{24\ hours}\right)\times GSF_a\,(1.0)}$$

- total

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

Definitions of the input variables are in Table 1.

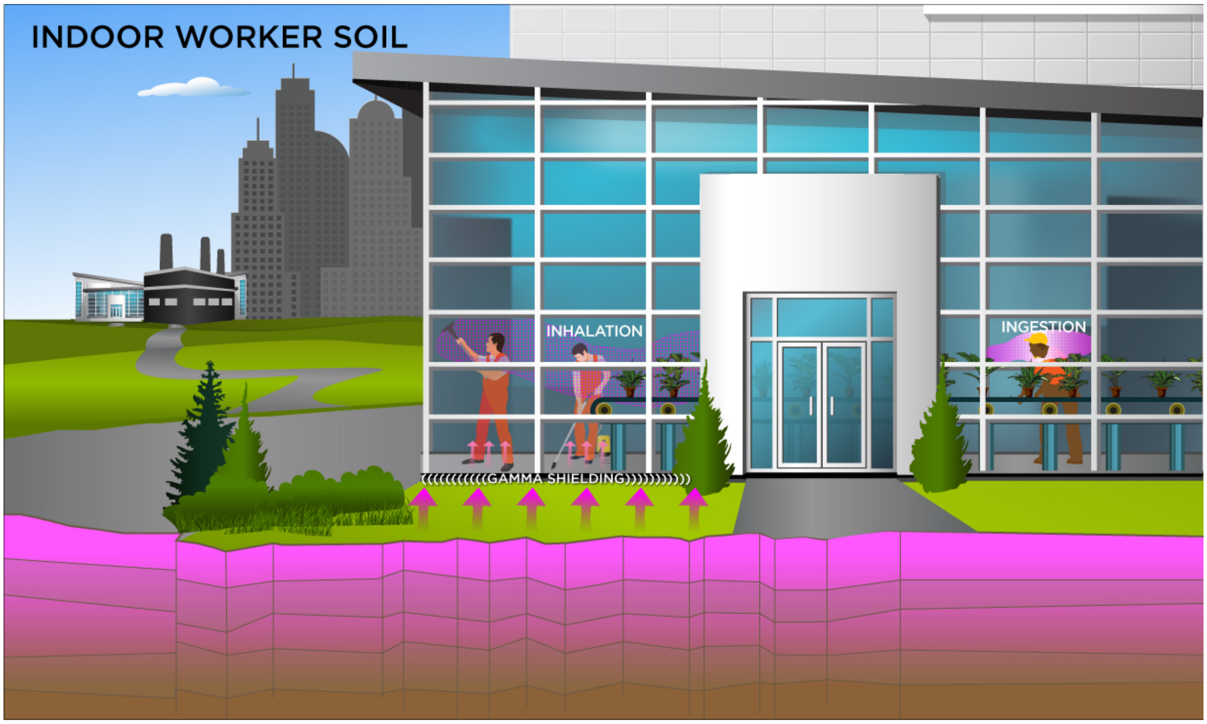
## 4.4 Indoor Worker

### 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. DCCs 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 DCC Download Area but DCCs can be created by using the Calculator to modify the exposure parameters for the composite worker to match the equations that follow.

#### Graphical Representation




#### Equations

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

- incidental ingestion of soil,

$$DCC_{iw\text{-}soil\text{-}ing}(pCi/g) = \frac{DL\left(\frac{mrem}{year}\right) \times t_{iw}(year) \times \lambda\left(\frac{1}{year}\right)}{\left(1-e^{-\lambda t_{iw}}\right) \times DCF_{oa}\left(\frac{mrem}{pCi}\right) \times EF_{iw}\left(\frac{250\ days}{year}\right) \times IRS_{iw}\left(\frac{50\ mg}{day}\right) \times \left(\frac{g}{1000\ mg}\right)}$$

- inhalation of particulates emitted from soil,

$$DCC_{iw\text{-}soil\text{-}inh}(pCi/g) = \frac{DL\left(\frac{mrem}{year}\right) \times t_{iw}(year) \times \lambda\left(\frac{1}{year}\right)}{\left(1-e^{-\lambda t_{iw}}\right) \times SF_{i}\left(\frac{mrem}{pCi}\right) \times EF_{iw}\left(\frac{250\ days}{year}\right) \times ET_{iw}\left(\frac{8\ hours}{day}\right) \times \left(\frac{1\ day}{24\ hours}\right) \times IRA_{iw}\left(\frac{60\ m^3}{day}\right) \times \frac{1}{PEF\left(\frac{m^3}{kg}\right)} \times \left(\frac{1000\ g}{kg}\right)}$$

- external exposure to ionizing radiation, and

$$DCC_{iw\text{-}soil\text{-}ext}(pCi/g) = \frac{DL\left(\frac{mrem}{year}\right) \times t_{iw}(year) \times \lambda\left(\frac{1}{year}\right)}{\left(1-e^{-\lambda t_{iw}}\right) \times DCF_{ext\text{-}sv}\left(\frac{mrem/year}{pCi/g}\right) \times EF_{iw}\left(\frac{250\ days}{year}\right) \times \left(\frac{1\ year}{365\ day}\right) \times ET_{iw}\left(\frac{8\ hours}{day}\right) \times \left(\frac{1\ day}{24\ hours}\right) \times GSF_{i\text{-}total} \times ACF_{ext\text{-}sv}}$$

- total

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

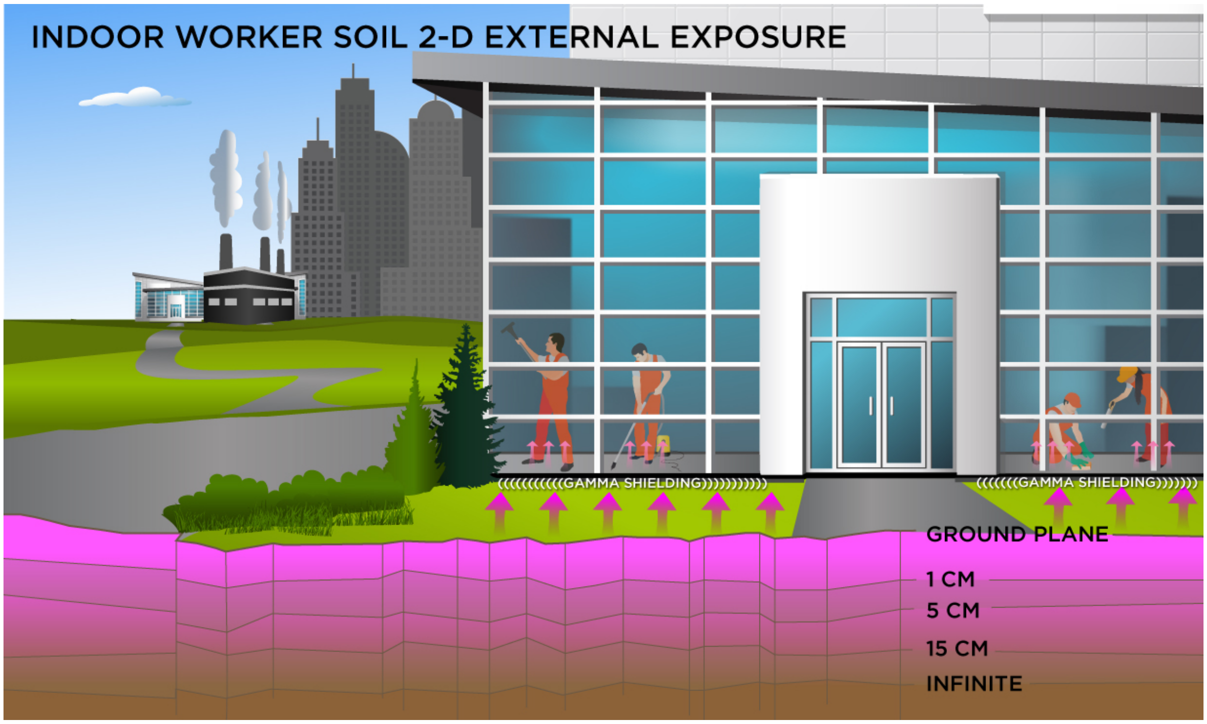
Definitions of the input variables are in Table 1.

## 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




### Equations

- Direct External Exposure to contamination at infinite depth

$$DCC_{iw\text{-}soil\text{-}sv}\,(pCi/g) = \frac{DL\left(\frac{mrem}{year}\right) \times t_{iw}\,(year) \times \lambda\left(\frac{1}{year}\right)}{\left(1-e^{-\lambda t_{iw}}\right) \times DCF_{ext\text{-}sv}\left(\frac{mrem/year}{pCi/g}\right) \times EF_{iw}\left(\frac{250\ days}{year}\right) \times \left(\frac{1\ year}{365\ days}\right) \times ET_{iw}\left(\frac{8\ hours}{day}\right) \times \left(\frac{1\ day}{24\ hours}\right) \times GSF_{i\text{-}total} \times ACF_{ext\text{-}sv}}$$

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

- Direct External Exposure to contamination 1 cm thick

$$DCC_{iw\text{-}soil\text{-}1\,cm}\,(pCi/g) = \frac{DL\left(\frac{mrem}{year}\right) \times t_{iw}\,(year) \times \lambda\left(\frac{1}{year}\right)}{\left(1-e^{-\lambda t_{iw}}\right) \times DCF_{ext\text{-}1cm}\left(\frac{mrem/year}{pCi/g}\right) \times EF_{iw}\left(\frac{250\ days}{year}\right) \times \left(\frac{1\ year}{365\ days}\right) \times ET_{iw}\left(\frac{8\ hours}{day}\right) \times \left(\frac{1\ day}{24\ hours}\right) \times GSF_{i\text{-}total} \times ACF_{ext\text{-}1\,cm}}$$

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

- Direct External Exposure to contamination 5 cm thick

$$DCC_{iw\text{-}soil\text{-}5\,cm}\,(pCi/g) = \frac{DL\left(\frac{mrem}{year}\right) \times t_{iw}\,(year) \times \lambda\left(\frac{1}{year}\right)}{\left(1-e^{-\lambda t_{iw}}\right) \times DCF_{ext\text{-}5cm}\left(\frac{mrem/year}{pCi/g}\right) \times EF_{iw}\left(\frac{250\ days}{year}\right) \times \left(\frac{1\ year}{365\ days}\right) \times ET_{iw}\left(\frac{8\ hours}{day}\right) \times \left(\frac{1\ day}{24\ hours}\right) \times GSF_{i\text{-}total} \times ACF_{ext\text{-}5cm}}$$

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

- Direct External Exposure to contamination 15 cm thick

$$DCC_{iw\text{-}soil\text{-}15cm}(pCi/g) = \frac{DL\left(\frac{mrem}{year}\right) \times t_{iw}(year) \times \lambda\left(\frac{1}{year}\right)}{\left(1-e^{-\lambda t_{iw}}\right) \times DCF_{ext\text{-}15cm}\left(\frac{mrem/year}{pCi/g}\right) \times EF_{iw}\left(\frac{250\ days}{year}\right) \times \left(\frac{1\ year}{365\ days}\right) \times ET_{iw}\left(\frac{8\ hours}{day}\right) \times \left(\frac{1\ day}{24\ hours}\right) \times GSF_{i\text{-}total} \times ACF_{ext\text{-}15cm}}$$

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

- Direct External Exposure to surface contamination

$$DCC_{iw\text{-}soil\text{-}gp}(pCi/cm^2) = \frac{DL\left(\frac{mrem}{year}\right) \times t_{iw}(year) \times \lambda\left(\frac{1}{year}\right)}{\left(1-e^{-\lambda t_{iw}}\right) \times DCF_{ext\text{-}gp}\left(\frac{mrem/year}{pCi/cm^2}\right) \times EF_{iw}\left(\frac{250\ days}{year}\right) \times \left(\frac{1\ year}{365\ days}\right) \times ET_{iw}\left(\frac{8\ hours}{day}\right) \times \left(\frac{1\ day}{24\ hours}\right) \times GSF_{i\text{-}total} \times ACF_{ext\text{-}gp}}$$

The resulting units for this recommended DCC are in $pCi/cm^2$. The units are based on area because the DCF used is the ground plane for external exposure.

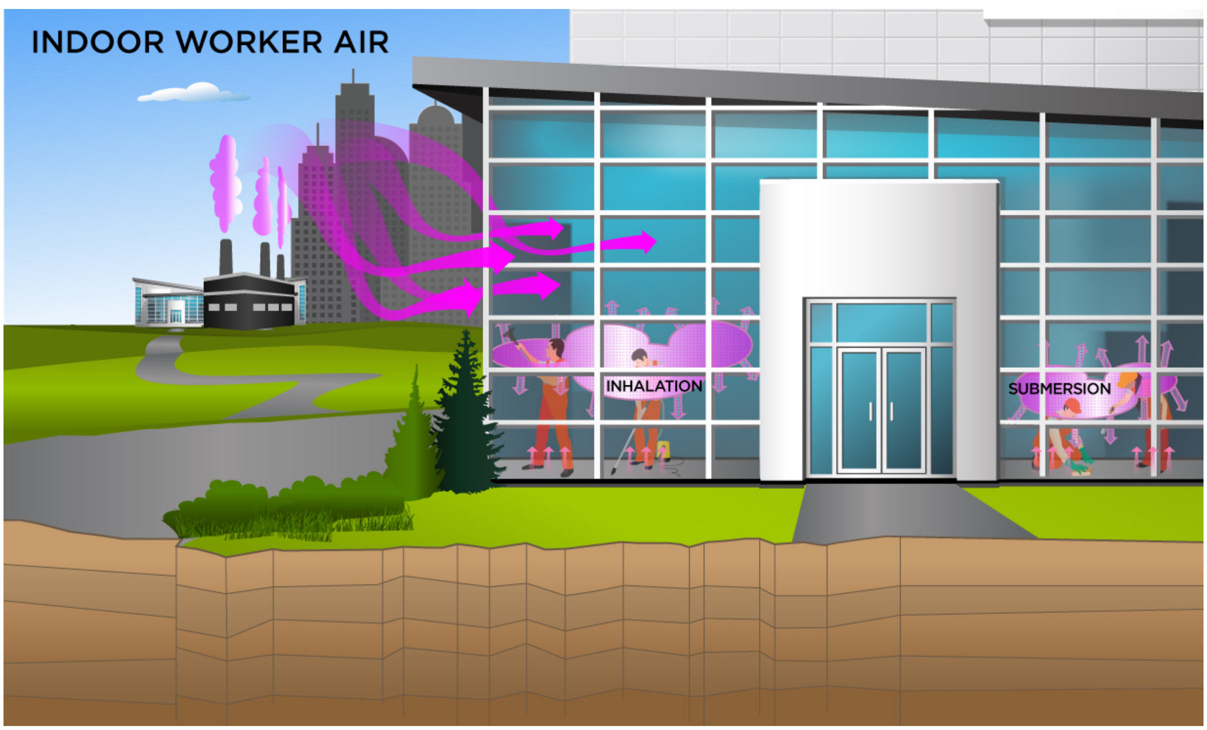
Definitions of the input variables are in Table 1.

## 4.4.3 Indoor Worker Air

This is a long-term receptor exposed during the work day who 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.

Two ambient air exposure conditions are offered for this scenario. The first scenario includes a half-life decay function and the second scenario does not. In situations where the contaminant in the air is not being replenished (e.g., an accidental one-time air release from a factory), equations for the first scenario 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), equations for the second scenario should be used.

### Graphical Representation




### Equations

Two sets of ambient air exposure equations are presented below. The first set of equations include a half-life decay function and the second set of equations does not. In situations where the contaminant in the air is not being replenished (e.g., contaminated settled dust from a previous release that is being resuspended), the first equation should be used. In situations where the contaminant in the air has a continual source (e.g., indoor radon from radium in the soil), the second equation should be used.

The indoor worker ambient air land use equation, presented here, contains the following exposure routes with half-life decay:

- inhalation and

$$DCC_{iw\text{-}air\text{-}inh\text{-}decay}\left(pCi/m^3\right) = \frac{DL\left(\frac{mrem}{year}\right)\times t_{iw}\,(year)\times\lambda\left(\frac{1}{year}\right)}{(1-e^{-\lambda t_{iw}})\times DCF_i\left(\frac{mrem}{pCi}\right)\times EF_{iw}\left(\frac{250\ days}{year}\right)\times ET_{iw}\left(\frac{8\ hours}{day}\right)\times\left(\frac{1\ day}{24\ hours}\right)\times IRA_{iw}\left(\frac{60\ m^3}{day}\right)}$$

- external exposure to ionizing radiation

$$DCC_{iw\text{-}air\text{-}sub\text{-}decay}\left(pCi/m^3\right) = \frac{DL\left(\frac{mrem}{year}\right)\times t_{iw}\,(year)\times\lambda\left(\frac{1}{year}\right)}{(1-e^{-\lambda t_{iw}})\times DCF_{sub}\left(\frac{mrem/year}{pCi/m^3}\right)\times EF_{iw}\left(\frac{250\ days}{year}\right)\times\left(\frac{1\ year}{365\ day}\right)\times ET_{iw}\left(\frac{8\ hours}{day}\right)\times\left(\frac{1\ day}{24\ hours}\right)\times GSF_a\,(1.0)}$$

- total

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

The indoor worker ambient air land use equation, presented here, contains the following exposure routes without half-life decay:

- inhalation and

$$DCC_{iw\text{-}air\text{-}inh\text{-}nodecay}\left(pCi/m^3\right) = \frac{DL\left(\frac{mrem}{year}\right)}{DCF_i\left(\frac{mrem}{pCi}\right)\times EF_{iw}\left(\frac{250\ days}{year}\right)\times ET_{iw}\left(\frac{8\ hours}{day}\right)\times\left(\frac{1\ day}{24\ hours}\right)\times IRA_{iw}\left(\frac{60\ m^3}{day}\right)}$$

- external exposure to ionizing radiation

$$DCC_{iw\text{-}air\text{-}sub\text{-}nodecay}\left(pCi/m^3\right) = \frac{DL\left(\frac{mrem}{year}\right)}{DCF_{sub}\left(\frac{mrem/year}{pCi/m^3}\right)\times EF_{iw}\left(\frac{250\ days}{year}\right)\times\left(\frac{1\ year}{365\ day}\right)\times ET_{iw}\left(\frac{8\ hours}{day}\right)\times\left(\frac{1\ day}{24\ hours}\right)\times GSF_a\,(1.0)}$$

- total

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

Definitions of the input variables are in Table 1.

## 4.5 Construction Worker

### 4.5.1 Construction Worker Soil Exposure to Unpaved Road Traffic

This is a short-term receptor exposed during the work day working around 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, inhalation of fugitive dust. The only difference between this construction worker and the one described in section 4.5.3 is that this construction worker uses a different PEF.

The construction worker soil land use is not provided in the Generic Tables but DCCs 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


**Equations**

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

- incidental ingestion of soil,

$$DCC_{cw\text{-}soil\text{-}ing}(pCi/g) = \frac{DL\left(\frac{mrem}{year}\right) \times t_{cw}\,(year) \times \lambda\left(\frac{1}{year}\right)}{\left(1-e^{-\lambda t_{cw}}\right) \times DCF_{oa}\left(\frac{mrem}{pCi}\right) \times EF_{cw}\left(EW_{cw}\,\frac{50\text{ weeks}}{year} \times DW_{cw}\,\frac{5\text{ days}}{week}\right) \times IRS_{cw}\left(\frac{330\text{ mg}}{day}\right) \times \left(\frac{g}{1000\text{ mg}}\right)}$$

- inhalation of particulates emitted from soil,

$$DCC_{cw\text{-}soil\text{-}inh}(pCi/g) = \frac{DL\left(\frac{mrem}{year}\right) \times t_{cw}\,(year) \times \lambda\left(\frac{1}{year}\right)}{\left(1-e^{-\lambda t_{cw}}\right) \times DCF_{i}\left(\frac{mrem}{pCi}\right) \times EF_{cw}\left(EW_{cw}\,\frac{50\text{ weeks}}{year} \times DW_{cw}\,\frac{5\text{ days}}{week}\right) \times ET_{cw}\left(\frac{8\text{ hours}}{day}\right) \times \left(\frac{1\text{ day}}{24\text{ hours}}\right) \times IRA_{cw}\left(\frac{60\text{ m}^3}{day}\right) \times \frac{1}{PEF_{sc}\left(\frac{m^3}{kg}\right)} \times \left(\frac{1000\text{ g}}{kg}\right)}$$

- external exposure to ionizing radiation, and

$$DCC_{cw\text{-}soil\text{-}ext}(pCi/g) = \frac{DL\left(\frac{mrem}{year}\right) \times t_{cw}\,(year) \times \lambda\left(\frac{1}{year}\right)}{\left(1-e^{-\lambda t_{cw}}\right) \times DCF_{ext\text{-}sv}\left(\frac{mrem/year}{pCi/g}\right) \times EF_{cw}\left(EW_{cw}\,\frac{50\text{ weeks}}{year} \times DW_{cw}\,\frac{5\text{ days}}{week}\right) \times \left(\frac{1\text{ year}}{365\text{ days}}\right) \times ET_{cw}\left(\frac{8\text{ hours}}{day}\right) \times \left(\frac{1\text{ day}}{24\text{ hours}}\right) \times GSF_{ext\text{-}sv}\,(1.0) \times ACF_{ext\text{-}sv}}$$

- total

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

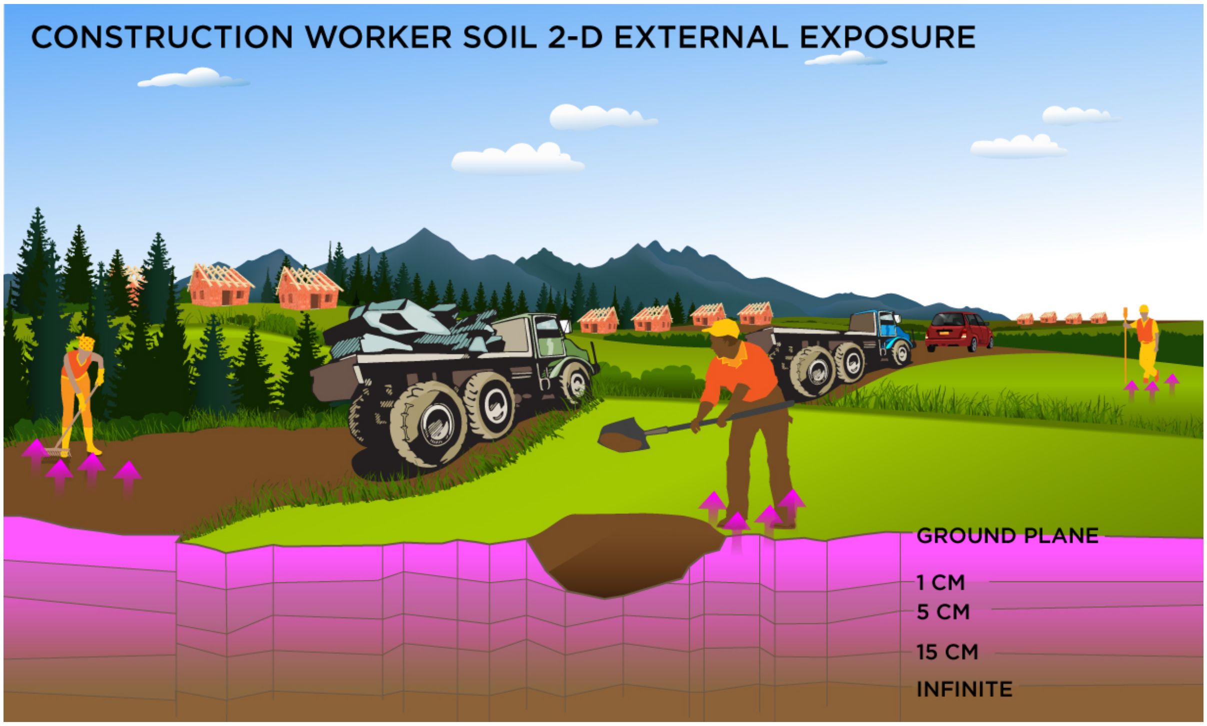
Definitions of the input variables are in Table 1.

