⬡EPA United States
Environmental Protection
Agency

Waste and Cleanup Risk Assessment
Updates to the secular equilibrium options are underway.

Preliminary Remediation Goals for Radionuclides (PRG)

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PRG User's Guide

PDF of User's Guide.

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

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Disclaimer

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

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

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

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

1. Introduction

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

The recommended approach for developing remediation goals is to identify PRGs at scoping, modify them as needed at the end of the RI or during the FS based on site-specific information from the baseline risk assessment, and ultimately select remediation levels in the Record of Decision (ROD). In order to set radionuclide-specific PRGs in a site-specific context, however, assessors must answer fundamental questions about the site. Information on the radionuclides that are present onsite, the specific

contaminated media, land-use assumptions, and the exposure assumptions behind pathways of individual exposure is necessary in order to develop radionuclide-specific PRGs. The PRG calculator provides the ability to modify the standard default PRG exposure parameters to calculate site-specific PRGs.

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

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

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

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

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

In addition to this guidance, for relevant training, see the internet-based course "Radiation Risk Assessment: Updates and Tools."
http://www.epa.gov/superfund/health/contaminants/radiation/radrisk.htm#train

2. Understanding the PRG Website

2.1 General Considerations

PRGs are isotope concentrations that correspond to certain levels of risk in air, soil, water and biota. Slope factors (SFs), for a given radionuclide represent the risk equivalent per unit intake (i.e. , ingestion or inhalation) or external exposure of that radionuclide. In risk assessments these SFs are used in calculations with radionuclide concentrations and exposure assumptions to estimate cancer risk from exposure to radioactive contamination. The calculations may be rearranged to generate PRGs for a specified level of risk. SFs may be specified for specific body organs or tissues of interest, or as a weighted sum of individual organ dose, termed the effective dose equivalent. These SFs may be multiplied by the total activity of each radionuclide inhaled or ingested per year, or the external exposure concentration to which a receptor may be exposed, to estimate the risk to the receptor. Cancer slope factors used are provided by the Center for Radiation Protection Knowledge. The main report is Calculations of Slope Factors and Dose Coefficients and the tables of slope factors are in a separate appendix.

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

The PRGs are generated with standard exposure route equations using EPA SFs and exposure parameters.

2.2 PRG Output Options

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

2.2.1 Assume Secular Equilibrium Throughout the Chain (no decay)

This is the preferred PRG 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 PRGs 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 PRG is now based on secular equilibrium of the full chain. For straight chain decay, all the progeny would be at the same activity of the parent and the PRG provided in the output would be the inverse sum of the reciprocal PRGs of the parent and all the progeny. Currently, all the soil PRG 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 PRG option as the assumption of secular equilibrium is that the parent is continually being renewed.

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

2.2.2 Provide Results for Progeny Throughout Chain (with decay)

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

2.2.3 No Progeny Included (with decay)

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

2.3 Slope Factors (SFs)

EPA classifies all radionuclides as Group A carcinogens ("carcinogenic to humans"). Group A classification is used only when there is sufficient evidence from epidemiologic studies to support a causal association between exposure to the agents and cancer. The appendix radionuclide table, from the Center for Radiation Protection Knowledge, lists ingestion, inhalation and external exposure cancer slope factors (risk coefficients for total cancer morbidity) for radionuclides in conventional units of picocuries (pCi). Ingestion and inhalation slope factors are central estimates in a linear model of the age-averaged, lifetime attributable radiation cancer incidence (fatal and nonfatal cancer) risk per unit of activity inhaled or ingested, expressed as risk/pCi. External exposure slope factors are central estimates of lifetime attributable radiation cancer incidence risk for each year of exposure to external radiation from photon-emitting radionuclides distributed uniformly in a thick layer of soil, and are expressed as risk/yr per pCi/gram soil. External exposure slope