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

This is a short-term receptor exposed during the work day who is a full time employee working on-site and who spends most of the workday conducting maintenance activities outdoors. 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**




## Equations

- Direct External Exposure to contamination at infinite depth

$$DCC_{cw\text{-}soil\text{-}sv}(pCi/g) = \frac{DL\left(\frac{mrem}{year}\right) \times t_{cw}\,(year) \times \lambda\left(\frac{1}{year}\right)}{\left(1-e^{-\lambda t_{cw}}\right) \times DCF_{ext\text{-}sv}\left(\frac{mrem/year}{pCi/g}\right) \times EF_{cw}\left(EW_{cw}\,\frac{50\ weeks}{year} \times DW_{cw}\,\frac{5\ days}{week}\right) \times \left(\frac{1\ year}{365\ days}\right) \times ET_{cw}\left(\frac{8\ hours}{day}\right) \times \left(\frac{1\ day}{24\ hours}\right) \times GSF_{ext\text{-}sv}\,(1.0) \times ACF_{ext\text{-}sv}}$$

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

- Direct External Exposure to contamination 1 cm thick

$$DCC_{cw\text{-}soil\text{-}1\,cm}(pCi/g) = \frac{DL\left(\frac{mrem}{year}\right) \times t_{cw}\,(year) \times \lambda\left(\frac{1}{year}\right)}{\left(1-e^{-\lambda t_{cw}}\right) \times DCF_{ext\text{-}1cm}\left(\frac{mrem/year}{pCi/g}\right) \times EF_{cw}\left(EW_{cw}\,\frac{50\ weeks}{year} \times DW_{cw}\,\frac{5\ days}{week}\right) \times \left(\frac{1\ year}{365\ days}\right) \times ET_{cw}\left(\frac{8\ hours}{day}\right) \times \left(\frac{1\ day}{24\ hours}\right) \times GSF_{ext\text{-}1cm}\,(1.0) \times ACF_{ext\text{-}1\,cm}}$$

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

- Direct External Exposure to contamination 5 cm thick

$$DCC_{cw\text{-}soil\text{-}5\,cm}(pCi/g) = \frac{DL\left(\frac{mrem}{year}\right) \times t_{ow}\,(year) \times \lambda\left(\frac{1}{year}\right)}{\left(1-e^{-\lambda t_{cw}}\right) \times DCF_{ext\text{-}5cm}\left(\frac{mrem/year}{pCi/g}\right) \times EF_{cw}\left(EW_{cw}\,\frac{50\ weeks}{year} \times DW_{cw}\,\frac{5\ days}{week}\right) \times \left(\frac{1\ year}{365\ days}\right) \times ET_{cw}\left(\frac{8\ hours}{day}\right) \times \left(\frac{1\ day}{24\ hours}\right) \times GSF_{ext\text{-}5cm}\,(1.0) \times ACF_{ext\text{-}5cm}}$$

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

- Direct External Exposure to contamination 15 cm thick

$$DCC_{cw\text{-}soil\text{-}15cm}(pCi/g) = \frac{DL\left(\frac{mrem}{year}\right) \times t_{cw}\,(year) \times \lambda\left(\frac{1}{year}\right)}{\left(1-e^{-\lambda t_{cw}}\right) \times DCF_{ext\text{-}15cm}\left(\frac{mrem/year}{pCi/g}\right) \times EF_{cw}\left(EW_{cw}\,\frac{50\ weeks}{year} \times DW_{cw}\,\frac{5\ days}{week}\right) \times \left(\frac{1\ year}{365\ days}\right) \times ET_{cw}\left(\frac{8\ hours}{day}\right) \times \left(\frac{1\ day}{24\ hours}\right) \times GSF_{ext\text{-}15cm}\,(1.0) \times ACF_{ext\text{-}15cm}}$$

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

- Direct External Exposure to surface contamination

$$DCC_{cw\text{-}soil\text{-}gp}(pCi/cm^2) = \frac{DL\left(\frac{mrem}{year}\right) s \times t_{cw}(year) \times \lambda\left(\frac{1}{year}\right)}{\left(1\text{-}e^{-\lambda t_{cw}}\right) \times DCF_{ext\text{-}gp}\left(\frac{mrem/year}{pCi/cm^2}\right) \times EF_{cw}\left(EW_{cw}\frac{50\ weeks}{year} \times DW_{cw}\frac{5\ days}{week}\right) \times \left(\frac{1\ year}{365\ days}\right) \times ET_{cw}\left(\frac{8\ hours}{day}\right) \times \left(\frac{1\ day}{24\ hours}\right) \times GSF_{ext\text{-}gp}(1.0) \times ACF_{ext\text{-}gp}}$$

The resulting units for this recommended DCC are in $pCi/cm^2$. The units are based on area because the DCF used is the ground plane for external exposure.

Definitions of the input variables are in Table 1.

### 4.5.3 Construction Worker Air

This is a short-term receptor exposed during the work day during heavy construction activities outdoors. 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.

Two ambient air exposure conditions are offered for this scenario. The first scenario includes a half-life decay function and the second scenario does not. In situations where the contaminant in the air is not being replenished (e.g., an accidental one-time air release from a factory), equations for the first scenario 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), equations for the second scenario should be used.

#### Graphical Representation


#### Equations

The construction worker ambient air land use equations, presented here, contain the following exposure routes with half-life decay:

- inhalation and

$$DCC_{cw\text{-}air\text{-}inh\text{-}decay}\left(pCi/m^3\right) = \frac{DL\left(\frac{mrem}{year}\right) \times t_{cw}(year) \times \lambda\left(\frac{1}{year}\right)}{(1\text{-}e^{-\lambda t_{cw}}) \times DCF_i\left(\frac{mrem}{pCi}\right) \times EF_{cw}\left(EW_{cw}\frac{50\ weeks}{year} \times DW_{cw}\frac{5\ days}{week}\right) \times ET_{cw}\left(\frac{8\ hours}{day}\right) \times \left(\frac{1\ day}{24\ hours}\right) \times IRA_{cw}\left(\frac{60\ m^3}{day}\right)}$$

- external exposure to ionizing radiation

$$DCC_{cw\text{-}air\text{-}sub\text{-}decay}\left(pCi/m^3\right) = \frac{DL\left(\frac{mrem}{year}\right)\times t_{cw}\,(yr)\times\lambda\left(\frac{1}{yr}\right)}{(1-e^{-\lambda t_{cw}})\times DCF_{sub}\left(\frac{mrem/yr}{pCi/m^3}\right)\times EF_{cw}\left(EW_{cw}\,\frac{50\ weeks}{year}\times DW_{cw}\,\frac{5\ days}{week}\right)\times\left(\frac{1\ yr}{365\ day}\right)\times ET_{cw}\left(\frac{8\ hr}{day}\right)\times\left(\frac{1\ day}{24\ hours}\right)\times GSF_a\,(1.0)}$$

- total

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

The composite worker ambient air land use equation, presented here, contains the following exposure routes without half-life decay:

- inhalation and

$$DCC_{cw\text{-}air\text{-}inh\text{-}nodecay}\left(pCi/m^3\right) = \frac{DL\left(\frac{mrem}{year}\right)}{DCF_i\left(\frac{mrem}{pCi}\right)\times EF_{cw}\left(EW_{cw}\,\frac{50\ weeks}{year}\times DW_{cw}\,\frac{5\ days}{week}\right)\times ET_{cw}\left(\frac{8\ hours}{day}\right)\times\left(\frac{1\ day}{24\ hours}\right)\times IRA_{cw}\left(\frac{60\ m^3}{day}\right)}$$

- external exposure to ionizing radiation

$$DCC_{cw\text{-}air\text{-}sub\text{-}nodecay}\left(pCi/m^3\right) = \frac{DL\left(\frac{mrem}{year}\right)}{DCF_{sub}\left(\frac{mrem/year}{pCi/m^3}\right)\times EF_{cw}\left(EW_{cw}\,\frac{50\ weeks}{year}\times DW_{cw}\,\frac{5\ days}{week}\right)\times\left(\frac{1\ year}{365\ days}\right)\times ET_{cw}\left(\frac{8\ hours}{day}\right)\times\left(\frac{1\ day}{24\ hours}\right)\times GSF_a\,(1.0)}$$

- total

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

Definitions of the input variables are in Table 1.

### 4.5.4 Construction Worker Soil Exposure to Other Construction Activities

This is a short-term receptor exposed during the work day working around heavy vehicles suspending dust in the air. The activities for this receptor (e.g., dozing, grading, tilling, dumping, 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, 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 Generic Tables but DCCs 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


**Equations**

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

- incidental ingestion of soil,

$$DCC_{cw\text{-}soil\text{-}ing\text{-}sa}(pCi/g) = \frac{DL\left(\frac{mrem}{year}\right)\times t_{cw}\,(year)\times\lambda\left(\frac{1}{year}\right)}{\left(1\text{-}e^{-\lambda t_{cw}}\right)\times DCF_{oa}\left(\frac{mrem}{pCi}\right)\times EF_{cw}\left(EW_{cw}\frac{50\ weeks}{year}\times DW_{cw}\frac{5\ days}{week}\right)\times IRS_{cw}\left(\frac{330\ mg}{day}\right)\times\left(\frac{g}{1000\ mg}\right)}$$

- inhalation of particulates emitted from soil,

$$DCC_{cw\text{-}soil\text{-}inh\text{-}sa}(pCi/g) = \frac{DL\left(\frac{mrem}{year}\right)\times t_{cw}\,(year)\times\lambda\left(\frac{1}{year}\right)}{\left(1\text{-}e^{-\lambda t_{cw}}\right)\times DCF_{i}\left(\frac{mrem}{pCi}\right)\times EF_{cw}\left(EW_{cw}\frac{50\ weeks}{year}\times DW_{cw}\frac{5\ days}{week}\right)\times ET_{cw}\left(\frac{8\ hours}{day}\right)\times\left(\frac{1\ day}{24\ hours}\right)\times IRA_{cw}\left(\frac{60\ m^3}{day}\right)\times\frac{1}{PEF'_{sc}\left(\frac{m^3}{kg}\right)}\times\left(\frac{1000\ g}{kg}\right)}$$

- external exposure to ionizing radiation, and

$$DCC_{cw\text{-}soil\text{-}ext\text{-}sa}(pCi/g) = \frac{DL\left(\frac{mrem}{year}\right)\times t_{cw}\,(year)\times\lambda\left(\frac{1}{year}\right)}{\left(1\text{-}e^{-\lambda t_{cw}}\right)\times DCF_{ext\text{-}sv}\left(\frac{mrem/year}{pCi/g}\right)\times EF_{cw}\left(EW_{cw}\frac{50\ weeks}{year}\times DW_{cw}\frac{5\ days}{week}\right)\times\left(\frac{1\ year}{365\ days}\right)\times ET_{cw}\left(\frac{8\ hours}{day}\right)\times\left(\frac{1\ day}{24\ hours}\right)\times GSF_{ext\text{-}sv}\,(1.0)\times ACF_{ext\text{-}sv}}$$

- total

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

Definitions of the input variables are in Table 1.

### 4.5.4.1 Construction Worker Soil Exposure to Other Construction Activities 2-D External Exposure

This assessment is the same as Unpaved Roads.

### 4.5.4.2 Construction Worker Air from Exposure to Other Construction Activities

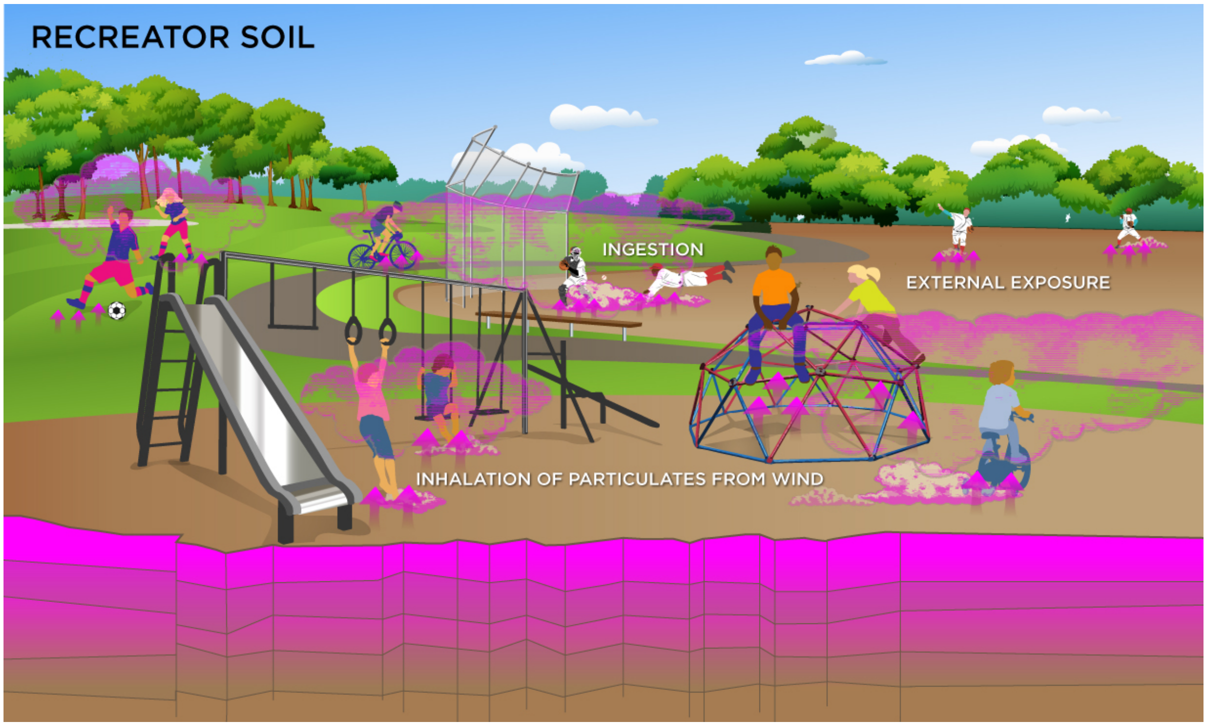
This assessment is the same as Unpaved Roads.

## 4.6 Recreator

## 4.6.1 Recreator Soil

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

### Graphical Representation




### Equations

- incidental ingestion of soil

$$DCC_{rec\text{-}soil\text{-}ing}(pCi/g) = \frac{DL\left(\frac{mrem}{year}\right)\times t_{rec}(years)\times\lambda\left(\frac{1}{years}\right)}{\left(1-e^{-\lambda t_{rec}}\right)\times DCF_{s}\left(\frac{mrem}{pCi}\right)\times IFS_{rec\text{-}adj}\left(\frac{mg}{year}\right)\times\left(\frac{g}{1000\ mg}\right)}$$

where:

$$IFS_{rec\text{-}adj}\left(\frac{mg}{year}\right) = \left(\begin{array}{l}\left(EF_{rec\text{-}c}\left(\frac{days}{year}\right)\times IRS_{rec\text{-}c}\left(\frac{200\ mg}{day}\right)\times AAF_{rec\text{-}c}\right)+\\ \left(EF_{rec\text{-}a}\left(\frac{days}{year}\right)\times IRS_{rec\text{-}a}\left(\frac{100\ mg}{day}\right)\times AAF_{rec\text{-}a}\right)\end{array}\right)$$

where:

$$AAF_{rec\text{-}c} = \left(\frac{ED_{rec\text{-}c}(years)}{ED_{rec}(years)}\right)\ \text{and: } AAF_{rec\text{-}a} = \left(\frac{ED_{rec\text{-}a}(years)}{ED_{rec}(years)}\right)$$

- inhalation of particulates emitted from soil

$$DCC_{rec\text{-}soil\text{-}inh}(pCi/g) = \frac{DL\left(\frac{mrem}{year}\right)\times t_{rec}(years)\times\lambda\left(\frac{1}{years}\right)}{\left(1-e^{-\lambda t_{rec}}\right)\times DCF_{i}\left(\frac{mrem}{pCi}\right)\times IFA_{rec\text{-}adj}\left(\frac{m^3}{year}\right)\times\frac{1}{PEF\left(\frac{m^3}{kg}\right)}\times\left(\frac{1000\ g}{kg}\right)}$$

where:

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

where:

$$AAF_{rec\text{-}c} = \left(\frac{ED_{rec\text{-}c}(years)}{ED_{rec}(years)}\right)\ \text{and: } AAF_{rec\text{-}a} = \left(\frac{ED_{rec\text{-}a}(years)}{ED_{rec}(years)}\right)$$

- external exposure to ionizing radiation

$$DCC_{rec\text{-}sol\text{-}ext}(pCi/g) = \frac{DL\left(\frac{mrem}{year}\right) \times t_{rec}(years) \times \lambda\left(\frac{1}{years}\right)}{\left(1-e^{-\lambda t_{rec}}\right) \times DCF_{ext\text{-}sv}\left(\frac{mrem/year}{pCi/g}\right) \times EF_{rec}\left(\frac{days}{year}\right) \times \left(\frac{1\ year}{365\ days}\right) \times ET_{rec}\left(\frac{hours}{day}\right) \times \left(\frac{1\ day}{24\ hours}\right) \times GSF_{ext\text{-}sv}(1.0) \times ACF_{ext\text{-}sv}}$$

- total

$$DCC_{rec\text{-}sol\text{-}tot}(pCi/g) = \frac{1}{\frac{1}{DCC_{rec\text{-}sol\text{-}ing}} + \frac{1}{DCC_{rec\text{-}sol\text{-}inh}} + \frac{1}{DCC_{rec\text{-}sol\text{-}ext}}}$$

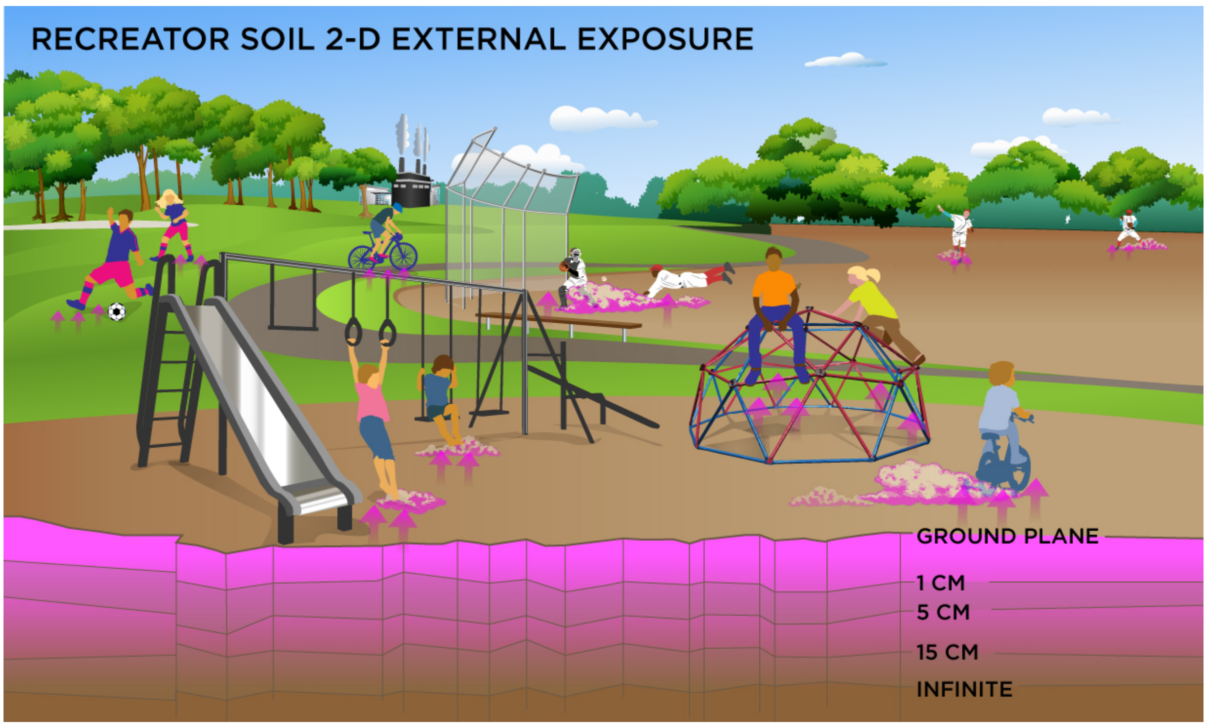
Definitions of the input variables are in Table 1.

### 4.6.2 Recreator Soil 2-D External Exposure

This receptor spends time outside involved in recreational activities. There are no default DCCs 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




#### Equations

- Direct External Exposure to contamination at infinite depth

$$DCC_{rec\text{-}sol\text{-}sv}(pCi/g) = \frac{DL\left(\frac{mrem}{year}\right) \times t_{rec}(years) \times \lambda\left(\frac{1}{years}\right)}{\left(1-e^{-\lambda t_{rec}}\right) \times DCF_{ext\text{-}sv}\left(\frac{mrem/year}{pCi/g}\right) \times EF_{rec}\left(\frac{days}{year}\right) \times \left(\frac{1\ year}{365\ days}\right) \times ET_{rec}\left(\frac{hours}{day}\right) \times \left(\frac{1\ day}{24\ hours}\right) \times GSF_{ext\text{-}sv}(1.0) \times ACF_{ext\text{-}sv}}$$

- Direct External Exposure to contamination 1 cm thick

$$DCC_{rec\text{-}sol\text{-}1cm}(pCi/g) = \frac{DL\left(\frac{mrem}{year}\right) \times t_{rec}(years) \times \lambda\left(\frac{1}{years}\right)}{\left(1-e^{-\lambda t_{rec}}\right) \times DCF_{ext\text{-}1cm}\left(\frac{mrem/year}{pCi/g}\right) \times EF_{rec}\left(\frac{days}{year}\right) \times \left(\frac{1\ year}{365\ days}\right) \times ET_{rec}\left(\frac{hours}{day}\right) \times \left(\frac{1\ day}{24\ hours}\right) \times GSF_{ext\text{-}1cm}(1.0) \times ACF_{ext\text{-}1cm}}$$

- Direct External Exposure to contamination 5 cm thick

$$DCC_{rec\text{-}sol\text{-}5cm}(pCi/g) = \frac{DL\left(\frac{mrem}{year}\right) \times t_{rec}(years) \times \lambda\left(\frac{1}{years}\right)}{\left(1-e^{-\lambda t_{rec}}\right) \times DCF_{ext\text{-}5cm}\left(\frac{mrem/year}{pCi/g}\right) \times EF_{rec}\left(\frac{days}{year}\right) \times \left(\frac{1\ year}{365\ days}\right) \times ET_{rec}\left(\frac{hours}{day}\right) \times \left(\frac{1\ day}{24\ hours}\right) \times GSF_{ext\text{-}5cm}(1.0) \times ACF_{ext\text{-}5cm}}$$

- Direct External Exposure to contamination 15 cm thick

$$DCC_{rec\text{-}sol\text{-}15cm}(pCi/g) = \frac{DL\left(\frac{mrem}{year}\right)\times t_{rec}\,(years)\times\lambda\left(\frac{1}{years}\right)}{\left(1-e^{-\lambda t_{rec}}\right)\times DCF_{ext\text{-}15cm}\left(\frac{mrem/year}{pCi/g}\right)\times EF_{rec}\left(\frac{days}{year}\right)\times\left(\frac{1\ year}{365\ days}\right)\times ET_{rec}\left(\frac{hours}{day}\right)\times\left(\frac{1\ day}{24\ hours}\right)\times GSF_{ext\text{-}15cm}(1.0)\times ACF_{ext\text{-}15cm}}$$

- Direct External Exposure to surface contamination

$$DCC_{rec\text{-}sol\text{-}gp}(pCi/g) = \frac{DL\left(\frac{mrem}{year}\right)\times t_{rec}\,(years)\times\lambda\left(\frac{1}{years}\right)}{\left(1-e^{-\lambda t_{rec}}\right)\times DCF_{ext\text{-}gp}\left(\frac{mrem/year}{pCi/g}\right)\times EF_{rec}\left(\frac{days}{year}\right)\times\left(\frac{1\ year}{365\ days}\right)\times ET_{rec}\left(\frac{hours}{day}\right)\times\left(\frac{1\ day}{24\ hours}\right)\times GSF_{ext\text{-}gp}(1.0)\times ACF_{ext\text{-}gp}}$$

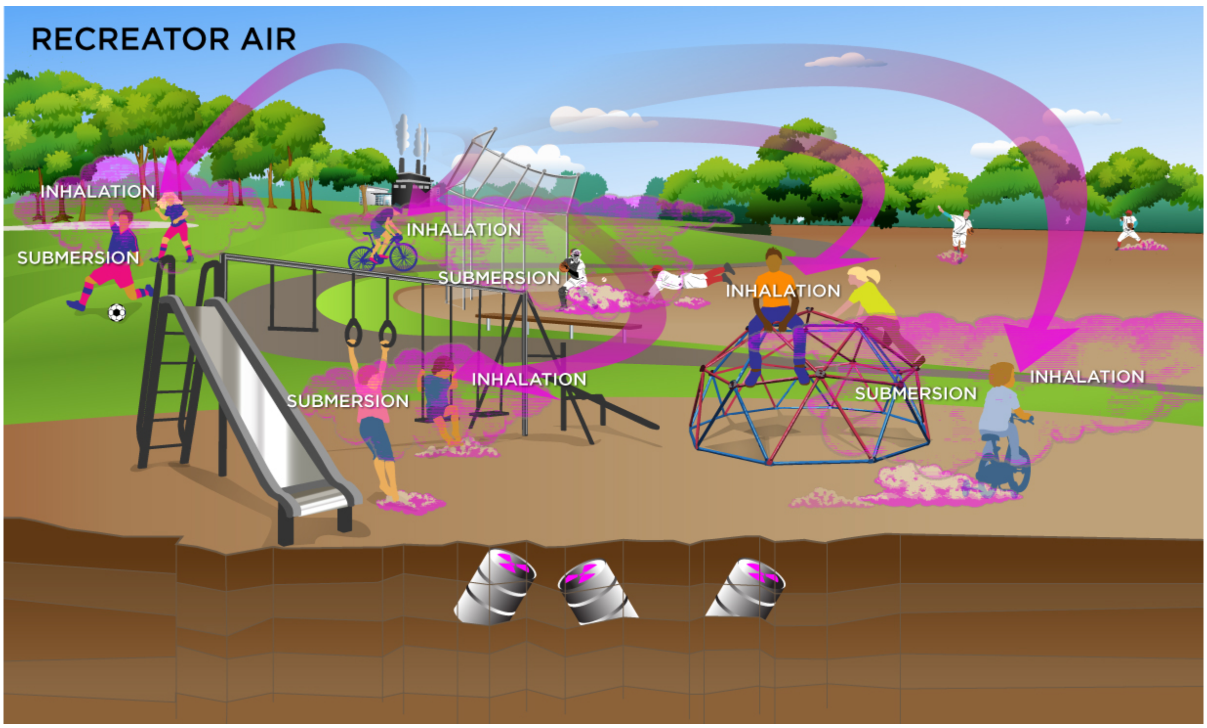
Definitions of the input variables are in Table 1.

## 4.6.3 Recreator Air

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

Two ambient air exposure conditions are offered for this scenario. The first scenario includes a half-life decay function and the second scenario does not. In situations where the contaminant in the air is not being replenished (e.g., an accidental one-time air release from a factory), equations for the first scenario 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), equations for the second scenario should be used.

### Graphical Representation




### Equations

The recreator ambient air land use equation, presented here, contains the following exposure routes with half-life decay:

- inhalation (with half-life decay)

$$DCC_{rec\text{-}air\text{-}inh\text{-}decay}\left(pCi/m^3\right) = \frac{DL\left(\frac{mrem}{year}\right)\times t_{rec}\,(years)\times\lambda\left(\frac{1}{years}\right)}{\left(1-e^{-\lambda t_{rec}}\right)\times DCF_{i}\left(\frac{mrem}{pCi}\right)\times IFA_{rec\text{-}adj}\left(\frac{m^3}{year}\right)}$$

where:

$$IFA_{rec\text{-}adj}\left(\frac{m^3}{year}\right) = \left(\begin{array}{l}\left(EF_{rec\text{-}c}\left(\frac{days}{year}\right)\times ET_{rec\text{-}c}\left(\frac{hours}{day}\right)\times\left(\frac{1\ day}{24\ hours}\right)\times IRA_{rec\text{-}c}\left(\frac{m^3}{day}\right)\times AAF_{rec\text{-}c}\right)+\\ \left(EF_{rec\text{-}a}\left(\frac{days}{year}\right)\times ET_{rec\text{-}a}\left(\frac{hours}{day}\right)\times\left(\frac{1\ day}{24\ hours}\right)\times IRA_{rec\text{-}a}\left(\frac{m^3}{day}\right)\times AAF_{rec\text{-}a}\right)\end{array}\right)$$

where:

$$AAF_{rec\text{-}c} = \left(\frac{ED_{rec\text{-}c}(years)}{ED_{rec}(years)}\right)\ \text{and:}\ AAF_{rec\text{-}a} = \left(\frac{ED_{rec\text{-}a}(years)}{ED_{rec}(years)}\right)$$

- external exposure to ionizing radiation (with half-life decay)

$$DCC_{rec\text{-}air\text{-}sub\text{-}decay}\left(pCi/m^3\right) = \frac{DL\left(\frac{mrem}{year}\right)\times t_{rec}\,(years)\times\lambda\left(\frac{1}{years}\right)}{(1-e^{-\lambda t_{rec}})\times DCF_{sub}\left(\frac{mrem/year}{pCi/m^3}\right)\times EF_{rec}\left(\frac{days}{year}\right)\times\left(\frac{1\ year}{365\ days}\right)\times ET_{rec}\left(\frac{hours}{day}\right)\times\left(\frac{1\ day}{24\ hours}\right)\times GSF_a\,(1.0)}$$

- total (with half-life decay)

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

The recreator ambient air land use equation, presented here, contains the following exposure routes without half-life decay:

- inhalation (without half-life decay)

$$DCC_{rec\text{-}air\text{-}inh\text{-}nodecay}\left(pCi/m^3\right) = \frac{DL\left(\frac{mrem}{year}\right)}{DCF_i\left(\frac{mrem}{pCi}\right)\times ED_{reca}\,(years)\times IFA_{rec\text{-}adj}\left(\frac{m^3}{year}\right)}$$

where:

$$IFA_{rec\text{-}adj}\left(\frac{m^3}{year}\right) = \left(\begin{array}{l}\left(EF_{rec\text{-}c}\left(\frac{days}{year}\right)\times ET_{rec\text{-}c}\left(\frac{hours}{day}\right)\times\left(\frac{1\ day}{24\ hours}\right)\times IRA_{rec\text{-}c}\left(\frac{m^3}{day}\right)\times AAF_{rec\text{-}c}\right)+\\\left(EF_{rec\text{-}a}\left(\frac{days}{year}\right)\times ET_{rec\text{-}a}\left(\frac{hours}{day}\right)\times\left(\frac{1\ day}{24\ hours}\right)\times IRA_{rec\text{-}a}\left(\frac{m^3}{day}\right)\times AAF_{rec\text{-}a}\right)\end{array}\right)$$

where:

$$AAF_{rec\text{-}c} = \left(\frac{ED_{rec\text{-}c}(years)}{ED_{rec}(years)}\right)\text{ and: }AAF_{rec\text{-}a} = \left(\frac{ED_{rec\text{-}a}(years)}{ED_{rec}(years)}\right)$$

- external exposure to ionizing radiation (without half-life decay)

$$DCC_{rec\text{-}air\text{-}sub\text{-}nodecay}\left(pCi/m^3\right) = \frac{DL\left(\frac{mrem}{year}\right)}{DCF_{sub}\left(\frac{mrem/year}{pCi/m^3}\right)\times EF_{rec}\left(\frac{days}{year}\right)\times\left(\frac{1\ year}{365\ days}\right)\times ET_{rec}\left(\frac{hours}{day}\right)\times\left(\frac{1\ day}{24\ hours}\right)\times GSF_a\,(1.0)}$$

- total (without half-life decay)

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

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 exposure assumptions this receptor.

### Graphical Representation


## Equations

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

- consumption of fowl - direct

$$DCC_{rec\text{-}fowl\text{-}ing}\left(pCi/g\right) = \frac{DL\left(\frac{mrem}{year}\right)}{DCF_o\left(\frac{mrem}{pCi}\right) \times EF_{rec}\left(\frac{days}{year}\right) \times IRGF_{rec}\left(\frac{g}{day}\right) \times CF_{rec\text{-}fowl}(1)}$$

- consumption of fowl - back-calculated to soil

$$DCC_{soil\text{-}rec\text{-}fowl\text{-}ing}\left(pCi/g\right) = \frac{DCC_{rec\text{-}fowl\text{-}ing}\left(pCi/g\right)}{TF_{fowl}\left(\frac{day}{kg}\right) \times \left[\left(Q_{p\text{-}fowl}\left(\frac{kg}{day}\right) \times f_{p\text{-}fowl}(1) \times f_{s\text{-}fowl}(1) \times \left(R_{upp} + R_{es}\right)\right) + \left(Q_{s\text{-}fowl}\left(\frac{kg}{day}\right) \times f_{p\text{-}fowl}(1)\right)\right]} \times \left(\frac{t_{rec}\left(year\right) \times \lambda\left(\frac{1}{year}\right)}{\left(1 - e^{-\lambda t_{rec}}\right)}\right)$$

where:

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

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

- consumption of fowl - back-calculated to water

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

- consumption of land game - direct

$$DCC_{rec\text{-}game\text{-}ing}\left(pCi/g\right) = \frac{DL\left(\frac{mrem}{year}\right)}{DCF_o\left(\frac{mrem}{pCi}\right) \times EF_{rec}\left(\frac{days}{year}\right) \times IRGL_{rec}\left(\frac{g}{day}\right) \times CF_{rec\text{-}game}(1)}$$

- consumption of land game - back-calculated to soil

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

where:

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

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

- consumption of land game - back-calculated to water.

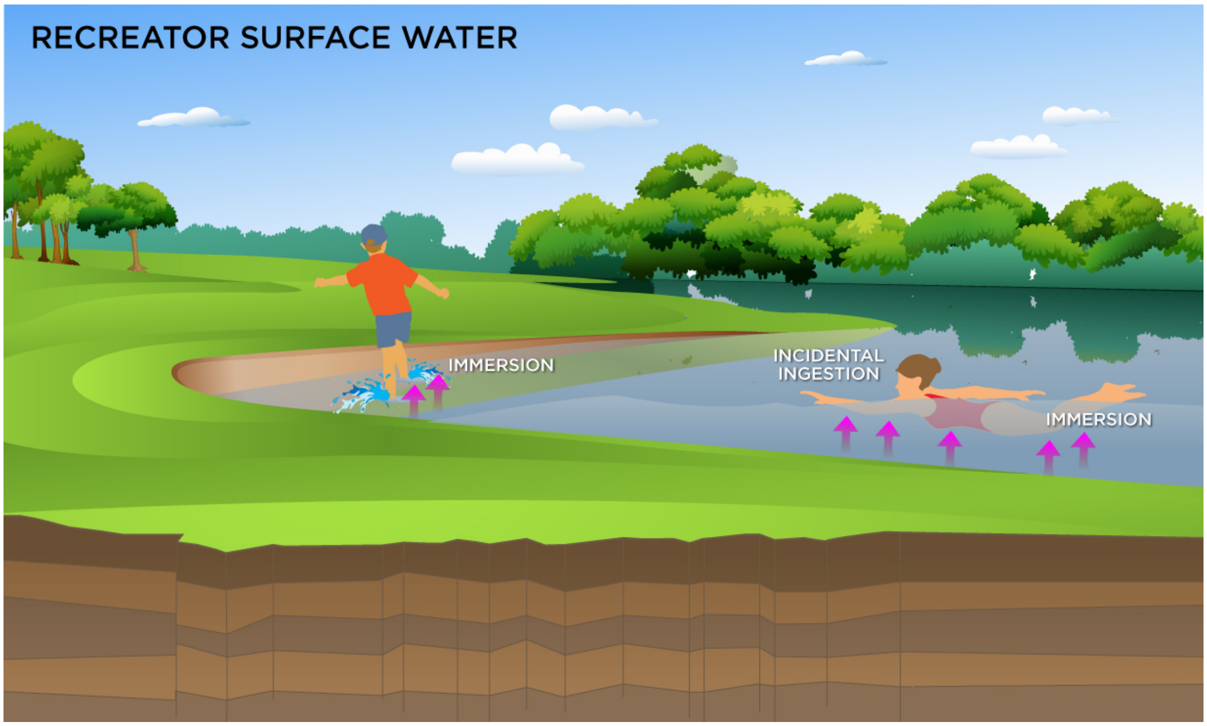
$$DCC_{water\text{-}rec\text{-}game\text{-}ing}\left(pCi/L\right) = \frac{DCC_{rec\text{-}game\text{-}ing}\left(pCi/g\right)}{TF_{game}\left(\frac{day}{kg}\right) \times Q_{w\text{-}game}\left(\frac{L}{day}\right) \times \left(\frac{1\ kg}{1000\ g}\right)}$$

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 DCCs for this scenario; only site-specific.

#### Graphical Representation




#### Equations

- ingestion of surface water

$$DCC_{rec\text{-}water\text{-}ing}\left(pCi/L\right) = \frac{DL\left(\frac{mrem}{year}\right)}{DCF_{o}\left(\frac{mrem}{pCi}\right) \times IFW_{rec\text{-}adj}\left(\frac{L}{year}\right)}$$

where:

$$IFW_{rec\text{-}adj}\left(\frac{L}{year}\right) = \left(\begin{array}{l}\left(EF_{rec\text{-}c}\left(\frac{days}{year}\right) \times ET_{event\text{-}rec\text{-}c}\left(\frac{hours}{event}\right) \times EV_{rec\text{-}c}\left(\frac{events}{day}\right) \times IRW_{rec\text{-}c}\left(\frac{0.12\ L}{hour}\right) \times AAF_{rec\text{-}c}\right) + \\ \left(EF_{rec\text{-}a}\left(\frac{days}{year}\right) \times ET_{event\text{-}rec\text{-}a}\left(\frac{hours}{event}\right) \times EV_{rec\text{-}a}\left(\frac{events}{day}\right) \times IRW_{rec\text{-}a}\left(\frac{0.071\ L}{hour}\right) \times AAF_{rec\text{-}a}\right)\end{array}\right)$$

where:

$$AAF_{rec\text{-}c} = \left(\frac{ED_{rec\text{-}c}\left(years\right)}{ED_{rec}\left(years\right)}\right) \text{ and: } AAF_{rec\text{-}a} = \left(\frac{ED_{rec\text{-}a}\left(years\right)}{ED_{rec}\left(years\right)}\right)$$

- immersion

$$DCC_{rec\text{-}water\text{-}imm}\left(pCi/L\right) = \frac{DL\left(\frac{mrem}{year}\right)}{DCF_{imm}\left(\frac{mrem/year}{pCi/L}\right)\times\left(\frac{1\ year}{8760\ hours}\right)\times DFA_{rec\text{-}adj}\left(\frac{hours}{year}\right)}$$

where:

$$DFA_{rec\text{-}adj}\left(\frac{hours}{year}\right) = \left(\begin{array}{l}\left(EF_{rec\text{-}c}\left(\frac{days}{year}\right)\times EV_{rec\text{-}c}\left(\frac{event}{day}\right)\times ET_{event\text{-}rec\text{-}c}\left(\frac{hours}{event}\right)\times AAF_{rec\text{-}c}\right)+\\ \left(EF_{rec\text{-}a}\left(\frac{days}{year}\right)\times EV_{rec\text{-}a}\left(\frac{event}{day}\right)\times ET_{event\text{-}rec\text{-}a}\left(\frac{hours}{event}\right)\times AAF_{rec\text{-}a}\right)\end{array}\right)$$

where:

$$AAF_{rec\text{-}c} = \left(\frac{ED_{rec\text{-}c}(years)}{ED_{rec}(years)}\right) \text{ and: } AAF_{rec\text{-}a} = \left(\frac{ED_{rec\text{-}a}(years)}{ED_{rec}(years)}\right)$$

- total

$$DCC_{rec\text{-}water\text{-}tot}\left(pCi/L\right) = \frac{1}{\frac{1}{DCC_{rec\text{-}water\text{-}ing}}+\frac{1}{DCC_{rec\text{-}water\text{-}imm}}}$$

Definitions of the input variables are in Table 1.

## 4.7 Consumption of Fish

The fish DCC represents the concentration, in the fish, that can be consumed. This is unlike the farmer scenario where the DCC is calculated for soil levels protective of fish consumption. Further the ingestion rate is not age adjusted like the farmer scenario.

### Graphical Representation


### Equation

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

- consumption of fish.

$$DCC_{res\text{-}fsh\text{-}ing}\left(pCi/g\right) = \frac{DL\left(\frac{mrem}{year}\right)}{DCF_{o}\left(\frac{mrem}{pCi}\right)\times EF_{res}\left(\frac{350\ days}{year}\right)\times IRFI_{res\text{-}a}\left(\frac{54{,}000\ mg}{day}\right)\times\left(\frac{10^{-3}\ g}{1\ mg}\right)\times CF_{res\text{-}fish}} \quad (1)$$

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

Definitions of the input variables are in Table 1.

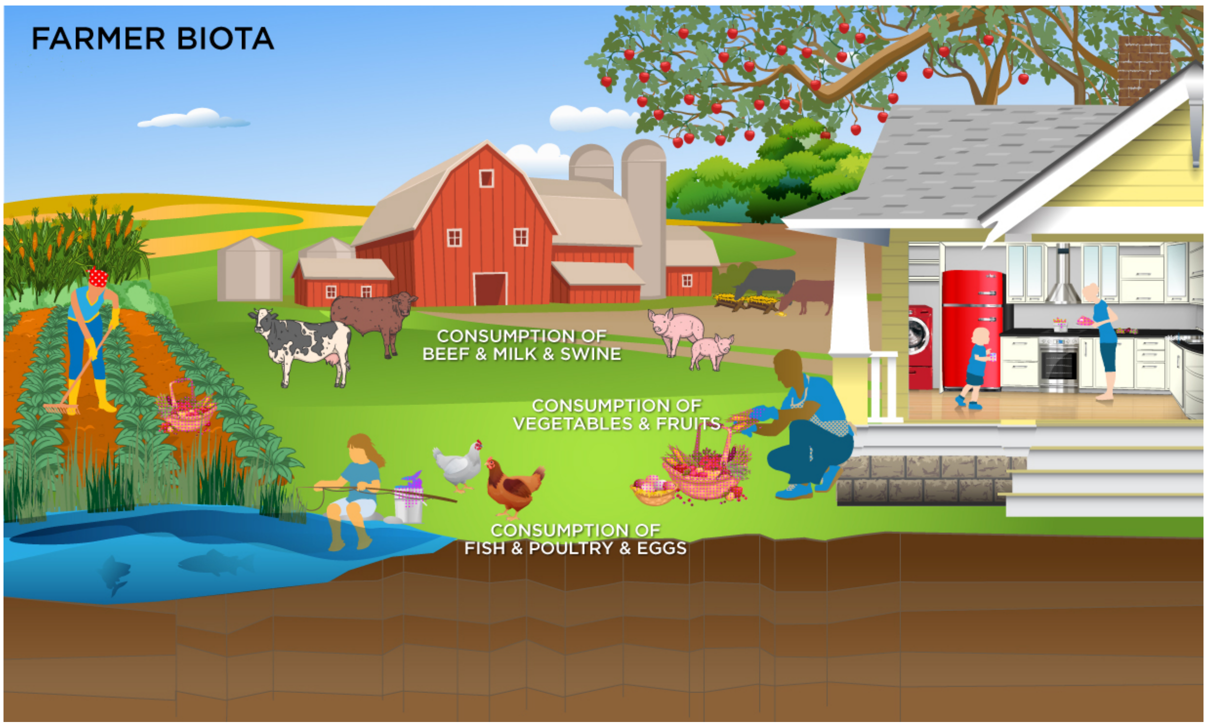
## 4.8 Farmer

### 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, milk, fish, 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, dose-based DCCs are provided for the farm product itself (vegetables, beef, milk, 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




**Equations**

- consumption of produce (fruits and vegetables). Sections 9 and 13 of the 2011 Exposure Factors Handbook were used to derive the intakes for home-grown produce.

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

where:

n = total number of produce items included

and:

$$DCC_{far\text{-}produce\text{-}ing}(pCi/g) = \frac{DL\left(\frac{mrem}{year}\right)}{DCF_o\left(\frac{mrem}{pCi}\right) \times IF_{far\text{-}adj}\left(\frac{g}{year}\right) \times CF_{far\text{-}produce}\,(1)}$$

where:

$$IF_{far\text{-}adj}\left(\frac{g}{year}\right) = \left(\begin{array}{l}\left(EF_{far\text{-}c}\left(\frac{350\ days}{year}\right) \times IR_{far\text{-}c}\left(\frac{g}{day}\right) \times AAF_{far\text{-}c}(0.15)\right) + \\ \left(EF_{far\text{-}a}\left(\frac{350\ days}{year}\right) \times IR_{far\text{-}a}\left(\frac{g}{day}\right) \times AAF_{far\text{-}a}(0.85)\right)\end{array}\right)$$

and:

$$AAF_{far\text{-}c}(0.15) = \left(\frac{ED_{far\text{-}c}(6\ years)}{ED_{far}(40\ years)}\right) \text{ and: } AAF_{far\text{-}a}(0.85) = \left(\frac{ED_{far\text{-}a}(34\ years)}{ED_{far}(40\ years)}\right)$$

- consumption of poultry. Table 13-52 of the 2011 Exposure Factors Handbook was used to derive the intakes for home-produced poultry.

$$DCC_{far\text{-}poultry\text{-}ing}(pCi/g) = \frac{DL\left(\frac{mrem}{year}\right)}{DCF_o\left(\frac{mrem}{pCi}\right) \times IFP_{far\text{-}adj}\left(\frac{34{,}414\ g}{year}\right) \times CF_{far\text{-}poultry}(1)}$$

where:

$$IFP_{far\text{-}adj}\left(\frac{34{,}414\ g}{year}\right) = \left(\begin{array}{l}\left(EF_{far\text{-}c}\left(\frac{350\ days}{year}\right) \times IRP_{far\text{-}c}\left(\frac{46.9\ g}{day}\right) \times AAF_{far\text{-}c}(0.15)\right) + \\ \left(EF_{far\text{-}a}\left(\frac{350\ days}{year}\right) \times IRP_{far\text{-}a}\left(\frac{107.4\ g}{day}\right) \times AAF_{far\text{-}a}(0.85)\right)\end{array}\right)$$

where:

$$AAF_{far\text{-}c}(0.15) = \left(\frac{ED_{far\text{-}c}(6\ years)}{ED_{far}(40\ years)}\right) \text{ and: } AAF_{far\text{-}a}(0.85) = \left(\frac{ED_{far\text{-}a}(34\ years)}{ED_{far}(40\ years)}\right)$$

- consumption of eggs. Table 13-40 of the 2011 Exposure Factors Handbook was used to derive the intakes for home-produced eggs.

$$DCC_{far\text{-}egg\text{-}ing}(pCi/g) = \frac{DL\left(\frac{mrem}{year}\right)}{DCF_o\left(\frac{mrem}{pCi}\right) \times IFE_{far\text{-}adj}\left(\frac{19{,}395\ g}{year}\right) \times CF_{far\text{-}egg}(1)}$$

where:

$$IFE_{far\text{-}adj}\left(\frac{19{,}395\ g}{year}\right) = \left(\begin{array}{l}\left(EF_{far\text{-}c}\left(\frac{350\ days}{year}\right) \times IRE_{far\text{-}c}\left(\frac{31.7\ g}{day}\right) \times AAF_{far\text{-}c}(0.15)\right) + \\ \left(EF_{far\text{-}a}\left(\frac{350\ days}{year}\right) \times IRE_{far\text{-}a}\left(\frac{59.6\ g}{day}\right) \times AAF_{far\text{-}a}(0.85)\right)\end{array}\right)$$

where:

$$AAF_{far\text{-}c}(0.15) = \left(\frac{ED_{far\text{-}c}(6\ years)}{ED_{far}(40\ years)}\right) \text{ and: } AAF_{far\text{-}a}(0.85) = \left(\frac{ED_{far\text{-}a}(34\ years)}{ED_{far}(40\ years)}\right)$$

- consumption of beef. Table 13-33 of the 2011 Exposure Factors Handbook was used to derive the intakes for home-produced beef.

$$DCC_{far\text{-}beef\text{-}ing}(pCi/g) = \frac{DL\left(\frac{mrem}{year}\right)}{DCF_o\left(\frac{mrem}{pCi}\right) \times IFB_{far\text{-}adj}\left(\frac{52{,}474\ g}{year}\right) \times CF_{far\text{-}beef}(1)}$$

where:

$$IFB_{far\text{-}adj}\left(\frac{52{,}474\ g}{year}\right) = \left(\begin{array}{l}\left(EF_{far\text{-}c}\left(\frac{350\ days}{year}\right) \times IRB_{far\text{-}c}\left(\frac{62.8\ g}{day}\right) \times AAF_{far\text{-}c}(0.15)\right) + \\ \left(EF_{far\text{-}a}\left(\frac{350\ days}{year}\right) \times IRB_{far\text{-}a}\left(\frac{165.3\ g}{day}\right) \times AAF_{far\text{-}a}(0.85)\right)\end{array}\right)$$

where:

$$AAF_{far\text{-}c}(0.15) = \left(\frac{ED_{far\text{-}c}(6\ years)}{ED_{far}(40\ years)}\right) \text{ and: } AAF_{far\text{-}a}(0.85) = \left(\frac{ED_{far\text{-}a}(34\ years)}{ED_{far}(40\ years)}\right)$$

- consumption of milk. Table 11-4 of the 2011 Exposure Factors Handbook was used to derive the intakes for total dairy.

$$DCC_{far\text{-}dairy\text{-}ing}(pCi/g) = \frac{DL\left(\frac{mrem}{year}\right)}{DCF_o\left(\frac{risk}{pCi}\right) \times IFD_{far\text{-}adj}\left(\frac{253{,}451\ g}{year}\right) \times CF_{far\text{-}dairy}(1)}$$

where:

$$IFD_{far\text{-}adj}\left(\frac{253{,}451\ g}{year}\right) = \left(\begin{array}{l}\left(EF_{far\text{-}c}\left(\frac{350\ days}{year}\right) \times IRD_{far\text{-}c}\left(\frac{994.7\ g}{day}\right) \times AAF_{far\text{-}c}(0.15)\right) + \\ \left(EF_{far\text{-}a}\left(\frac{350\ days}{year}\right) \times IRD_{far\text{-}a}\left(\frac{676.4\ g}{day}\right) \times AAF_{far\text{-}a}(0.85)\right)\end{array}\right)$$

where:

$$AAF_{far\text{-}c}(0.15) = \left(\frac{ED_{far\text{-}c}(6\ years)}{ED_{far}(40\ years)}\right) \text{ and: } AAF_{far\text{-}a}(0.85) = \left(\frac{ED_{far\text{-}a}(34\ years)}{ED_{far}(40\ years)}\right)$$

- consumption of swine. Table 13-51 of the 2011 Exposure Factors Handbook was used to derive the intakes for home-produced swine.

$$DCC_{far\text{-}swine\text{-}ing}\,(pCi/g) = \frac{DL\left(\frac{mrem}{year}\right)}{DCF_o\left(\frac{mrem}{pCi}\right) \times IFSW_{far\text{-}adj}\left(\frac{29{,}288\ g}{year}\right) \times CF_{far\text{-}swine}\,(1)}$$

where:

$$IFSW_{far\text{-}adj}\left(\frac{29{,}288\ g}{year}\right) = \left(\begin{array}{l}\left(EF_{far\text{-}c}\left(\frac{350\ days}{year}\right) \times IRSW_{far\text{-}c}\left(\frac{33.7\ g}{day}\right) \times AAF_{far\text{-}c}(0.15)\right) + \\ \left(EF_{far\text{-}a}\left(\frac{350\ days}{year}\right) \times IRSW_{far\text{-}a}\left(\frac{92.5\ g}{day}\right) \times AAF_{far\text{-}a}(0.85)\right)\end{array}\right)$$

where:

$$AAF_{far\text{-}c}(0.15) = \left(\frac{ED_{far\text{-}c}(6\ years)}{ED_{far}(40\ years)}\right) \text{ and: } AAF_{far\text{-}a}(0.85) = \left(\frac{ED_{far\text{-}a}(34\ years)}{ED_{far}(40\ years)}\right)$$

- consumption of fish. Table 13-20 of the 2011 Exposure Factors Handbook was used to derive the intakes for home-caught fish.

$$DCC_{far\text{-}fish\text{-}ing}\,(pCi/g) = \frac{DL\left(\frac{mrem}{year}\right)}{DCF_o\left(\frac{mrem}{pCi}\right) \times IFFI_{far\text{-}adj}\left(\frac{250{,}474\ g}{year}\right) \times CF_{far\text{-}fish}\,(1)}$$

where:

$$IFFI_{far\text{-}adj}\left(\frac{250{,}474\ g}{year}\right) = \left(\begin{array}{l}\left(EF_{far\text{-}c}\left(\frac{350\ days}{year}\right) \times IRFI_{far\text{-}c}\left(\frac{57.4\ g}{day}\right) \times AAF_{far\text{-}c}(0.15)\right) + \\ \left(EF_{far\text{-}a}\left(\frac{350\ days}{year}\right) \times IRFI_{far\text{-}a}\left(\frac{831.8\ g}{day}\right) \times AAF_{far\text{-}a}(0.85)\right)\end{array}\right)$$

where:

$$AAF_{far\text{-}c}(0.15) = \left(\frac{ED_{far\text{-}c}(6\ years)}{ED_{far}(40\ years)}\right) \text{ and: } AAF_{far\text{-}a}(0.85) = \left(\frac{ED_{far\text{-}a}(34\ years)}{ED_{far}(40\ years)}\right)$$

- consumption of goat. There are no widely accepted human intakes for home-produced goat.

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

where:

$$IFGO_{far\text{-}adj}\left(\frac{g}{year}\right) = \left(\begin{array}{l}\left(EF_{far\text{-}c}\left(\frac{350\ days}{year}\right) \times IRGO_{far\text{-}c}\left(\frac{g}{day}\right) \times AAF_{far\text{-}c}(0.15)\right) + \\ \left(EF_{far\text{-}a}\left(\frac{350\ days}{year}\right) \times IRGO_{far\text{-}a}\left(\frac{g}{day}\right) \times AAF_{far\text{-}a}(0.85)\right)\end{array}\right)$$

where:

$$AAF_{far\text{-}c}(0.15) = \left(\frac{ED_{far\text{-}c}(6\ years)}{ED_{far}(40\ years)}\right) \text{ and: } AAF_{far\text{-}a}(0.85) = \left(\frac{ED_{far\text{-}a}(34\ years)}{ED_{far}(40\ years)}\right)$$

- consumption of goat milk. There are no widely accepted human intakes for home-produced goat dairy.

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

where:

$$IFGM_{far\text{-}adj}\left(\frac{g}{year}\right) = \left(\begin{array}{l}\left(EF_{far\text{-}c}\left(\frac{350\ days}{year}\right) \times IRGM_{far\text{-}c}\left(\frac{g}{day}\right) \times AAF_{far\text{-}c}(0.15)\right) + \\ \left(EF_{far\text{-}a}\left(\frac{350\ days}{year}\right) \times IRGM_{far\text{-}a}\left(\frac{g}{day}\right) \times AAF_{far\text{-}a}(0.85)\right)\end{array}\right)$$

where:

$$AAF_{far\text{-}c}(0.15) = \left(\frac{ED_{far\text{-}c}(6\ years)}{ED_{far}(40\ years)}\right) \text{ and: } AAF_{far\text{-}a}(0.85) = \left(\frac{ED_{far\text{-}a}(34\ years)}{ED_{far}(40\ years)}\right)$$

- consumption of sheep. There are no widely accepted human intakes for home-produced sheep.

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

where:

$$IFSH_{far\text{-}adj}\left(\frac{g}{year}\right) = \left(\begin{array}{l}\left(EF_{far\text{-}c}\left(\frac{350\ days}{year}\right) \times IRSH_{far\text{-}c}\left(\frac{g}{day}\right) \times AAF_{far\text{-}c}(0.15)\right) + \\ \left(EF_{far\text{-}a}\left(\frac{350\ days}{year}\right) \times IRSH_{far\text{-}a}\left(\frac{g}{day}\right) \times AAF_{far\text{-}a}(0.85)\right)\end{array}\right)$$

where:

$$AAF_{far\text{-}c}(0.15) = \left(\frac{ED_{far\text{-}c}(6\ years)}{ED_{far}(40\ years)}\right) \text{ and: } AAF_{far\text{-}a}(0.85) = \left(\frac{ED_{far\text{-}a}(34\ years)}{ED_{far}(40\ years)}\right)$$

- consumption of sheep milk. There are no widely accepted human intakes for home-produced sheep dairy.

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

where:

$$IFSM_{far\text{-}adj}\left(\frac{g}{year}\right) = \left(\begin{array}{l}\left(EF_{far\text{-}c}\left(\frac{350\ days}{year}\right) \times IRSM_{far\text{-}c}\left(\frac{g}{day}\right) \times AAF_{far\text{-}c}(0.15)\right) + \\ \left(EF_{far\text{-}a}\left(\frac{350\ days}{year}\right) \times IRSM_{far\text{-}a}\left(\frac{g}{day}\right) \times AAF_{far\text{-}a}(0.85)\right)\end{array}\right)$$

where:

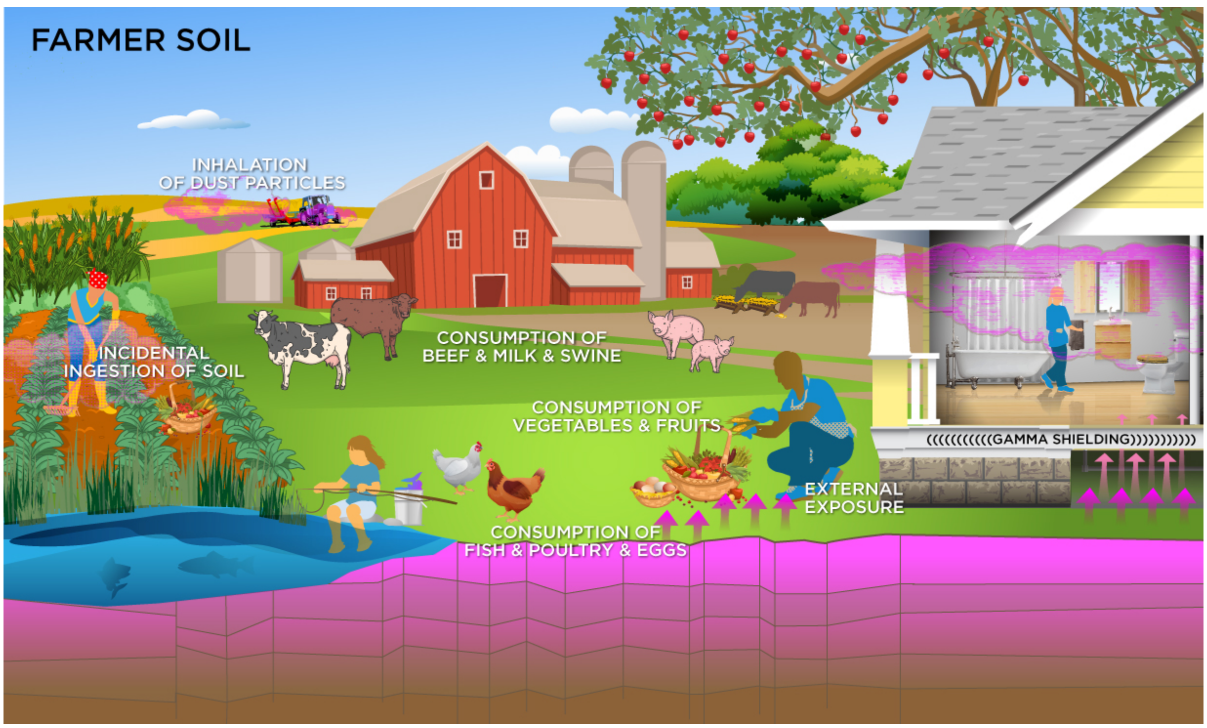
$$AAF_{far\text{-}c}(0.15) = \left(\frac{ED_{far\text{-}c}(6\ years)}{ED_{far}(40\ years)}\right) \text{ and: } AAF_{far\text{-}a}(0.85) = \left(\frac{ED_{far\text{-}a}(34\ years)}{ED_{far}(40\ years)}\right)$$

Definitions of the input variables are in Table 1.

## 4.8.2 Farmer Direct Exposure and Consumption of Agricultural Products - Back-Calculated to Soil

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 scenario assumes the receptor will be exposed via the following pathways: incidental ingestion of soil, external radiation from contaminants in soil, 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, milk, fish, 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, dose-based DCCs 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




### Equations

- incidental ingestion of soil,

$$DCC_{far\text{-}soil\text{-}ing}(pCi/g) = \frac{DL\left(\frac{mrem}{year}\right) \times t_{far}(year) \times \lambda\left(\frac{1}{year}\right)}{\left(1-e^{-\lambda t_{far}}\right) \times DCF_o\left(\frac{mrem}{pCi}\right) \times IFS_{far\text{-}adj}\left(\frac{40{,}250\ mg}{year}\right) \times \left(\frac{g}{1000\ mg}\right)}$$

where:

$$IFS_{far\text{-}adj}\left(\frac{40{,}250\ mg}{year}\right) = \left(\begin{array}{l}\left(EF_{far\text{-}c}\left(\frac{350\ days}{year}\right) \times IRS_{far\text{-}c}\left(\frac{200\ mg}{day}\right) \times AAF_{far\text{-}c}(0.15)\right) + \\ \left(EF_{far\text{-}a}\left(\frac{350\ days}{year}\right) \times IRS_{far\text{-}a}\left(\frac{100\ mg}{day}\right) \times AAF_{far\text{-}a}(0.85)\right)\end{array}\right)$$

where:

$$AAF_{far\text{-}c}(0.15) = \left(\frac{ED_{far\text{-}c}(6\ years)}{ED_{far}(40\ years)}\right) \text{ and: } AAF_{far\text{-}a}(0.85) = \left(\frac{ED_{far\text{-}a}(34\ years)}{ED_{far}(40\ years)}\right)$$

- inhalation of particulates emitted from soil,

$$DCC_{far\text{-}soil\text{-}inh}(pCi/g) = \frac{DL\left(\frac{mrem}{year}\right) \times t_{far}(year) \times \lambda\left(\frac{1}{year}\right)}{\left(1-e^{-\lambda t_{far}}\right) \times DCF_i\left(\frac{mrem}{pCi}\right) \times IFA_{far\text{-}adj}\left(\frac{6{,}475\ m^3}{year}\right) \times \frac{1}{PEF\left(\frac{m^3}{kg}\right)} \times \left(\frac{1000\ g}{kg}\right)}$$

where:

$$IFA_{far\text{-}adj}\left(\frac{6{,}475\ m^3}{year}\right) = \left(\begin{array}{l}\left(EF_{far\text{-}c}\left(\frac{350\ days}{year}\right) \times ET_{far\text{-}c}\left(\frac{24\ hours}{day}\right) \times \left(\frac{1\ day}{24\ hours}\right) \times IRA_{far\text{-}c}\left(\frac{10\ m^3}{day}\right) \times AAF_{far\text{-}c}(0.15)\right) + \\ \left(EF_{far\text{-}a}\left(\frac{350\ days}{year}\right) \times ET_{far\text{-}a}\left(\frac{24\ hours}{day}\right) \times \left(\frac{1\ day}{24\ hours}\right) \times IRA_{far\text{-}a}\left(\frac{20\ m^3}{day}\right) \times AAF_{far\text{-}a}(0.85)\right)\end{array}\right)$$

where:

$$AAF_{far\text{-}c}(0.15) = \left(\frac{ED_{far\text{-}c}(6\ years)}{ED_{far}(40\ years)}\right) \text{ and: } AAF_{far\text{-}a}(0.85) = \left(\frac{ED_{far\text{-}a}(34\ years)}{ED_{far}(40\ years)}\right)$$

- external exposure to ionizing radiation, and

$$DCC_{far\text{-}soil\text{-}ext}(pCi/g) = \frac{DL\left(\frac{mrem}{year}\right) \times t_{far}(year) \times \lambda\left(\frac{1}{year}\right)}{\begin{array}{c}\left(1-e^{-\lambda t_{far}}\right) \times DCF_{ext\text{-}sv}\left(\frac{mrem/year}{pCi/g}\right) \times EF_{far}\left(\frac{350\ days}{year}\right) \times \left(\frac{1\ year}{365\ days}\right) \times ACF_{ext\text{-}sv} \times \\ \left[\left(ET_{far\text{-}o}\left(\frac{12.168\ hours}{day}\right) \times \left(\frac{1\ day}{24\ hours}\right) \times GSF_{ext\text{-}sv}(1.0)\right) + \left(ET_{far\text{-}i}\left(\frac{10.008\ hours}{day}\right) \times \left(\frac{1\ day}{24\ hours}\right) \times GSF_{i\text{-}total}\right)\right]\end{array}}$$

- consumption of produce (fruits and vegetables). Sections 9 and 13 of the 2011 Exposure Factors Handbook were used to derive the intakes for home-grown produce.

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

where:

n = total number of produce items included

and:

$$DCC_{soil\text{-}far\text{-}produce\text{-}ing}(pCi/g) = \frac{DCC_{far\text{-}produce\text{-}ing}(pCi/g)}{\left(R_{upv} + R_{es}\right)} \times \left(\frac{t_{far}(year) \times \lambda\left(\frac{1}{year}\right)}{\left(1-e^{-\lambda t_{far}}\right)}\right)$$

where:

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

The consumption of produce exposure route drives the DCCs 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 DCC 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.

where:

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

where:

n = total number of produce items included

and:

$$DCC_{far\text{-}produce\text{-}ing}(pCi/g) = \frac{DL\left(\frac{mrem}{year}\right)}{DCF_o\left(\frac{mrem}{pCi}\right) \times IF_{far\text{-}adj}\left(\frac{g}{year}\right) \times CF_{far\text{-}produce}(1)}$$

where:

$$IF_{far\text{-}adj}\left(\frac{g}{year}\right) = \left(\begin{array}{l}\left(EF_{far\text{-}c}\left(\frac{350\ days}{year}\right) \times IR_{far\text{-}c}\left(\frac{g}{day}\right) \times AAF_{far\text{-}c}(0.15)\right) + \\ \left(EF_{far\text{-}a}\left(\frac{350\ days}{year}\right) \times IR_{far\text{-}a}\left(\frac{g}{day}\right) \times AAF_{far\text{-}a}(0.85)\right)\end{array}\right)$$

and:

$$AAF_{far\text{-}c}(0.15) = \left(\frac{ED_{far\text{-}c}(6\ years)}{ED_{far}(40\ years)}\right) \text{ and: } AAF_{far\text{-}a}(0.85) = \left(\frac{ED_{far\text{-}a}(34\ years)}{ED_{far}(40\ years)}\right)$$

- consumption of eggs. Table 13-40 of the 2011 Exposure Factors Handbook was used to derive the intakes for home-produced eggs.

$$DCC_{soil\text{-}far\text{-}egg\text{-}ing}(pCi/g) = \frac{DCC_{far\text{-}egg\text{-}ing}(pCi/g)}{TF_{egg}\left(\frac{day}{kg}\right) \times \left[\left(Q_{p\text{-}poultry}\left(\frac{0.2\ kg}{day}\right) \times f_{p\text{-}poultry}(1) \times f_{s\text{-}poultry}(1) \times \left(R_{upp} + R_{es}\right)\right) + \left(Q_{s\text{-}poultry}\left(\frac{0.022\ kg}{day}\right) \times f_{p\text{-}poultry}(1)\right)\right]} \times \left(\frac{t_{far}(year) \times \lambda\left(\frac{1}{year}\right)}{\left(1 - e^{-\lambda t_{far}}\right)}\right)$$

where:

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

- consumption of poultry. Table 13-52 of the 2011 Exposure Factors Handbook was used to derive the intakes for home-produced poultry.

$$DCC_{soil\text{-}far\text{-}poultry\text{-}ing}(pCi/g) = \frac{DCC_{far\text{-}poultry\text{-}ing}(pCi/g)}{TF_{poultry}\left(\frac{day}{kg}\right) \times \left[\left(Q_{p\text{-}poultry}\left(\frac{0.2\ kg}{day}\right) \times f_{p\text{-}poultry}(1) \times f_{s\text{-}poultry}(1) \times \left(R_{upp} + R_{es}\right)\right) + \left(Q_{s\text{-}poultry}\left(\frac{0.022\ kg}{day}\right) \times f_{p\text{-}poultry}(1)\right)\right]} \times \left(\frac{t_{far}(year) \times \lambda\left(\frac{1}{year}\right)}{\left(1 - e^{-\lambda t_{far}}\right)}\right)$$

where:

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

- consumption of fish. Table 13-20 of the 2011 Exposure Factors Handbook was used to derive the intakes for home-caught fish.

$$DCC_{soil\text{-}far\text{-}fish\text{-}ing}(pCi/g) = \frac{DCC_{far\text{-}fish\text{-}ing}(pCi/g) \times Kd\left(\frac{L}{kg}\right)}{BCF\left(\frac{L}{kg}\right)} \times \left(\frac{t_{far}(year) \times \lambda\left(\frac{1}{year}\right)}{\left(1 - e^{-\lambda t_{far}}\right)}\right)$$

- consumption of beef. Table 13-33 of the 2011 Exposure Factors Handbook was used to derive the intakes for home-produced beef.

$$DCC_{soil\text{-}far\text{-}beef\text{-}ing}(pCi/g) = \frac{DCC_{far\text{-}beef\text{-}ing}(pCi/g)}{TF_{beef}\left(\frac{day}{kg}\right) \times \left[\left(Q_{p\text{-}beef}\left(\frac{11.77\ kg}{day}\right) \times f_{p\text{-}beef}(1) \times f_{s\text{-}beef}(1) \times \left(R_{upp} + R_{es}\right)\right) + \left(Q_{s\text{-}beef}\left(\frac{0.5\ kg}{day}\right) \times f_{p\text{-}beef}(1)\right)\right]} \times \left(\frac{t_{far}(year) \times \lambda\left(\frac{1}{year}\right)}{\left(1 - e^{-\lambda t_{far}}\right)}\right)$$

where:

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

- consumption of milk. Table 11-4 of the 2011 Exposure Factors Handbook was used to derive the intakes for total dairy.

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

where:

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

- consumption of swine. Table 13-51 of the 2011 Exposure Factors Handbook was used to derive the intakes for home-produced swine.

$$DCC_{soil\text{-}far\text{-}swine\text{-}ing}\left(pCi/g\right) = \frac{DCC_{far\text{-}swine\text{-}ing}\left(pCi/g\right)}{TF_{swine}\left(\frac{day}{kg}\right)\times\left[\left(Q_{p\text{-}swine}\left(\frac{4.7\ kg}{day}\right)\times f_{p\text{-}swine}(1)\times f_{s\text{-}swine}(1)\times\left(R_{upp}+R_{es}\right)\right)+\left(Q_{s\text{-}swine}\left(\frac{0.37\ kg}{day}\right)\times f_{p\text{-}swine}(1)\right)\right]}\times\left(\frac{t_{far}\left(year\right)\times\lambda\left(\frac{1}{year}\right)}{\left(1-e^{-\lambda t_{far}}\right)}\right)$$

where:

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

- total.

$$DCC_{soil\text{-}far\text{-}tot}\left(pCi/g\right) = \frac{1}{\frac{1}{DCC_{soil\text{-}far\text{-}sol\text{-}ing}}+\frac{1}{DCC_{soil\text{-}far\text{-}sol\text{-}inh}}+\frac{1}{DCC_{soil\text{-}far\text{-}sol\text{-}ext}}+\frac{1}{DCC_{soil\text{-}far\text{-}produce\text{-}ing\text{-}tot}}+\frac{1}{DCC_{soil\text{-}far\text{-}egg\text{-}ing}}+\frac{1}{DCC_{soil\text{-}far\text{-}poultry\text{-}ing}}+\frac{1}{DCC_{soil\text{-}far\text{-}fish\text{-}ing}}+\frac{1}{DCC_{soil\text{-}far\text{-}beef\text{-}ing}}+\frac{1}{DCC_{soil\text{-}far\text{-}dairy\text{-}ing}}+\frac{1}{DCC_{soil\text{-}far\text{-}swine\text{-}ing}}}$$

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

- consumption of goat. Please see table 1, in section 5 below, for sources of derived intakes for home-produced goat.

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

where:

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

- consumption of goat milk. Please see table 1, in section 5 below, for sources of derived intakes for home-produced goat dairy.

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

where:

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

- consumption of sheep. Please see table 1, in section 5 below, for sources of derived intakes for home-produced sheep.

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

where:

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

- consumption of sheep milk. Please see table 1, in section 5 below, for sources of derived intakes for home-produced sheep dairy.

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

where:

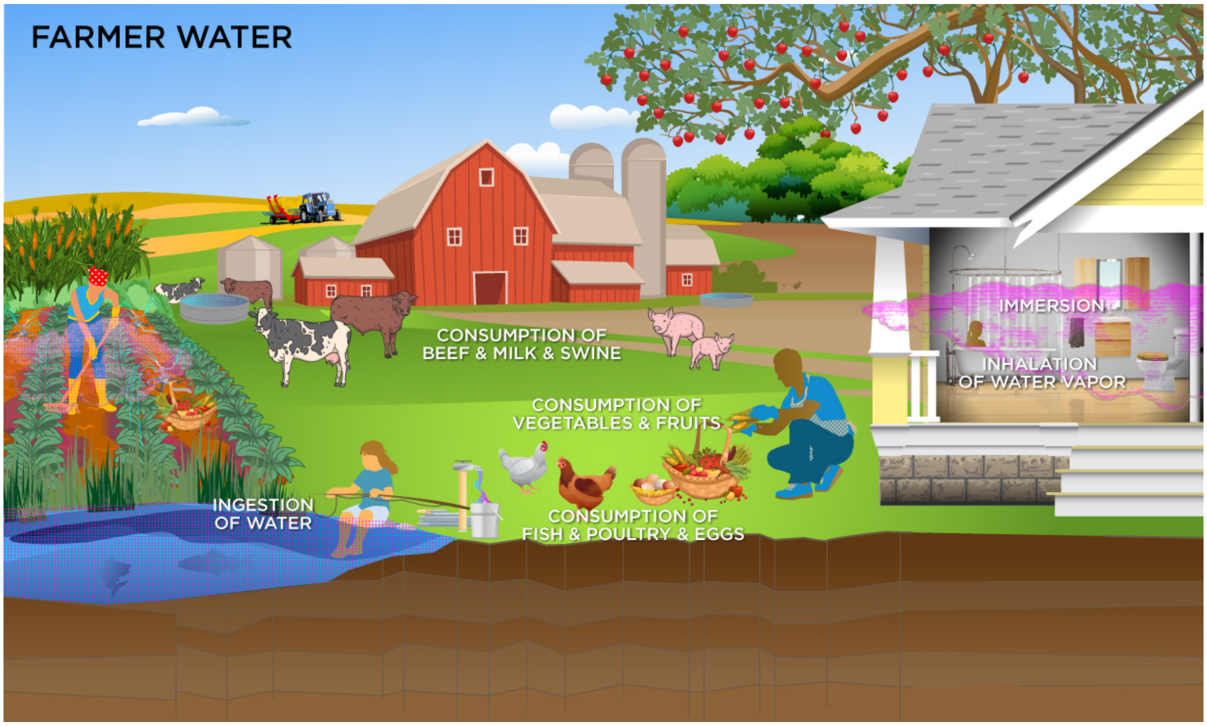
$$R_{upp} = Bv_{dry}\left(\frac{pCi\,/\,g\text{-}dry\ plant}{pCi\,/\,g\text{-}dry\ soil}\right);\ R_{es} = MLF_{pasture}\left(\frac{0.25\ g\text{-}dry\ soil}{g\text{-}dry\ plant}\right)$$

Definitions of the input variables are in Table 1.

## 4.8.3 Farmer Direct Exposure and Consumption of Agricultural Products - Back-Calculated to Water

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 scenario assumes the receptor will be exposed via the following pathways: ingestion of tapwater, external radiation from contaminants in tapwater, 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, Ra-224, and Ra-226 which volatilize. In addition to produce, 100% of consumption of the following are also considered to be from the farm: beef, milk, fish, 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, dose-based DCCs are provided for the water 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




**Equations**

- ingestion of tapwater,

$$DCC_{water\text{-}far\text{-}ing}\,(pCi/L) = \frac{DL\left(\frac{mrem}{year}\right)}{DCF_o\left(\frac{mrem}{pCi}\right)\times\left(IFW_{far\text{-}adj}\left(\frac{785\ L}{year}\right)\right)}$$

where:

$$IFW_{far\text{-}adj}\left(\frac{785\ L}{year}\right) = \left(\begin{array}{l}\left(EF_{far\text{-}c}\left(\frac{350\ days}{year}\right)\times IRW_{far\text{-}c}\left(\frac{0.78\ L}{day}\right)\times AAF_{far\text{-}c}\,(0.15)\right)+\\ \left(EF_{far\text{-}a}\left(\frac{350\ days}{year}\right)\times IRW_{far\text{-}a}\left(\frac{2.5\ L}{day}\right)\times AAF_{far\text{-}a}\,(0.85)\right)\end{array}\right)$$

where:

$$AAF_{far\text{-}c}(0.15) = \left(\frac{ED_{far\text{-}c}(6\ years)}{ED_{far}(40\ years)}\right)\ \text{and: }AAF_{far\text{-}a}(0.85) = \left(\frac{ED_{far\text{-}a}(34\ years)}{ED_{far}(40\ years)}\right)$$

- immersion in tapwater,

$$DCC_{water\text{-}far\text{-}imm}\,(pCi/L) = \frac{DL\left(\frac{mrem}{year}\right)}{DCF_{imm}\left(\frac{mrem/year}{pCi/L}\right)\times DFA_{far\text{-}adj}\left(\frac{240\ hours}{year}\right)\times\left(\frac{1\ year}{8760\ hours}\right)}$$

where:

$$DFA_{far\text{-}adj}\left(\frac{240\ hours}{year}\right) = \left(\begin{array}{l}\left(EF_{far\text{-}c}\left(\frac{350\ days}{year}\right)\times EV_{far\text{-}c}\left(\frac{1\ event}{day}\right)\times ET_{event\text{-}far\text{-}c}\left(\frac{0.54\ hours}{event}\right)\times AAF_{far\text{-}c}\,(0.15)\right)+\\ \left(EF_{far\text{-}a}\left(\frac{350\ days}{year}\right)\times EV_{far\text{-}a}\left(\frac{1\ event}{day}\right)\times ET_{event\text{-}far\text{-}a}\left(\frac{0.71\ hours}{event}\right)\times AAF_{far\text{-}a}\,(0.85)\right)\end{array}\right)$$

where:

$$AAF_{far\text{-}c}(0.15) = \left(\frac{ED_{far\text{-}c}(6\ years)}{ED_{far}(40\ years)}\right)\ \text{and: }AAF_{far\text{-}a}(0.85) = \left(\frac{ED_{far\text{-}a}(34\ years)}{ED_{far}(40\ years)}\right)$$

- inhalation,

$$DCC_{water\text{-}far\text{-}inh}\,(pCi/L) = \frac{DL\left(\frac{mrem}{year}\right)}{DCF_i\left(\frac{mrem}{pCi}\right)\times IFA_{far\text{-}adj}\left(\frac{6{,}475\ m^3}{year}\right)\times K\left(\frac{0.5\ L}{m^3}\right)}$$

where:

$$IFA_{far\text{-}adj}\left(\frac{6{,}475\ m^3}{year}\right) = \left(\begin{array}{l}\left(EF_{far\text{-}c}\left(\frac{350\ days}{year}\right)\times ET_{far\text{-}c}\left(\frac{24\ hours}{day}\right)\times\left(\frac{1\ day}{24\ hours}\right)\times IRA_{far\text{-}c}\left(\frac{10\ m^3}{day}\right)\times AAF_{far\text{-}c}\,(0.15)\right)+\\ \left(EF_{far\text{-}a}\left(\frac{350\ days}{year}\right)\times ET_{far\text{-}a}\left(\frac{24\ hours}{day}\right)\times\left(\frac{1\ day}{24\ hours}\right)\times IRA_{far\text{-}a}\left(\frac{20\ m^3}{day}\right)\times AAF_{far\text{-}c}\,(0.85)\right)\end{array}\right)$$

where:

$$AAF_{far\text{-}c}(0.15) = \left(\frac{ED_{far\text{-}c}(6\ years)}{ED_{far}(40\ years)}\right)\ \text{and: } AAF_{far\text{-}a}(0.85) = \left(\frac{ED_{far\text{-}a}(34\ years)}{ED_{far}(40\ years)}\right)$$

- consumption of produce (fruits and vegetables). Sections 9 and 13 of the 2011 Exposure Factors Handbook were used to derive the intakes for home-grown produce.

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

where:
n = total number of produce items included

and:

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

where:

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

and:

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

where:

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

where:
n = total number of produce items included

and:

$$DCC_{far\text{-}produce\text{-}ing}(pCi/g) = \frac{DL\left(\frac{mrem}{year}\right)}{DCF_o\left(\frac{mrem}{pCi}\right)\times IF_{far\text{-}adj}\left(\frac{g}{year}\right)\times CF_{far\text{-}produce}\,(1)}$$

where:

$$IF_{far\text{-}adj}\left(\frac{g}{year}\right) = \left(\begin{array}{l}\left(EF_{far\text{-}c}\left(\frac{350\ days}{year}\right)\times IR_{far\text{-}c}\left(\frac{g}{day}\right)\times AAF_{far\text{-}c}(0.15)\right)+\\ \left(EF_{far\text{-}a}\left(\frac{350\ days}{year}\right)\times IR_{far\text{-}a}\left(\frac{g}{day}\right)\times AAF_{far\text{-}a}(0.85)\right)\end{array}\right)$$

and:

$$AAF_{far\text{-}c}(0.15) = \left(\frac{ED_{far\text{-}c}(6\ years)}{ED_{far}(40\ years)}\right)\ \text{and: } AAF_{far\text{-}a}(0.85) = \left(\frac{ED_{far\text{-}a}(34\ years)}{ED_{far}(40\ years)}\right)$$

- total

$$DCC_{water\text{-}far\text{-}tot}\,(pCi/g) = \frac{1}{\frac{1}{DCC_{water\text{-}far\text{-}ing}}+\frac{1}{DCC_{water\text{-}far\text{-}inh}}+\frac{1}{DCC_{water\text{-}far\text{-}imm}}+\frac{1}{DCC_{water\text{-}far\text{-}produce\text{-}tot}}}$$

- consumption of eggs. Table 13-40 of the 2011 Exposure Factors Handbook was used to derive the intakes for home-produced eggs.

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

- consumption of poultry. Table 13-52 of the 2011 Exposure Factors Handbook was used to derive the intakes for home-produced poultry.

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

- consumption of fish. Table 13-20 of the 2011 Exposure Factors Handbook was used to derive the intakes for home-caught fish.

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

- consumption of beef. Table 13-33 of the 2011 Exposure Factors Handbook was used to derive the intakes for home-produced beef.

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

- consumption of milk. Table 11-4 of the 2011 Exposure Factors Handbook was used to derive the intakes for total dairy.

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

- consumption of swine. Table 13-51 of the 2011 Exposure Factors Handbook was used to derive the intakes for home-produced swine.

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

- total.

$$DCC_{wat\text{-}far\text{-}tot}\left(pCi/L\right) = \frac{1}{\frac{1}{DCC_{water\text{-}far\text{-}ing}} + \frac{1}{DCC_{water\text{-}far\text{-}inh}} + \frac{1}{DCC_{water\text{-}far\text{-}imm}} + \frac{1}{DCC_{water\text{-}far\text{-}produce\text{-}ing\text{-}tot}} + \frac{1}{DCC_{water\text{-}far\text{-}egg\text{-}ing}} + \frac{1}{DCCwat_{water\text{-}far\text{-}poultry\text{-}ing}} + \frac{1}{DCC_{water\text{-}far\text{-}fish\text{-}ing}} + \frac{1}{DCC_{water\text{-}far\text{-}beef\text{-}ing}} + \frac{1}{DCC_{water\text{-}far\text{-}dairy\text{-}ing}} + \frac{1}{DCC_{water\text{-}far\text{-}swine\text{-}ing}}}$$

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

- consumption of goat. Please see table 1, in section 5 below, for sources of derived intakes for home-produced goat.

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

- consumption of goat milk. Please see table 1, in section 5 below, for sources of derived intakes for home-produced goat dairy.

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

- consumption of sheep. Please see table 1, in section 5 below, for sources of derived intakes for home-produced goat.

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

- consumption of sheep milk. Please see table 1, in section 5 below, for sources of derived intakes for home-produced sheep dairy.

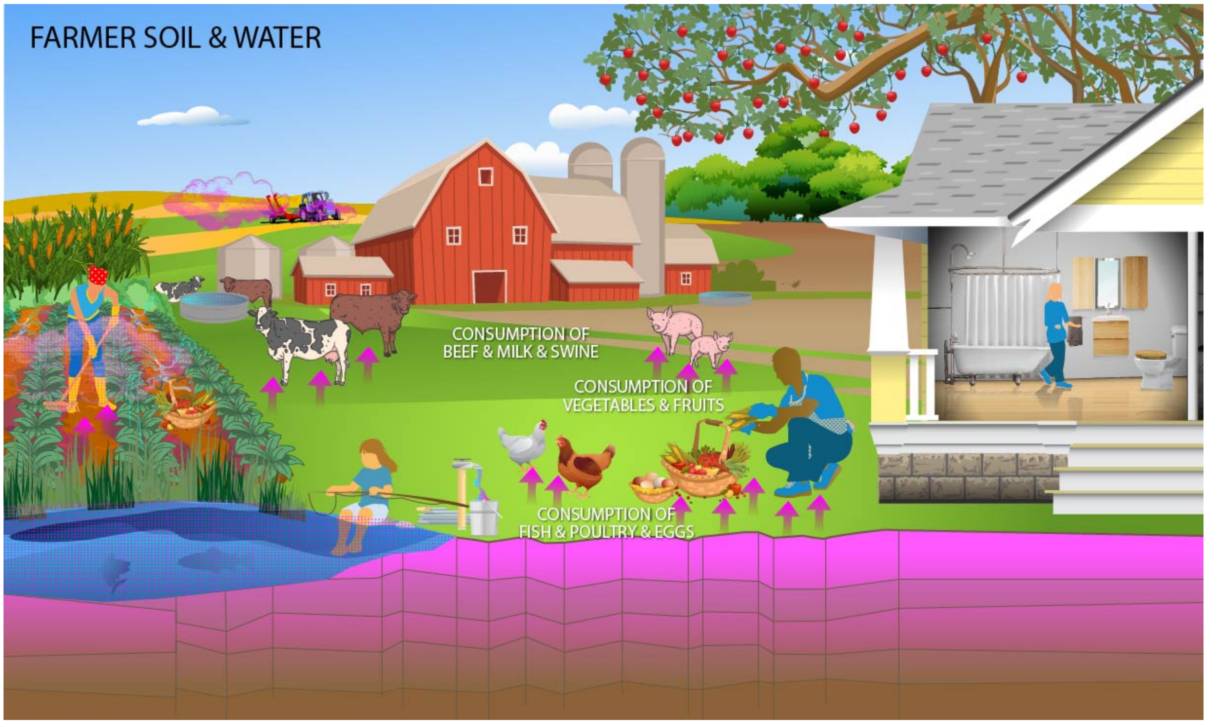
$$DCC_{water\text{-}far\text{-}sheep\text{-}milk\text{-}ing}\left(pCi/L\right) = \frac{DCC_{far\text{-}sheep\text{-}milk\text{-}ing}\left(pCi/g\right)}{TF_{sheep\text{-}milk}\left(\frac{day}{L\ milk}\right) \times \rho_m\left(\frac{1.03\ kg}{1\ L\ milk}\right)^{-1} \times Q_{w\text{-}sheep\text{-}milk}\left(\frac{10.4\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

Definitions of the input variables are in Table 1.

## 4.8.4 Farmer Consumption of Agricultural Products - Back-Calculated to Soil and Water

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 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, milk, fish, 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, dose-based DCCs are provided for both soil and water which may contribute contaminants to the products. The results are presented in an interactive graphic that shows the contribution from both sources. See section 4.8.4 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




## Equations

Results of back-calculating exposure to soil and water are presented in an interactive graph. See Section 4.8.4 for details.

- consumption of produce (fruits and vegetables).

y-INTERCEPT =

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

and:

x-INTERCEPT =

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

where:

n = total number of produce items included.

- consumption of eggs.

$DCC_{soil\text{-}far\text{-}egg\text{-}ing} =$

$$\text{y-INTERCEPT} = \frac{DCC_{far\text{-}egg\text{-}ing}(pCi/g)}{TF_{egg}\left(\frac{day}{kg}\right)\times\left[\left(Q_{p\text{-}poultry}\left(\frac{0.2\ kg}{day}\right)\times f_{p\text{-}poultry}(1)\times f_{s\text{-}poultry}(1)\times\left(R_{upp}+R_{es}\right)\right)+\left(Q_{s\text{-}poultry}\left(\frac{0.022\ kg}{day}\right)\times f_{p\text{-}poultry}(1)\right)\right]}\times\left(\frac{t_{far}(year)\times\lambda\left(\frac{1}{year}\right)}{\left(1-e^{-\lambda t_{far}}\right)}\right)$$

and:

$DCC_{water\text{-}far\text{-}egg\text{-}ing}(pCi/L) =$

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

where:

$$\text{SLOPE} = \frac{-Q_{w\text{-}poultry}\left(\frac{0.4\ L}{day}\right)}{\left(Q_{p\text{-}poultry}\left(\frac{0.2\ kg}{day}\right)\times f_{p\text{-}poultry}(1)\times f_{s\text{-}poultry}(1)\times\left(R_{upp}+R_{es}\right)\right)+\left(Q_{s\text{-}poultry}\left(\frac{0.022\ kg}{day}\right)\times f_{p\text{-}poultry}(1)\right)}$$

where:

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

- consumption of poultry.

$DCC_{soil\text{-}far\text{-}poultry\text{-}ing} =$

$$\text{y-INTERCEPT} = \frac{DCC_{far\text{-}poultry\text{-}ing}(pCi/g)}{TF_{poultry}\left(\frac{day}{kg}\right)\times\left[\left(Q_{p\text{-}poultry}\left(\frac{0.2\ kg}{day}\right)\times f_{p\text{-}poultry}(1)\times f_{s\text{-}poultry}(1)\times\left(R_{upp}+R_{es}\right)\right)+\left(Q_{s\text{-}poultry}\left(\frac{0.022\ kg}{day}\right)\times f_{p\text{-}poultry}(1)\right)\right]}\times\left(\frac{t_{far}(year)\times\lambda\left(\frac{1}{year}\right)}{\left(1-e^{-\lambda t_{far}}\right)}\right)$$

and:

$DCC_{water\text{-}far\text{-}poultry\text{-}ing}(pCi/L) =$

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

where:

$$\text{SLOPE} = \frac{-Q_{w\text{-}poultry}\left(\frac{0.4\ L}{day}\right)}{\left(Q_{p\text{-}poultry}\left(\frac{0.2\ kg}{day}\right)\times f_{p\text{-}poultry}(1)\times f_{s\text{-}poultry}(1)\times\left(R_{upp}+R_{es}\right)\right)+\left(Q_{s\text{-}poultry}\left(\frac{0.022\ kg}{day}\right)\times f_{p\text{-}poultry}(1)\right)}$$

where:

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

- consumption of beef.

$DCC_{soil\text{-}far\text{-}beef\text{-}ing} =$

$$\text{y-INTERCEPT} = \frac{DCC_{far\text{-}beef\text{-}ing}(pCi/g)}{TF_{beef}\left(\frac{day}{kg}\right)\times\left[\left(Q_{p\text{-}beef}\left(\frac{11.77\ kg}{day}\right)\times f_{p\text{-}beef}(1)\times f_{s\text{-}beef}(1)\times\left(R_{upp}+R_{es}\right)\right)+\left(Q_{s\text{-}beef}\left(\frac{0.5\ kg}{day}\right)\times f_{p\text{-}beef}(1)\right)\right]}\times\left(\frac{t_{far}(year)\times\lambda\left(\frac{1}{year}\right)}{\left(1-e^{-\lambda t_{far}}\right)}\right)$$

and:

$DCC_{water\text{-}far\text{-}beef\text{-}ing}(pCi/L) =$

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

where:

$$\text{SLOPE} = \frac{-Q_{w\text{-}beef}\left(\frac{53\ L}{day}\right)}{\left(Q_{p\text{-}beef}\left(\frac{11.77\ kg}{day}\right)\times f_{p\text{-}beef}(1)\times f_{s\text{-}beef}(1)\times\left(R_{upp}+R_{es}\right)\right)+\left(Q_{s\text{-}beef}\left(\frac{0.5\ kg}{day}\right)\times f_{p\text{-}beef}(1)\right)}$$

where:

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

- consumption of milk.

$DCC_{soil\text{-}far\text{-}dairy\text{-}ing} =$

$$\text{y-INTERCEPT} = \frac{DCC_{far\text{-}dairy\text{-}ing}(pCi/g)}{TF_{dairy}\left(\frac{day}{L\ milk}\right)\times\rho_m\left(\frac{1.03\ kg}{1\ L\ milk}\right)^{-1}\times\left[\left(Q_{p\text{-}dairy}\left(\frac{20.3\ kg}{day}\right)\times f_{p\text{-}dairy}(1)\times f_{s\text{-}dairy}(1)\times\left(R_{upp}+R_{es}\right)\right)+\left(Q_{s\text{-}dairy}\left(\frac{0.4\ kg}{day}\right)\times f_{p\text{-}dairy}(1)\right)\right]}\times\left(\frac{t_{far}(year)\times\lambda\left(\frac{1}{year}\right)}{\left(1-e^{-\lambda t_{far}}\right)}\right)$$

and:

$DCC_{water\text{-}far\text{-}dairy\text{-}ing}(pCi/L) =$

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

where:

$$\text{SLOPE} = \frac{-Q_{w\text{-}dairy}\left(\frac{92\ L}{day}\right)}{\left(Q_{p\text{-}dairy}\left(\frac{20.3\ kg}{day}\right)\times f_{p\text{-}dairy}(1)\times f_{s\text{-}dairy}(1)\times\left(R_{upp}+R_{es}\right)\right)+\left(Q_{s\text{-}dairy}\left(\frac{0.4\ kg}{day}\right)\times f_{p\text{-}dairy}(1)\right)}$$

where:

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

- consumption of swine.

$DCC_{soil\text{-}far\text{-}swine\text{-}ing}=$

$$\text{y-INTERCEPT} = \frac{DCC_{far\text{-}swine\text{-}ing}(pCi/g)}{TF_{swine}\left(\frac{day}{kg}\right)\times\left[\left(Q_{p\text{-}swine}\left(\frac{4.7\ kg}{day}\right)\times f_{p\text{-}swine}(1)\times f_{s\text{-}swine}(1)\times\left(R_{upp}+R_{es}\right)\right)+\left(Q_{s\text{-}swine}\left(\frac{0.37\ kg}{day}\right)\times f_{p\text{-}swine}(1)\right)\right]}\times\left(\frac{t_{far}(year)\times\lambda\left(\frac{1}{year}\right)}{\left(1-e^{-\lambda t_{far}}\right)}\right)$$

and:

$DCC_{water\text{-}far\text{-}swine\text{-}ing}(pCi/L)=$

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

where:

$$\text{SLOPE} = \frac{-Q_{w\text{-}swine}\left(\frac{11.4\ L}{day}\right)}{\left(Q_{p\text{-}swine}\left(\frac{4.7\ kg}{day}\right)\times f_{p\text{-}swine}(1)\times f_{s\text{-}swine}(1)\times\left(R_{upp}+R_{es}\right)\right)+\left(Q_{s\text{-}swine}\left(\frac{0.37\ kg}{day}\right)\times f_{p\text{-}swine}(1)\right)}$$

where:

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

- consumption of fish.

$DCC_{soil\text{-}far\text{-}fsh\text{-}ing}=$

$$\text{y-INTERCEPT} = \frac{DCC_{far\text{-}fish\text{-}ing}(pCi/g)\times Kd\left(\frac{L}{kg}\right)}{BCF\left(\frac{day}{kg}\right)}\times\left(\frac{t_{far}(year)\times\lambda\left(\frac{1}{year}\right)}{\left(1-e^{-\lambda t_{far}}\right)}\right)$$

and:

$DCC_{water\text{-}far\text{-}fish\text{-}ing}(pCi/L) =$

$$\text{x-INTERCEPT} = \frac{DCC_{far\text{-}fish\text{-}ing}(pCi/g)}{BCF\left(\frac{L}{kg}\right)\times\left(\frac{1\ kg}{1000\ g}\right)}$$

where:

$$\text{SLOPE} = \frac{-Kd\left(\frac{L}{kg}\right)}{1000}$$

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

- consumption of goat.

$PRG_{soil\text{-}far\text{-}goat\text{-}ing} =$

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

and:

$PRG_{water\text{-}far\text{-}goat\text{-}ing}(pCi/L) =$

$$\text{x-INTERCEPT} = \frac{PRG_{far\text{-}goat\text{-}ing}(pCi/g)}{TF_{goat}\left(\frac{day}{kg}\right)\times Q_{w\text{-}goat}\left(\frac{3.81\ L}{day}\right)\times\left(\frac{1\ kg}{1000\ g}\right)}$$

where:

$$\text{SLOPE} = \frac{-Q_{w\text{-}goat}\left(\frac{3.81\ L}{day}\right)}{\left(Q_{p\text{-}goat}\left(\frac{1.27\ kg}{day}\right)\times f_{p\text{-}goat}(1)\times f_{s\text{-}goat}(1)\times\left(R_{upp}+R_{es}\right)\right)+\left(Q_{s\text{-}goat}\left(\frac{0.23\ kg}{day}\right)\times f_{p\text{-}goat}(1)\right)}$$

where:

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

- consumption of goat milk.

$PRG_{soil\text{-}far\text{-}goat\text{-}milk\text{-}ing} =$

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

and:

$PRG_{water\text{-}far\text{-}goat\text{-}milk\text{-}ing}(pCi/L) =$

$$\text{x-INTERCEPT} = \frac{PRG_{far\text{-}goat\text{-}milk\text{-}ing}(pCi/g)}{TF_{goat\text{-}milk}\left(\frac{day}{L\ milk}\right)\times\rho_m\left(\frac{1.03\ kg}{1\ L\ milk}\right)^{-1}\times Q_{w\text{-}goat\text{-}milk}\left(\frac{8.75\ L}{day}\right)\times\left(\frac{1\ kg}{1000\ g}\right)}$$

where:

$$\text{SLOPE} = \frac{-Q_{w\text{-}goat\text{-}milk}\left(\frac{8.75\ L}{day}\right)}{\left(Q_{p\text{-}goat\text{-}milk}\left(\frac{1.59\ kg}{day}\right)\times f_{p\text{-}goat\text{-}milk}(1)\times f_{s\text{-}goat\text{-}milk}(1)\times\left(R_{upp}+R_{es}\right)\right)+\left(Q_{s\text{-}goat\text{-}milk}\left(\frac{0.29\ kg}{day}\right)\times f_{p\text{-}goat\text{-}milk}(1)\right)}$$

where:

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

- consumption of sheep.

$PRG_{soil\text{-}far\text{-}sheep\text{-}ing} =$

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

and:

$PRG_{water\text{-}far\text{-}sheep\text{-}ing}(pCi/L) =$

$$\text{x-INTERCEPT} = \frac{PRG_{far\text{-}mutton\text{-}ing}(pCi/g)}{TF_{sheep}\left(\frac{day}{kg}\right)\times Q_{w\text{-}sheep}\left(\frac{5.25\ L}{day}\right)\times\left(\frac{1\ kg}{1000\ g}\right)}$$

where:

$$\text{SLOPE} = \frac{-Q_{w\text{-}sheep}\left(\frac{5.25\ L}{day}\right)}{\left(Q_{p\text{-}sheep}\left(\frac{1.75\ kg}{day}\right)\times f_{p\text{-}sheep}(1)\times f_{s\text{-}sheep}(1)\times\left(R_{upp}+R_{es}\right)\right)+\left(Q_{s\text{-}sheep}\left(\frac{0.32\ kg}{day}\right)\times f_{p\text{-}sheep}(1)\right)}$$

where:

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

- consumption of sheep milk.

$$PRG_{soil\text{-}far\text{-}sheep\text{-}milk\text{-}ing} =$$

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

and:

$$PRG_{water\text{-}far\text{-}sheep\text{-}milk\text{-}ing}\left(pCi/L\right) =$$

$$\text{x-INTERCEPT} = \frac{PRG_{far\text{-}sheep\text{-}milk\text{-}ing}\left(pCi/g\right)}{TF_{sheep\text{-}milk}\left(\frac{day}{L\ milk}\right)\times\rho_m\left(\frac{1.03\ kg}{1\ L\ milk}\right)^{-1}\times Q_{w\text{-}sheep\text{-}milk}\left(\frac{10.4\ L}{day}\right)\times\left(\frac{1\ kg}{1000\ g}\right)}$$

where:

$$\text{SLOPE} = \frac{-Q_{w\text{-}sheep\text{-}milk}\left(\frac{10.4\ L}{day}\right)}{\left(Q_{p\text{-}sheep\text{-}milk}\left(\frac{3.15\ kg}{day}\right)\times f_{p\text{-}sheep\text{-}milk}(1)\times f_{s\text{-}sheep\text{-}milk}(1)\times\left(R_{upp}+R_{es}\right)\right)+\left(Q_{s\text{-}sheep\text{-}milk}\left(\frac{0.57\ kg}{day}\right)\times f_{p\text{-}sheep\text{-}milk}(1)\right)}$$

where:

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

Results of back-calculating exposure to soil and water are presented in an interactive graph. See Section 4.8.4 for details.

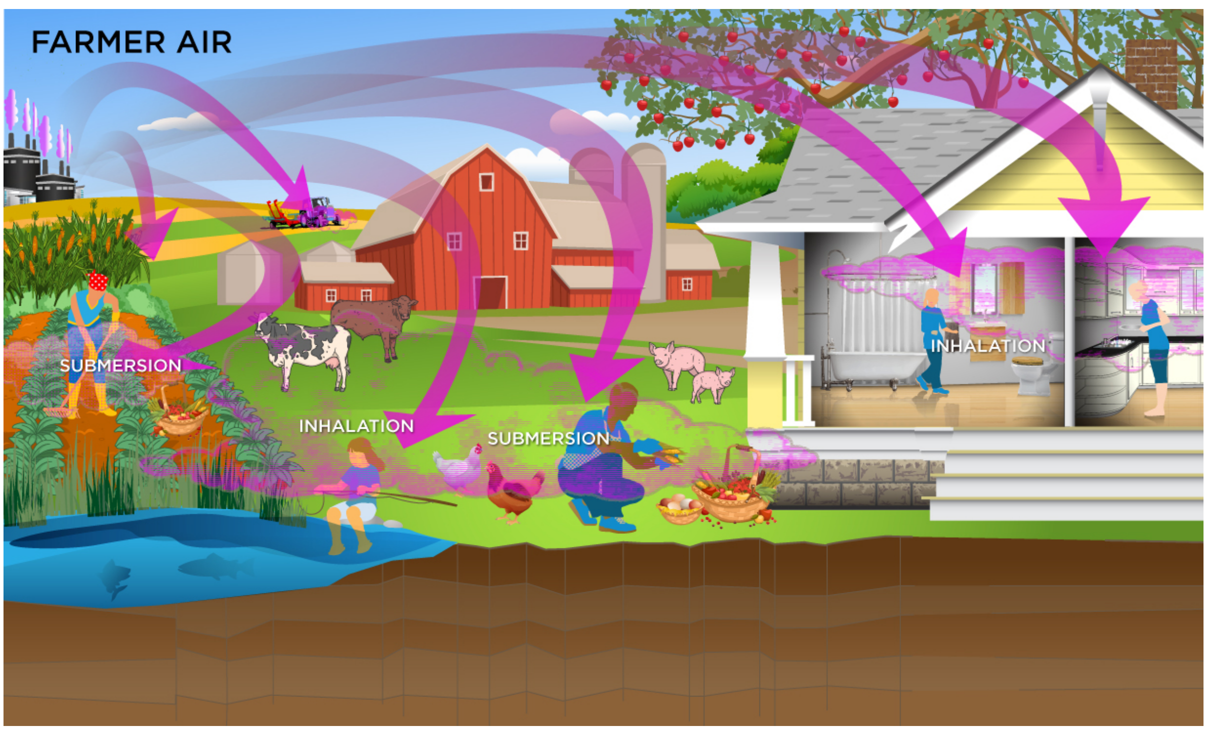
Definitions of the input variables are in Table 1.

## 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 making 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.

Two ambient air exposure conditions are offered for this scenario. The first scenario includes a half-life decay function and the second scenario does not. In situations where the contaminant in the air is not being replenished (e.g., an accidental one-time air release from a factory), equations for the first scenario 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), equations for the second scenario should be used.

### Graphical Representation




### Equations

Two ambient air exposure conditions are offered for this scenario. The first scenario includes a half-life decay function and the second scenario does not. In situations where the contaminant in the air is not being replenished (e.g., an accidental one-time air release from a factory), equations for the first scenario 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), equations for the second scenario should be used.

The farmer ambient air land use equation, presented here, contains the following exposure routes with half-life decay:

- inhalation and

$$DCC_{far-air-inh-decay}\left(pCi/m^3\right) = \frac{DL\left(\frac{mrem}{year}\right) \times t_{far}\,(year) \times \lambda\left(\frac{1}{year}\right)}{(1-e^{-\lambda t_{far}}) \times DCF_i\left(\frac{mrem}{pCi}\right) \times IFA_{far-adj}\left(\frac{6{,}475\ m^3}{year}\right)}$$

where:

$$IFA_{far-adj}\left(\frac{6{,}475\ m^3}{year}\right) = \left(\begin{array}{l}\left(EF_{far-c}\left(\frac{350\ days}{year}\right) \times ET_{far-c}\left(\frac{24\ hours}{day}\right) \times \left(\frac{1\ day}{24\ hours}\right) \times IRA_{far-c}\left(\frac{10\ m^3}{day}\right) \times AAF_{far-c}\,(0.15)\right) + \\ \left(EF_{far-a}\left(\frac{350\ days}{year}\right) \times ET_{far-a}\left(\frac{24\ hours}{day}\right) \times \left(\frac{1\ day}{24\ hours}\right) \times IRA_{far-a}\left(\frac{20\ m^3}{day}\right) \times AAF_{far-a}\,(0.85)\right)\end{array}\right)$$

where:

$$AAF_{far-c}(0.15) = \left(\frac{ED_{farc}(6\ years)}{ED_{far}(40\ years)}\right) \text{ and: } AAF_{far-a}(0.85) = \left(\frac{ED_{far-a}(34\ years)}{ED_{far}(40\ years)}\right)$$

- external exposure to ionizing radiation

$$DCC_{far-air-sub-decay}\left(pCi/m^3\right) = \frac{DL\left(\frac{mrem}{year}\right) \times t_{far}\,(year) \times \lambda\left(\frac{1}{year}\right)}{(1-e^{-\lambda t_{far}}) \times DCF_{sub}\left(\frac{mrem/year}{pCi/m^3}\right) \times EF_{far}\left(\frac{350\ days}{year}\right) \times \left(\frac{1\ year}{365\ days}\right) \times ET_{far}\left(\frac{24\ hours}{day}\right) \times \left(\frac{1\ day}{24\ hours}\right) \times GSF_a\,(1.0)}$$

- total

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

The resident ambient air land use equation, presented here, contains the following exposure routes without half-life decay:

- inhalation and

$$DCC_{far-air-inh-nodecay}\left(pCi/m^3\right) = \frac{DL\left(\frac{mrem}{year}\right)}{DCF_i\left(\frac{mrem}{pCi}\right) \times IFA_{far-adj}\left(\frac{6{,}475\ m^3}{year}\right)}$$

where:

$$IFA_{far-adj}\left(\frac{6{,}475\ m^3}{year}\right) = \left(\begin{array}{l}\left(EF_{far-c}\left(\frac{350\ days}{year}\right) \times ET_{far-c}\left(\frac{24\ hours}{day}\right) \times \left(\frac{1\ day}{24\ hours}\right) \times IRA_{far-c}\left(\frac{10\ m^3}{day}\right) \times AAF_{far-c}\,(0.15)\right) + \\ \left(EF_{far-a}\left(\frac{350\ days}{year}\right) \times ET_{far-a}\left(\frac{24\ hours}{day}\right) \times \left(\frac{1\ day}{24\ hours}\right) \times IRA_{far-a}\left(\frac{20\ m^3}{day}\right) \times AAF_{far-a}\,(0.85)\right)\end{array}\right)$$

where:

$$AAF_{far-c}(0.15) = \left(\frac{ED_{far-c}(6\ years)}{ED_{far}(40\ years)}\right) \text{ and: } AAF_{far-a}(0.85) = \left(\frac{ED_{far-a}(34\ years)}{ED_{far}(40\ years)}\right)$$

- external exposure to ionizing radiation

$$DCC_{far-air-sub-nodecay}\left(pCi/m^3\right) = \frac{DL\left(\frac{mrem}{year}\right)}{DCF_{sub}\left(\frac{mrem/year}{pCi/m^3}\right) \times EF_{far}\left(\frac{350\ days}{year}\right) \times \left(\frac{1\ year}{365\ days}\right) \times ET_{far}\left(\frac{24\ hours}{day}\right) \times \left(\frac{1\ day}{24\ hours}\right) \times GSF_a\,(1.0)}$$

- total

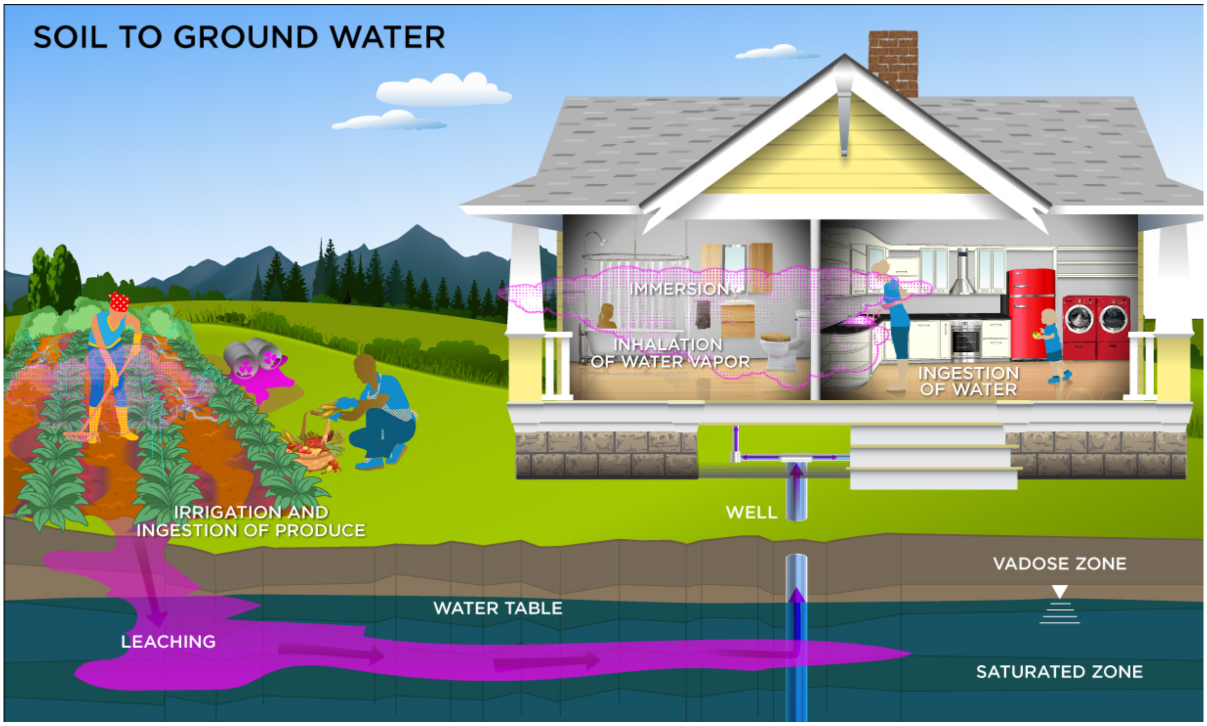
$$DCC_{far-air-tot-nodecay}\left(pCi/m^3\right) = \frac{1}{\frac{1}{DCC_{far-air-inh-nodecay}} + \frac{1}{DCC_{far-air-sub-nodecay}}}$$

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 dose-based DCCs 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.

### Graphical Representation




The SSL methodology was designed for use during the early stages of a site evaluation when information about subsurface conditions may be limited. Because of this constraint, the methodology is based on conservative, simplifying assumptions about the release and transport of contaminants in the subsurface.

## Equations

The method for calculating SSLs for the migration to groundwater pathway was developed to identify radionuclide concentrations in soil that have the potential to contaminate groundwater above screening levels (i.e., MCLs or dose-based concentrations). Migration of radionuclides from soil to groundwater can be envisioned as a two-stage process: (1) release of contaminant in soil leachate and (2) transport of the contaminant through the underlying soil and aquifer to a receptor well. The SSL method considers both of these fate and transport mechanisms.

SSLs are back-calculated from acceptable groundwater concentrations. 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 acceptable groundwater concentration is 10 pCi/L, the target soil leachate concentration would be 100 pCi/L. The partition equation is then used to calculate the total soil concentration (i.e., SSL) corresponding to this soil leachate concentration.

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 the user has all of the parameters needed to calculate a dilution factor, you may use the Method 2 (mass-limit equation for migration to groundwater).

**Method 1. Partitioning Equation for Migration to Groundwater**

$$SSL\left(\frac{pCi}{g}\right) = C_w\left(\frac{pCi}{L}\right) \times 10^{-3}\left(\frac{kg}{g}\right) \times \left(K_d\left(\frac{L}{kg}\right) + \frac{\theta_w\left(\frac{L_{water}}{L_{soil}}\right)}{\rho_b\left(\frac{kg}{L}\right)}\right) \times \frac{t \times \lambda}{\left(1 - e^{-\lambda t}\right)}$$

where:

$C_w = MCL \times DAF$

or:

$C_w = DCC \times DAF$

**Method 2. Mass-Limit Equation for Migration to Groundwater**

$$SSL\left(\frac{pCi}{g}\right) = \frac{C_w\left(\frac{pCi}{L}\right)\times I\left(\frac{m}{year}\right)\times ED_{gw}\,(70\ years)\times 10^{-3}\left(\frac{kg}{g}\right)\times t\times\lambda}{\rho_b\left(\frac{kg}{L}\right)\times d_s\,(m)\times\left(1-e^{-\lambda t}\right)}$$

where:

$$C_w = MCL \times DAF$$

or:

$$C_w = DCC \times DAF$$

Then calculate the dilution factor using this equation.

$$\text{Dilution Attenuation Factor (DAF)} = 1 + \frac{K\left(\frac{m}{year}\right)\times i\left(\frac{m}{m}\right)\times d(m)}{I\left(\frac{0.18\ m}{year}\right)\times L(m)}$$

where:

$$d(m) = \left(0.0112\times L^2(m)\right)^{0.5} + d_a \times \left[1-\exp\left(\frac{-L(m)\times I\left(\frac{m}{year}\right)}{K\left(\frac{m}{year}\right)\times i\left(\frac{m}{m}\right)\times d_a(m)}\right)\right]$$

where:

$$d(m) = \left(0.0112\times L(m)^2\right)^{0.5} + d_a\,(m)\times\left\{1-e^{\left[\left(-L(m)\times I\left(\frac{m}{year}\right)\right)/\left(K\left(\frac{m}{year}\right)\times i\left(\frac{m}{m}\right)\times d_a(m)\right)\right]}\right\}$$

Definitions of the input variables are in Table 1.

## 4.10 Supporting Equations and Parameter Discussion

There are five parts of the above land use equations that require further explanation. The first is explanation of two inhalation variables: the particulate emission factor (PEF) and the volatilization factor (VF). 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 x $10^9$ $m^3$/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 ug/$m^3$. 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 DCCs. 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.

$$PEF\left(\frac{m^3_{air}}{kg_{soil}}\right) = \frac{Q}{C_{wind}}\left(\frac{\left(\frac{g}{m^2\text{-}s}\right)}{\left(\frac{kg}{m^3}\right)}\right) \times \frac{3{,}600\left(\frac{s}{hour}\right)}{0.036 \times (1 - V) \times \left(\frac{U_m\left(\frac{m}{s}\right)}{U_t\left(\frac{m}{s}\right)}\right)^3 \times F(x)}$$

where:

$$\frac{Q}{C_{wind}} = A \times \exp\left[\frac{(\ln A_s\,(acre) - B)^2}{C}\right]$$

and:

$$\text{if } x < 2,\ F(x) = 1.91207 - 0.0278085\,x + 0.48113\,x^2 - 1.09871\,x^3 + 0.335341\,x^4$$

$$\text{if } x \geq 2,\ F(x) = 0.18\left(8x^3 + 12x\right)e^{\left(-x^2\right)}$$

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 $m^3$/kg for tritium. The VF replaces the PEF in the DCC 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

VFH-3 = 100 g H2O/kg soil / 6 g H2O/$m^3$ air

= 17 $m^3$ air/kg soil

= 17 $m^3$/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 cars x 2 tons/car) + (10 trucks x 20 tons/truck)]/30 vehicles = 8 tons

The sum of the fleet vehicle kilometers traveled during construction (∑ 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 $m^2$), 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 $m^2$, 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:

∑ VKT = 30 vehicles x 0.045 km/day x (52 weeks/year / 2) x 5 days/week = 175.5 km

$$PEF_{sc}\left(\frac{m^3_{air}}{kg_{soil}}\right) = \frac{Q}{C_{sr}}\left(\frac{\left(\frac{g}{m^2 - s}\right)}{\left(\frac{kg}{m^3}\right)}\right) \times \frac{1}{F_D} \times \left[\frac{T_t(s) \times A_R\left(m^2\right)}{\frac{2.6 \times \left(\frac{s}{12}\right)^{0.8} \times \left(\frac{W(tons)}{3}\right)^{0.4}}{\left(\frac{M_{dry}}{0.2}\right)^{0.3}} \times \frac{\left(365\left(\frac{days}{year}\right) - p\left(\frac{days}{year}\right)\right)}{365\left(\frac{days}{year}\right)} \times 281.9 \times \sum VKT(km)}\right]$$

$$\frac{Q}{C_{sr}}\left(\frac{\left(\frac{g}{m^2 - s}\right)}{\left(\frac{kg}{m^3}\right)}\right) = A \times \exp\left[\frac{\left(\ln A_s\,(acre) - B\right)^2}{C}\right]$$

$$A_R\left(m^2\right) = L_R\,(ft) \times W_R\,(20\ feet) \times 0.092903\left(\frac{m^2}{feet^2}\right)$$

$$W(tons) = \frac{\left(\text{number of cars} \times \frac{tons}{car} + \text{number of trucks} \times \frac{tons}{truck}\right)}{\text{total vehicles}}$$

$$\sum VKT\,(km) = \text{total vehicles} \times \text{distance}\left(\frac{km}{day}\right) \times EW_{cw}\left(\frac{weeks}{year}\right) \times DW_{cw}\left(\frac{days}{week}\right)$$

$$T_t\ (7200000\ s) = ED_{cw}\,(1\ years) \times EF_{cw}\left(\frac{250\ days}{year}\right) \times ET_{cw}\left(\frac{8\ hours}{day}\right) \times \left(\frac{3600\ s}{hour}\right)$$

$$F_D\,(0.18584) = 0.1852 + \left(5.3537 / t_c\right) + \left(-9.6318 / t_c^{\,2}\right)$$

$$t_c\,(8400\ hours) = ED_{cw}\,(1\ years) \times EW_{cw}\left(\frac{50\ weeks}{year}\right) \times \left(\frac{7\ days}{week}\right) \times \left(\frac{24\ hours}{day}\right)$$

### 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, and 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.

$$PEF'_{sc}\left(\frac{m^3_{air}}{kg_{soil}}\right) = \frac{Q}{C_{sa}}\left(\frac{\left(\frac{g}{m^2\text{-}s}\right)}{\left(\frac{kg}{m^3}\right)}\right) \times \frac{1}{F_D} \times \frac{1}{<J'_T>\left(\frac{g}{m^2-s}\right)}$$

where:

$$\frac{Q}{C_{sa}}\left(\frac{\left(\frac{g}{m^2\text{-}s}\right)}{\left(\frac{kg}{m^3}\right)}\right) = A \times \exp\left[\frac{\left(\ln A_c\left(acre\right)-B\right)^2}{C}\right]$$

$$<J'_T>\left(\frac{g}{m^2-s}\right) = \frac{M^{pc}_{wind}\left(g\right)+M_{excav}\left(g\right)+M_{doz}\left(g\right)+M_{grade}\left(g\right)+M_{till}\left(g\right)}{A_{surf}\left(m^2\right)\times T_t\left(s\right)}$$

$$M^{pc}_{wind}\left(g\right) = 0.036 \times \left(1\text{-}V\right) \times \left(\frac{U_m\left(\frac{m}{s}\right)}{U_t\left(\frac{m}{s}\right)}\right)^3 \times F\left(x\right) \times A_{surf}\left(m^2\right) \times ED\ \left(years\right) \times 8760\left(\frac{hours}{year}\right)$$

$$M_{excav}\left(g\right) = 0.35 \times 0.0016 \times \frac{\left(\frac{U_m\left(\frac{m}{s}\right)}{2.2}\right)^{1.3}}{\left(\frac{M_{m\text{-}excav}\left(\%\right)}{2}\right)^{1.4}} \times \rho_{soil}\left(\frac{Mg}{m^3}\right) \times A_{excav}\left(m^2\right) \times d_{excav}\left(m\right) \times N_{A\text{-}dump} \times 1000\left(\frac{g}{kg}\right)$$

$$M_{doz}\left(g\right) = 0.75 \times \frac{0.45 \times s_{doz}\left(\%\right)^{1.5}}{\left(M_{m\text{-}doz}\left(\%\right)\right)^{1.4}} \times \frac{\Sigma\, VKT_{doz}\left(km\right)}{S_{doz}\left(\frac{km}{hour}\right)} \times 1000\left(\frac{g}{kg}\right)$$

$$M_{grade}\left(g\right) = 0.60 \times 0.0056 \times S_{grade}\left(\frac{km}{hour}\right)^{2.0} \times \Sigma\, VKT_{grade}\left(km\right) \times 1000\left(\frac{g}{kg}\right)$$

and:

$$M_{till}\left(g\right) = 1.1 \times s_{till}\left(\%\right)^{0.6} \times A_{c\text{-}till}\left(acres\right) \times 4047\left(\frac{m^2}{acre}\right) \times 10^{-4}\left(\frac{ha}{m^2}\right) \times 1000\left(\frac{g}{kg}\right) \times N_{A\text{-}till}$$

where:

$$\Sigma\, VKT_{grade}\left(km\right) = A_{c\text{-}grade}\left(acres\right) \times 4047\left(\frac{m^2}{acre}\right) \times \frac{1}{B_{l\text{-}grade}\left(m\right)} \times \frac{1}{1000\left(\frac{m}{km}\right)} \times N_{A\text{-}grade}$$

where:

$$\Sigma\, VKT_{doz}\left(km\right) = A_{c\text{-}doz}\left(acres\right) \times 4047\left(\frac{m^2}{acre}\right) \times \frac{1}{B_{l\text{-}doz}\left(m\right)} \times \frac{1}{1000\left(\frac{m}{km}\right)} \times N_{A\text{-}doz}$$

$$T_t\ \left(7200000\ s\right) = ED_{cw}\left(1\ years\right) \times EF_{cw}\left(\frac{250\ days}{year}\right) \times ET_{cw}\left(\frac{8\ hours}{day}\right) \times \left(\frac{3600\ s}{hour}\right)$$

$$F_D\left(0.18584\right) = 0.1852 + \left(5.3537 / t_c\right) + \left(-9.6318 / t_c^{\,2}\right)$$

$$t_c\left(8400\ hours\right) = ED_{cw}\left(1\ years\right) \times EW_{cw}\left(\frac{50\ weeks}{year}\right) \times \left(\frac{7\ days}{week}\right) \times \left(\frac{24\ hours}{day}\right)$$

and:

$$\text{if } x < 2,\ F\left(x\right) = 1.91207 - 0.0278085\, x + 0.48113\, x^2 - 1.09871\, x^3 + 0.335341\, x^4$$

$$\text{if } x \geq 2,\ F\left(x\right) = 0.18\left(8x^3 + 12x\right)e^{\left(-x^2\right)}$$

where:

$$x = 0.886 \times \left(\frac{U_t}{U_m}\right)$$

## 4.10.4 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. λ = 0.693/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 DCC 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 DCCs will provide a protective screening value. Definitions of the input variables are in Table 1.

## 4.10.5 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 $m^2$ 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 conservative DCCs, 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 DCCs. 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/$cm^3$ has been used. For a description of other EPA default ACF values that predate this guidance, follow the link here.

## 4.10.6 Gamma Shielding Factor

DCCs 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. When the calculator is ran in 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 dose 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 corresponding to 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 gamma soil 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 $GSF_{o\text{-}ext\text{-}sv}$, $GSF_{o\text{-}ext\text{-}1cm}$, $GSF_{o\text{-}ext\text{-}5cm}$, $GSF_{o\text{-}ext\text{-}15cm}$, & $GSF_{o\text{-}ext\text{-}gp}$
- In the resident, farmer, and indoor worker soil external exposure equations $GSF_{i\text{-}total}$ is applied to account for the gamma sheilding provided by clean soil cover and the building subfloor. $GSF_{i\text{-}total} = GSF_i \times GSF_b$; 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/$cm^3$ has been used.

## 4.10.7 Using the Back-calculated to Soil and Water Interactive Graph

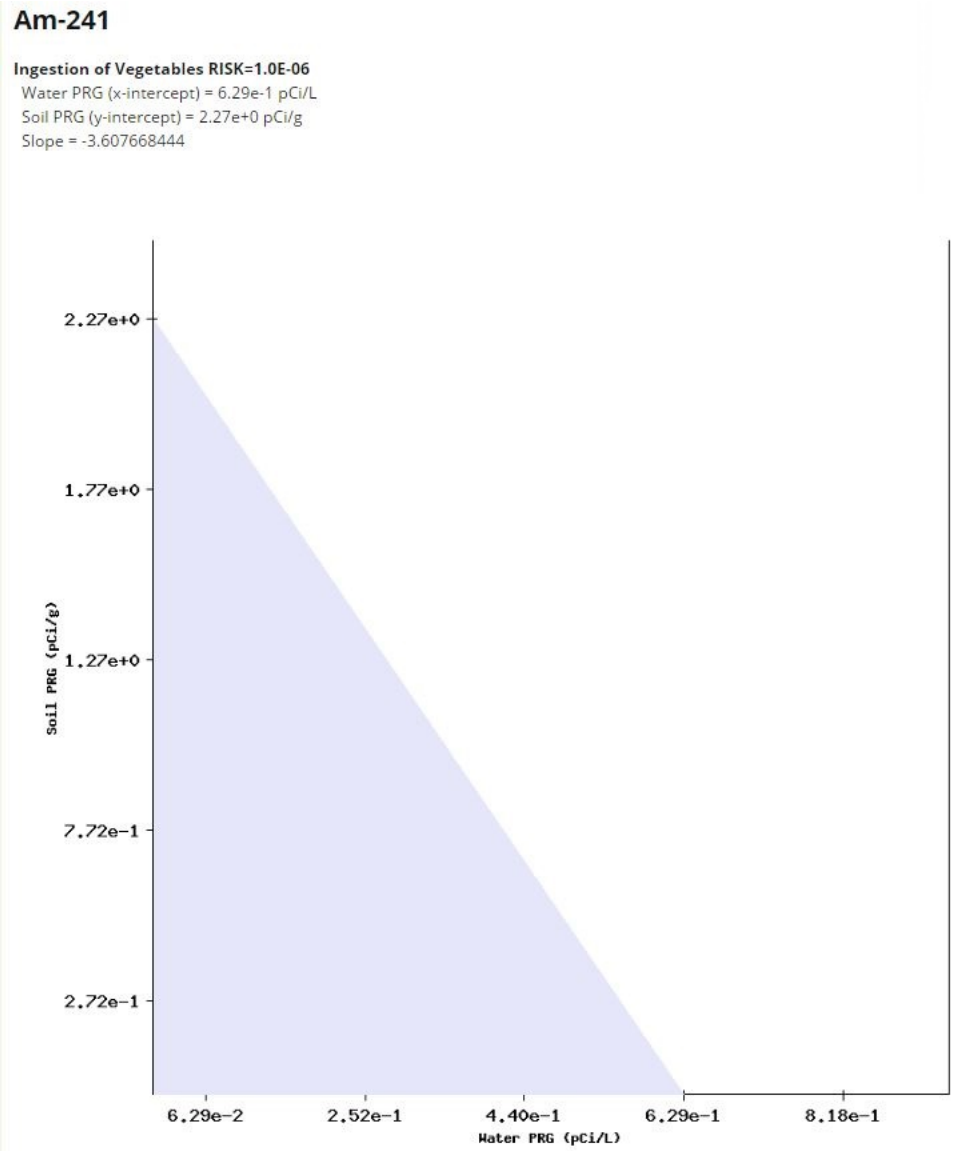
When multiple media are contributing to the overall site dose, it may be more practical to remediate one medium vs another. In the case of the agriculture scenario, water and soil may both contribute to the dose from ingesting produce, milk, beef, swine, poultry, eggs, and fish. The interactive graph shows the DCCs for soil and water to achieve the target dose or target hazard index for the exposure route of concern.

The back-calculated to soil and water DCC results are listed last on the results page. The interactive graph is available for ingestion of produce, ingestion milk, and ingestion of beef DCCs and may be accessed by clicking on any highlighted blue DCC like in the image below.

| Produce Slope | Produce Ingestion PRG (pCi/g soil) | Fish Slope | Fish Ingestion PRG (pCi/g soil) | Beef Slope | Beef Ingestion PRG (pCi/g soil) | Milk Slope | Milk Ingestion PRG (pCi/g soil) | Swine Slope | Swine Ingestion PRG (pCi/g soil) |
|---|---|---|---|---|---|---|---|---|---|
| -4.79E-02 | 8.41E-02 | -1.00E-02 | 8.74E-05 | -9.32E-03 | 9.42E-02 | -1.15E-02 | 5.30E-02 | -4.59E-03 | 4.83E-02 |

Clicking on a highlighted blue back-calculated to soil and water DCC will take the user to the Farmer DCC Graphical Results page where the interactive graph is displayed.

The x-intercept (coordinate x,0) shows where the water DCC = TR and soil concentration must equal 0. The y-intercept (coordinate 0,y) shows where the soil DCC = TR and the water concentration must equal 0. Any point between (x,0) and (0,y) shows a separate DCC for water and soil that will meet the TR. Hovering the mouse over the graph will display moving lines that follow the mouse based on the x-coordinate (water DCC). Click anywhere on the graph to stop the lines from moving and to display the soil and water DCCs associated with that specific x-coordinate.




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.

## 5. Recommended Default Exposure Parameters

Table 1 presents the definitions of the variables and their default values. The DCC default values and exposure models are consistent with the Preliminary Remediation Goals at Superfund Sites (PRG) calculator. Both the DCC and PRG calculator default values 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, the PRG, 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

| Dose Coefficients | | | |
|---|---|---|---|
| Symbol | Definition (units) | Default | Reference |
| $DCF_{ext-15cm}$ | Dose Conversion Factor - external exposure (mrem/year per pCi/g) | Isotope-specific | ORNL 2014c |
| $DCF_{ext-1cm}$ | Dose Conversion Factor - external exposure (mrem/year per pCi/g) | Isotope-specific | ORNL 2014c |
| $DCF_{ext-5cm}$ | Dose Conversion Factor - external exposure (mrem/year per pCi/g) | Isotope-specific | ORNL 2014c |
| $DCF_{ext-gp}$ | Dose Conversion Factor - external exposure (mrem/year per pCi/cm$^2$) | Isotope-specific | ORNL 2014c |
| $DCF_{ext-sv}$ | Dose Conversion Factor - external exposure (mrem/year per pCi/g) | Isotope-specific | ORNL 2014c |
| $DCF_i$ | Dose Conversion Factor - inhalation (mrem/pCi) | Isotope-specific | ORNL 2014c |

| | | | |
|---|---|---|---|
| $DCF_o$ | Oral Dose Conversion Factor - population (mrem/pCi) | Isotope-specific | ORNL 2014c |
| $DCF_{oa}$ | Oral Dose Conversion Factor - adult only (mrem/pCi) | Isotope-specific | ORNL 2014c |
| $DCF_{sub}$ | Dose Conversion Factor - submersion (mrem/yr per pCi/cm$^3$): For use in this tool, ORNL 2014c units were converted to (mrem/yr per pCi/m$^3$) | Isotope-specific | ORNL 2014c |

**Dose and Decay Constant Variables**

| Symbol | Definition (units) | Default | Reference |
|---|---|---|---|
| DL | Dose Limit (mrem/year) | 1 | |
| $t_{cw}$ | Time - construction worker (year) | 1 | U.S. EPA 2002 Exhibit 5-1 |
| $t_{far}$ | Time - farmer (year) | 1 | U.S. EPA 2005 (pg. C-24/C-26) |
| $t_{iw}$ | Time - indoor worker (year) | 1 | U.S. EPA 1991a (pg. 15) |
| $t_{ow}$ | Time - outdoor worker (year) | 1 | U.S. EPA 1991a (pg. 15) |
| $t_{rec}$ | Time - recreator (year) | site-specific | site-specific |
| $t_{res}$ | Time - resident (year) | 1 | U.S. EPA 2011a, Table 16-108; 90th percentile or current residence time. |
| $t_w$ | Time - worker (year) | 1 | U.S. EPA 1991a (pg. 15) |
| λ | decay constant = 0.693/half-life (year$^{-1}$)<br>where 0.693 = ln(2) | Isotope-specific | Developed for Radionuclide Soil Screening calculator |

**Miscellaneous Variables**

| Symbol | Definition (units) | Default | Reference |
|---|---|---|---|
| $AAF_{far-a}$ | Farmer Age Adjustment Factor - adult (unitless) | 0.85 | Developed for this calculator |
| $AAF_{far-c}$ | Farmer Age Adjustment Factor - child (unitless) | 0.15 | Developed for this calculator |
| $AAF_{rec-a}$ | Recreator Age Adjustment Factor - adult (unitless) | site-specific | Developed for this calculator |
| $AAF_{rec-c}$ | Recreator Age Adjustment Factor - child (unitless) | site-specific | Developed for this calculator |
| $AAF_{res-a}$ | Resident Age Adjustment Factor - adult (unitless) | 0.77 | Developed for this calculator |
| $AAF_{res-c}$ | Resident Age Adjustment Factor - child (unitless) | 0.23 | Developed for this calculator |
| $ACF_{ext-15cm}$ | 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 |
| $ACF_{ext-sv}$ | Area Correction Factor - soil volume (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 |
| $CF_{far-fish}$ | 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 |
| $CF_{far-swine}$ | 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 |
| $GSF_{ext-15cm}$ | Gamma Shielding Factor - 15cm (unitless) | Isotope-specific | ORNL 2014b |
| $GSF_{ext-1cm}$ | Gamma Shielding Factor - 1cm (unitless) | Isotope-specific | ORNL 2014b |
| $GSF_{ext-5cm}$ | Gamma Shielding Factor - 5cm (unitless) | Isotope-specific | ORNL 2014b |
| $GSF_{ext-gp}$ | Gamma Shielding Factor - ground plane (unitless) | Isotope-specific | ORNL 2014b |
| $GSF_{ext-sv}$ | Gamma Shielding Factor - soil volume (unitless) | Isotope-specific | ORNL 2014b |
| $GSF_i$ | Gamma Shielding Factor - Indoor (unitless) | 0.4 | U.S. EPA 2000a. (pg. 2-22). U.S. EPA 2000b. (pg. 2-18) |

| | | | |
|---|---|---|---|
| K | Andelman Volatilization Factor (L/m$^3$) | 0.5 | U.S. EPA 1991b (pg. 20) |
| $\rho_m$ | Density of milk (kg/L) | 1.03 | Milk Composition & Synthesis Resource Library |

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

| Symbol ▼ | Definition (units) | Default | Reference |
|---|---|---|---|
| BCF | Fish Transfer Factor (L/kg) | radionuclide-specific | hierarchy selection in Section 2.4.2 |
| $Bv_{dry}$ | Soil to Plant Transfer Factor - dry (pCi/g-dry plant per pCi/g-dry soil) | radionuclide-specific | hierarchy selection in Section 2.4.2 |
| $Bv_{wet}$ | Soil to Plant Transfer Factor - wet (pCi/g-fresh plant per pCi/g-dry soil) | radionuclide-specific | hierarchy selection in Section 2.4.2<br>climate and soil selection in 2.5.1.2 |
| F | Irrigation Period (unitless) | 0.25 | Personal communication |
| $f_{p\text{-}beef}$ | Animal On-site Fodder Fraction - beef (unitless) | 1 | Developed for this calculator |
| $f_{p\text{-}dairy}$ | Animal On-site Fodder Fraction - dairy (unitless) | 1 | Developed for this calculator |
| $f_{p\text{-}goat}$ | Animal On-site Fraction - goat (unitless) | 1 | Developed for this calculator |
| $f_{p\text{-}goat\text{-}milk}$ | Animal On-site Fraction - goat milk (unitless) | 1 | Developed for this calculator |
| $f_{p\text{-}poultry}$ | Animal On-site Fodder Fraction - poultry (unitless) | 1 | Developed for this calculator |
| $f_{p\text{-}sheep}$ | Animal On-site Fraction - sheep (unitless) | 1 | Developed for this calculator |
| $f_{p\text{-}sheep\text{-}milk}$ | Animal On-site Fraction - sheep milk (unitless) | 1 | Developed for this calculator |
| $f_{p\text{-}swine}$ | Animal On-site Fodder Fraction - swine (unitless) | 1 | Developed for this calculator |
| $f_{s\text{-}beef}$ | Animal On-Site Soil Fraction - beef (unitless) | 1 | Developed for this calculator |
| $f_{s\text{-}dairy}$ | Animal On-Site Soil Fraction - dairy (unitless) | 1 | Developed for this calculator |
| $f_{s\text{-}poultry}$ | Fraction of Year Animal On Site - poultry (unitless) | 1 | Developed for this calculator |
| $f_{s\text{-}swine}$ | Animal On-Site Soil Fraction - swine (unitless) | 1 | Developed for this calculator |
| $I_f$ | Interception Fraction (unitless) | 0.42 | Miller, C. W. 1980 |
| $I_r$ | Irrigation Rate (L/m$^2$) | 3.62 | Personal communication |
| $Irr_{dep}$ | aerial deposition from irrigation multiplier | isotope-specific | Calculated |
| $Irr_{res}$ | resuspension from irrigation multiplier | isotope-specific | Calculated |
| $Irr_{rup}$ | root uptake from irrigation multiplier | 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 2.5.3 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 |
| $Q_{p\text{-}beef}$ | Beef Fodder Intake Rate (kg/day) | 11.77 | U.S. EPA 2005 (pg. B-138) |
| $Q_{p\text{-}dairy}$ | Dairy Fodder Intake Rate (kg/day) | 20.3 | U.S. EPA 2005 (pg. B-145) |
| $Q_{p\text{-}goat}$ | Goat Fodder Intake Rate (kg/day) | 1.27 | Lyons et. al. 1999 |
| $Q_{p\text{-}goat\text{-}milk}$ | Goat Milk Fodder Intake Rate (kg/day) | 1.59 | Lyons et. al. 1999 and Tarr |
| $Q_{p\text{-}poultry}$ | Chicken Fodder Intake Rate (kg/day)<br>Duck Fodder Intake Rate (kg/day)<br>Turkey Fodder Intake Rate (kg/day)<br>Goose Fodder Intake Rate (kg/day) | 0.2<br>0.24<br>0.68<br>0.33 | U.S. EPA 2005 (pg. B-158/164)<br>NRC 1994<br>NRC 1994<br>NRC 1994 |
| $Q_{p\text{-}sheep}$ | Sheep Fodder Intake Rate (kg/day) | 1.75 | Lyons et. al. 1999 and OMAFRA |
| $Q_{p\text{-}sheep\text{-}milk}$ | Sheep Milk Fodder Intake Rate (kg/day) | 3.15 | Lyons et. al. 1999 and OMAFRA |
| $Q_{p\text{-}swine}$ | Swine Fodder Intake Rate (kg/day) | 4.7 | U.S. EPA 2005 (pg. B-152) |
| $Q_{s\text{-}beef}$ | Beef Soil Intake Rate (kg/day) | 0.5 | U.S. EPA 2005 (pg. B-139) |
| $Q_{s\text{-}dairy}$ | Dairy Soil Intake Rate (kg/day) | 0.4 | U.S. EPA 2005 (pg. B-146) |
| $Q_{s\text{-}goat}$ | Goat Soil Intake Rate (kg/day) | 0.23 | Handbook of Ecotoxicology ($Q_s$ is 18% of $Q_p$: sheep surrogate used) |
| $Q_{s\text{-}goat\text{-}milk}$ | Goat Milk Soil Intake Rate (kg/day) | 0.29 | Handbook of Ecotoxicology ($Q_s$ is 18% of $Q_p$: sheep surrogate used) |
| $Q_{s\text{-}poultry}$ | Chicken Soil Intake Rate (kg/day)<br>Duck Soil Intake Rate (kg/day)<br>Turkey Soil Intake Rate (kg/day)<br>Goose Soil Intake Rate (kg/day) | 0.022<br>0.024<br>0.068<br>0.033 | U.S. EPA 2005 (pg. B-159/165)<br>NRC 1994 ($Q_s$ is 10% of $Q_p$)<br>NRC 1994 ($Q_s$ is 10% of $Q_p$)<br>NRC 1994 ($Q_s$ is 10% of $Q_p$) |
| $Q_{s\text{-}sheep}$ | Sheep Soil Intake Rate (kg/day) | 0.32 | Handbook of Ecotoxicology ($Q_s$ is 18% of $Q_p$) |
| $Q_{s\text{-}sheep\text{-}milk}$ | Sheep Milk Soil Intake Rate (kg/day) | 0.57 | Handbook of Ecotoxicology ($Q_s$ is 18% of $Q_p$) |

| | | | |
|---|---|---|---|
| $Q_{s\text{-}swine}$ | Swine Soil Intake Rate (kg/day) | 0.37 | U.S. EPA 2005 (pg. B-153) |
| $Q_{w\text{-}beef}$ | Beef Water Intake Rate (L/day) | 53 | U.S. EPA 1999a (pg 10-23). U.S. EPA 1997b. |
| $Q_{w\text{-}dairy}$ | Dairy Water Intake Rate (L/day) | 92 | U.S. EPA 1999a (pg 10-23). U.S. EPA 1997b. |
| $Q_{w\text{-}goat}$ | Goat Water Intake Rate (L/day) | 3.81 | Tarr |
| $Q_{w\text{-}goat\text{-}milk}$ | Goat Milk Water Intake Rate (L/day) | 8.75 | Tarr |
| $Q_{w\text{-}poultry}$ | Chicken Water Intake Rate (L/day)<br>Duck Water Intake Rate (L/day)<br>Turkey Water Intake Rate (L/day)<br>Goose Water Intake Rate (L/day) | 0.4<br>0.48<br>1.36<br>0.66 | U.S. EPA 2005 (pg. B-159/165), NRC 1994 pg.15 ($Q_w$=2×$Q_p$)<br>NRC 1994 pg. 15 ($Q_w$ = 2 × $Q_p$)<br>NRC 1994 pg. 15 ($Q_w$ = 2 × $Q_p$)<br>NRC 1994 pg. 15 ($Q_w$ = 2 × $Q_p$) |
| $Q_{w\text{-}sheep}$ | Sheep Water Intake Rate (L/day) | 5.25 | OMAFRA |
| $Q_{w\text{-}sheep\text{-}milk}$ | 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 1984 |
| $t_b$ | Long Term Deposition and Buildup (day) | 10950 | NCRP 1985 |
| $TF_{beef}$ | 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 |
| $TF_{goat\text{-}milk}$ | 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 |
| $TF_{sheep\text{-}milk}$ | 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 1985 |
| $t_w$ | Weathering Half-life (day) | 14 | NCRP 1989 |
| $Y_v$ | Plant Yield - wet (kg/m$^2$) | 2 | NCRP 1985 |
| $\lambda_B$ | Effective Rate of Removal (1/day) | $\lambda_{HL} + \lambda_i$ | NCRP 1989 |
| $\lambda_E$ | Effective Rate for Removal from Produce (1/day) | $\lambda_i + (0.693/t_w)$ | NCRP 1989 |
| $\lambda_{HL}$ | Soil Leaching Rate (1/day) | 0.000027 | NCRP 1989 |
| $\lambda_i$ | decay (1/day) | 0.693/HL (days) | NCRP 1989 |

**Inhalation, Ingestion, and Consumption Rates**

| Symbol ▼ | Definition (units) | Default | Reference |
|---|---|---|---|
| $DFA_{rec\text{-}adj}$ | Recreator Surface Water Immersion Factor - age-adjusted (hour) | site-specific | U.S. EPA 1991a (pg. 15) |
| $IFA_{far\text{-}adj}$ | Farmer Inhalation Fraction - age-adjusted (m$^3$/year) | 6475 | Calculated using the age-adjusted intake factors equation. |
| $IFA_{rec\text{-}adj}$ | Recreator Inhalation Fraction - age-adjusted (m$^3$/year) | site-specific | Calculated using the age-adjusted intake factors equation. |
| $IFA_{res\text{-}adj}$ | Resident Inhalation Fraction - age-adjusted (m$^3$/year) | 6195 | Calculated using the age-adjusted intake factors equation. |
| $IFB_{far\text{-}adj}$ | Farmer Beef Ingestion Fraction - age-adjusted (g/year) | 52,474 | Calculated using the aged adjusted intake factors equation |
| $IFD_{far\text{-}adj}$ | Farmer Dairy Ingestion Fraction - age-adjusted (g/year) | 253,451 | Calculated using the aged adjusted intake factors equation |
| $IFE_{far\text{-}adj}$ | Farmer Egg Ingestion Fraction - age-adjusted (g/year) | 19,395 | Calculated using the aged adjusted intake factors equation |
| $IF_{far\text{-}adj}$ | Farmer Produce Ingestion Fraction - age-adjusted (g) | plant-specific | Calculated using the aged adjusted intake factors equation |
| $IFFI_{far\text{-}adj}$ | Farmer Fish Ingestion Fraction - age-adjusted (g/year) | 250,474 | Calculated using the aged adjusted intake factors equation |
| $IFP_{far\text{-}adj}$ | Farmer Poultry Ingestion Fraction - age-adjusted (g/year) | 34,414 | Calculated using the aged adjusted intake factors equation |
| $IF_{res\text{-}adj}$ | Resident Produce Ingestion Fraction - age-adjusted (g) | plant-specific | Calculated using the aged adjusted intake factors equation |
| $IFS_{rec\text{-}adj}$ | Recreator Soil Ingestion Fraction - age-adjusted (mg/year) | site-specific | Calculated using the age-adjusted intake factors equation. |
| $IFS_{res\text{-}adj}$ | Resident Soil Ingestion Fraction - age-adjusted (mg/year) | 43,050 | Calculated using the age-adjusted intake factors equation. |

| | | | |
|---|---|---|---|
| $IFSW_{far-adj}$ | Farmer Swine Ingestion Fraction - age-adjusted (g/year) | 29,288 | Calculated using the aged adjusted intake factors equation |
| $IFW_{rec-adj}$ | Recreator Surface Water Ingestion Fraction - age-adjusted (L/year) | site-specific | Calculated using the age-adjusted intake factors equation. |
| $IFW_{res-adj}$ | Resident Tapwater Ingestion Fraction - age-adjusted (L/year) | 737 | Calculated using the age-adjusted intake factors equation. |
| $IRA_{cw}$ | Construction Worker Soil Inhalation Rate ($m^3$/day; based on a rate of 2.5$m^3$/hr for 24hr) | 60 | U.S. EPA 1997a (pg. 5-11) |
| $IRA_{far-a}$ | Farmer Inhalation Rate - adult ($m^3$/day) | 20 | U.S. EPA 1991a (pg. 15) |
| $IRA_{far-c}$ | Farmer Inhalation Rate - child ($m^3$/day) | 10 | U.S. EPA 1997a (pg. 5-11) |
| $IRA_{iw}$ | Indoor Worker Soil Inhalation Rate ($m^3$/day; based on a rate of 2.5$m^3$/hr for 24hr) | 60 | U.S. EPA 1997a (pg. 5-11) |
| $IRA_{ow}$ | Outdoor Worker Soil Inhalation Rate ($m^3$/day; based on a rate of 2.5$m^3$/hr for 24hr) | 60 | U.S. EPA 1997a (pg. 5-11) |
| $IRA_{rec-a}$ | Recreator Soil 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 Soil Inhalation Rate - adult ($m^3$/day) | 20 | U.S. EPA 1991a (pg. 15) |
| $IRA_{res-c}$ | Resident Soil 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 2.5$m^3$/hr for 24hr) | 60 | U.S. EPA 1997a (pg. 5-11) |
| $IRB_{far-a}$ | Farmer Beef Ingestion Rate - adult (g/day) | 165.3 | U.S. EPA 2011 (Table 13-33) |
| $IRB_{far-c}$ | Farmer Beef Ingestion Rate - child (g/day) | 62.8 | U.S. EPA 2011 (Table 13-33) |
| $IRD_{far-a}$ | Farmer Dairy Ingestion Rate - adult (g/day) | 676.4 | U.S. EPA 2011 (Table 11-4) |
| $IRD_{far-c}$ | Farmer Dairy Ingestion Rate - child (g/day) | 994.7 | U.S. EPA 2011 (Table 11-4) |
| $IRE_{far-a}$ | Farmer Egg Ingestion Rate - adult (g/day) | 59.6 | U.S. EPA 2011 (Table 13-40) |
| $IRE_{far-c}$ | Farmer Egg Ingestion Rate - child (g/day) | 31.7 | U.S. EPA 2011 (Table 13-40) |
| $IR_{far-a}$ | Farmer Produce Ingestion Rate - adult (g/day) | plant-specific | U.S. EPA 2011 (Table 13-10) |
| $IR_{far-c}$ | Farmer Produce Ingestion Rate - child (g/day) | plant-specific | U.S. EPA 2011 (Table 13-10) |
| $IRFI_{far-a}$ | Farmer Fish Ingestion Rate - adult (g/day) | 831.8 | U.S. EPA 2011 (Table 13-20) |
| $IRFI_{far-c}$ | Farmer Fish Ingestion Rate - child (g/day) | 57.4 | U.S. EPA 2011 (Table 13-20) |
| $IRF_{res}$ | Resident Fish Ingestion Rate (g/day) | 54 | U.S. EPA 1991a (page 15) |
| $IRP_{far-a}$ | Farmer Poultry Ingestion Rate - adult (g/day) | 107.4 | U.S. EPA 2011 (Table 13-52) |
| $IRP_{far-c}$ | Farmer Poultry Ingestion Rate - child (g/day) | 46.9 | U.S. EPA 2011 (Table 13-52) |
| $IR_{res-a}$ | Resident Produce Ingestion Rate - adult (g/day) | plant-specific | U.S. EPA 2011 (Table 13-10) |
| $IR_{res-c}$ | Resident Produce Ingestion Rate - child (g/day) | plant-specific | U.S. EPA 2011 (Table 13-10) |
| $IRS_{cw}$ | Construction Worker Soil Ingestion Rate (mg/day) | 330 | U.S. EPA 1991a (pg. 15) |
| $IRS_{far-a}$ | Farmer Soil Ingestion Rate - adult (mg/day) | 100 | U.S. EPA 1991a (pg. 15) |
| $IRS_{far-adj}$ | Farmer Soil Ingestion Rate - age-adjusted (mg/day) | 115 | Calculated using the age-adjusted intake factors equation. |
| $IRS_{far-c}$ | Farmer Soil Ingestion Rate - child (mg/day) | 200 | U.S. EPA 1991a (pg. 15) |
| $IRS_{iw}$ | 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 Ingestion Rate - adult (g/day) | 92.5 | U.S. EPA 2011 (Table 13-51) |
| $IRSW_{far-c}$ | Farmer Swine Ingestion Rate - child (g/day) | 33.7 | U.S. EPA 2011 (Table 13-51) |
| $IRW_{rec-a}$ | Recreator Surface Water Ingestion Rate - adult (L/hour) | 0.071 | Adult upper percentile from Table 3.5 of EFH 2011 |
| $IRW_{rec-c}$ | 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 Rate - 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 Rate - 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 2002 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) |
| $ED_{rec}$ | 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 | $ED_{ress}$ (26 years) - $ED_{ressc}$ (6 years) |
| $ED_{res-c}$ | Resident Exposure Duration - child (years) | 6 | U.S. EPA 1991a, Pages 6 and 15 |
| $EF_{cw}$ | Construction Worker Exposure Frequency (days/year) | 250 | U.S. EPA 2002 Exhibit 5-1 |
| $EF_{far}$ | Farmer Exposure Frequency (days/year) | 350 | U.S. EPA 1991a (pg. 15) |
| $EF_{far-a}$ | Farmer Exposure Frequency - adult (days/year) | 350 | U.S. EPA 1991a (pg. 15) |
| $EF_{far-c}$ | Farmer Exposure Frequency - child (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) |
| $ET_{cw}$ | Construction Worker Exposure Time (hours/day) | 8 | Eight Hours per 24 hour Day |
| $ET_{event-far-a}$ | Farmer Water Exposure Time - adult (hours/event) | 0.71 | U.S. EPA 1997a |
| $ET_{event-far-c}$ | Farmer Water Exposure Time - child (hours/event) | 0.54 | U.S. EPA 1997a |
| $ET_{event-res-c}$ | Resident Tapwater Exposure Time - child (hours/event) | 0.54 | U.S. EPA 1997a |
| $ET_{event-res-c}$ | Resident Tapwater Exposure Time - adult (hours/event) | 0.71 | U.S. EPA 1997a |
| $ET_{far-a}$ | Farmer Exposure Time - adult (hours/day) | 24 | 24 Hours per 24 hour Day |
| $ET_{far-away}$ | Farmer Soil 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$^{th}$%) |
| $ET_{far-c}$ | Farmer Exposure Time - child (hours/day) | 24 | 24 Hours per 24 hour Day |
| $ET_{far-i}$ | Farmer Indoor Soil Exposure Time (hours/day) | 10.008 | 24 hours/day - ($ET_{fo}$ + $ET_{fa}$) |
| $ET_{far-o}$ | Farmer Outdoor Soil Exposure Time (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 | site-specific |
| $ET_{rec-a}$ | Recreator Exposure Time - adult (hours/day) | site-specific | site-specific |
| $ET_{rec-c}$ | Recreator Exposure Time - child (hours/day) | site-specific | site-specific |
| $ET_{res-a}$ | Resident Exposure Time - adult (hours/day) | 24 | 24 Hours per 24 hour Day |
| $ET_{res-c}$ | Resident Exposure Time - child (hours/day) | 24 | 24 Hours per 24 hour Day |
| $ET_{res-i}$ | Resident Indoor Soil Exposure Time (hours/day) | 16.416 | U.S. EPA 2011 (Table 16-16 50$^{th}$%) |
| $ET_{res-o}$ | Resident Outdoor Soil Exposure Time (hours/day) | 1.75 | U.S. EPA 2011 (Table 16-20 50$^{th}$%)) |
| $ET_{w}$ | Composite Worker Exposure Time (hours/day) | 8 | Eight Hours per 24 hour Day |
| $EV_{far-a}$ | Number of farmer tapwater bathing events per day - adult (events/day) | 1 | U.S. EPA 2004 Exhibit A-9 |
| $EV_{far-c}$ | Number of farmer tapwater bathing events per day - child | 1 | U.S. EPA 2004 Exhibit A-9 |

| | | | |
|---|---|---|---|
| | (events/day) | | |
| $EV_{rec-a}$ | Number of recreator surface water bathing events per day - adult (events/day) | site-specific | site-specific |
| $EV_{rec-c}$ | Number of recreator surface water bathing events per day - child (events/day) | site-specific | site-specific |
| $EV_{res-a}$ | Number of resident tapwater bathing events per day - adult (events/day) | 1 | U.S. EPA 2004 Exhibit A-9 |
| $EV_{res-c}$ | Number of resident tapwater bathing events per day - child (events/day) | 1 | U.S. EPA 2004 Exhibit A-9 |
| $EW_{cw}$ | Construction Worker Exposure Frequency (weeks/year) | 50 | U.S. EPA 2002 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. 2002 Equation 4-14 |
| d | mixing zone depth (m) | site-specific | U.S. EPA. 2002 Equation 4-12 |
| $d_a$ | aquifer thickness (m) | site-specific | U.S. EPA. 2002 Equation 4-10 |
| DAF | Dilution attenuation factor (unitless) | 1 (or site-specific) | U.S. EPA. 2002 Equation 4-11 |
| $d_s$ | depth of source (m) | site-specific | U.S. EPA. 2002 Equation 4-10 |
| $ED_{gw}$ | Exposure duration | 70 | U.S. EPA. 2002 Equation 4-14 |
| i | hydraulic gradient (m/m) | site-specific | U.S. EPA. 2002 Equation 4-11 |
| I | Infiltration Rate (m/year) | 0.18 | U.S. EPA. 2002 Equation 4-11 |
| K | aquifer hydraulic conductivity (m/year) | site-specific | U.S. EPA. 2002 Equation 4-11 |
| $K_d$ | soil-water partition coefficient (L/kg) | $= K_{oc}*f_{oc}$ for organics | U.S. EPA. 2002 Equation 4-10 |
| L | source length parallel to ground water flow (m) | site-specific | U.S. EPA. 2002 Equation 4-11 |
| n | total soil porosity($L_{pore}/L_{soil}$) | $= 1-(\rho_b/\rho_s)$ | U.S. EPA. 2002 Equation 4-10 |
| $\theta_a$ | air-filled soil porosity ($L_{air}/L_{soil}$) | $= n-\theta_w$ | U.S. EPA. 2002 Equation 4-10 |
| $\theta_w$ | water-filled soil porosity ($L_{water}/L_{soil}$) | 0.3 | U.S. EPA. 2002 Equation 4-10 |
| $\rho_b$ | dry soil bulk density (kg/L) | 1.5 | U.S. EPA. 2002 Equation 4-10 |
| $\rho_s$ | soil particle density (Kg/L) | 2.65 | U.S. EPA. 2002 Equation 4-10 |

**Wind Particulate Emission Factor Variables**

| Symbol | Definition (units) | Default | Reference |
|---|---|---|---|
| A | Dispersion constant (unitless) | PEF and region-specific | U.S. EPA 2002 Exhibit D-2 |
| $A_s$ | Areal extent of the site or contamination (acres) | 0.5 (range 0.5 to 500 ) | U.S. EPA 2002 Exhibit D-2 |
| B | Dispersion constant (unitless) | PEF and region-specific | U.S. EPA 2002 Exhibit D-2 |
| C | Dispersion constant (unitless) | PEF and region-specific | U.S. EPA 2002 Exhibit D-2 |
| F(x) | Function Dependent on 0.886 × ($U_t/U_m$) (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 2002 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. 2002 Equation 4-5 |
| $PEF_w$ | Particulate Emission Factor - Minneapolis ($m^3$/kg) | $1.36 \times 10^9$(region-specific) | U.S. EPA 2002 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 2002 Equation 5-6 |
| $A_R$ | Surface area of contaminated road segment ($m^2$) | ($A_R = L_R \times W_R \times 0.092903 m^2/ft^2$ ) | U.S. EPA 2002 Equation 5-5 |
| $A_s$ | Areal extent of site surface soil contamination (acres) | 0.5 (range 0.5 to 500 ) | U.S. EPA 2002 Equation 5-6 |
| B | Dispersion constant (unitless) | 5.7383 | U.S. EPA 2002 Equation 5-6 |
| C | Dispersion constant (unitless) | 71.7711 | U.S. EPA 2002 Equation 5-6 |
| $F_D$ | Dispersion correction factor (unitless) | 0.185 | U.S. EPA 2002 Equation 5-5 |
| $L_R$ | Length of road segment (ft) | Site-specific | U.S. EPA 2002 Equation 5-5 |
| p | Number of days with at least 0.01 inches of precipitation (days/year) | Site-specific | U.S. EPA 2002 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 2002 Equation 5-5 |
| T | Total time over which construction occurs (s) | site-specific | U.S. EPA 2002 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 2002 Equation 5-5 |
| $W_R$ | Width of road segment (ft) | 20 | U.S. EPA 2002 Equation E-18 |
| ∑VKT | Sum of fleet vehicle kilometers traveled during the exposure | ∑VKT = total vehicles x | U.S. EPA 2002 Equation 5-5 |

| | | | |
|---|---|---|---|
| | duration (km) | distance (km/day) x frequency (weeks/year) x (days/year) | |
| $PEF_{sc}$ | Particulate Emission Factor - subchronic ($m^3$/kg) | (site-specific) | U.S. EPA 2002 Equation 5-5 |

**Mechanical Particulate Emission Factor Variables from Other Construction Activities**

| Symbol | Definition (units) | Default | Reference |
|---|---|---|---|
| 0.35 | $PM_{10}$ particle size multiplier (unitless) | 0.35 | U.S. EPA 2002 Equation E-21 |
| 0.60 | $PM_{10}$ scaling factor (unitless) | 0.60 | U.S. EPA 2002 Equation E-23 |
| 0.75 | $PM_{10}$ scaling factor (unitless) | 0.75 | U.S. EPA 2002 Equation E-22 |
| A | Dispersion constant (unitless) | 2.4538 | U.S. EPA 2002 Equation E-15 |
| $A_{c\text{-}doz}$ | Areal extent of dozing (acres) | Site-specific | Necessary to solve $\sum VKT_{doz}$ in U.S. EPA 2002 Equation E-22 |
| $A_{c\text{-}till}$ | Areal extent of tilling (acres) | Site-specific | U.S. EPA 2002 Equation E-24 |
| $A_{excav}$ | Areal extent of excavation ($m^2$) | (range 0.5 to 500) | U.S. EPA 2002 Equation E-21 |
| $A_s$ | Areal extent of site surface soil contamination (acres) | (range 0.5 to 500) | U.S. EPA 2002 Equation E-15 |
| $A_{surf}$ | Areal extent of site surface soil contamination ($m^2$) | (range 0.5 to 500) | U.S. EPA 2002 Equation E-20 |
| B | Dispersion constant (unitless) | 17.5660 | U.S. EPA 2002 Equation E-15 |
| $B_d$ | Dozer blade length (m) | Site-specific | U.S. EPA 2002 Page E-28 |
| $B_g$ | Grader blade length (m) | Site-specific | U.S. EPA 2002 Page E-28 |
| C | Dispersion constant (unitless) | 189.0426 | U.S. EPA 2002 Equation E-15 |
| $d_{excav}$ | Average depth of excavation (m) | Site-specific | U.S. EPA 2002 Equation E-21 |
| ED | Exposure duration (years) | Site-specific | U.S. EPA 2002 Equation E-20 |
| F(x) | Function Dependent on 0.886 × ($U_t/U_m$) (unitless) | 0.194 | U.S. EPA. 1996, Appendix D Table 2 |
| $F_D$ | Dispersion correction factor (unitless) | Site-specific | U.S. EPA 2002 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 2002 Equation E-25 |
| $M_{doz}$ | Unit mass emitted from dozing operations (g) | site-specific | U.S. EPA 2002 Equation E-22 |
| $M_{excav}$ | Unit mass emitted from excavation soil dumping (g) | site-specific | U.S. EPA 2002 Equation E-21 |
| $M_{grade}$ | Unit mass emitted from grading operations (g) | site-specific | U.S. EPA 2002 Equation E-23 |
| $M_{m\text{-}doz}$ | Gravimetric soil moisture content (%) | 7.9 (mean value for overburden) | U.S. EPA 2002 Equation E-22 |
| $M_{m\text{-}excav}$ | Gravimetric soil moisture content (%) | 12 (mean value for municipal landfill cover) | U.S. EPA 2002 Equation E-21 |
| $M^{PC}_{wind}$ | Unit mass emitted from wind erosion (g) | site-specific | U.S. EPA 2002 Equation E-20 |
| $M_{till}$ | Unit mass emitted from tilling operations (g) | site-specific | U.S. EPA 2002 Equation E-24 |
| $N_{A\text{-}doz}$ | Number of times site is dozed (unitless) | Site-specific | U.S. EPA 2002 Equation E-22 |
| $N_{A\text{-}dump}$ | Number of times soil is dumped (unitless) | 2 | U.S. EPA 2002 Equation E-21 |
| $N_{A\text{-}grade}$ | Number of times site is graded (unitless) | Site-specific | U.S. EPA 2002 Equation E-23 |
| $N_{A\text{-}till}$ | Number of times soil is tilled (unitless) | 2 | U.S. EPA 2002 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/$m^2$-s per kg/$m^3$) | Site-specific | U.S. EPA 2002 Equation E-15 |
| $S_{doz}$ | Average dozing speed (kph) | 11.4 (mean value for graders) | U.S. EPA 2002 Equation E-22 |
| $s_{doz}$ | Soil silt content (%) | 6.9 | U.S. EPA 2002 Equation E-22 |
| $S_{grade}$ | Average grading speed (kph) | 11.4 (mean value for graders) | U.S. EPA 2002 Equation E-23 |
| $s_{till}$ | Soil silt content (%) | 18 | U.S. EPA 2002 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 2002 Equation E-20 |
| $\rho_{soil}$ | In situ soil density (includes water) (Mg/$m^3$) | 1.68 | U.S. EPA 2002 Equation E-21 |
| $\sum VKT_{doz}$ | Sum of dozing kilometers traveled (km) | Site-specific | U.S. EPA 2002 Equation E-22 |
| $\sum VKT_{grade}$ | Sum of grading kilometers traveled (km) | | U.S. EPA 2002 Equation E-23 |
| $A_{c\text{-}grade}$ | Areal extent of grading (acres) | Site-specific | Necessary to solve $\sum VKT_{grade}$ in U.S. EPA 2002 Equation E-23 |
| $PEF'_{sc}$ | Particulate Emission Factor - subchronic ($m^3$/kg) | (site-specific) | U.S. EPA 2002 Equation E-26 |

## 6. References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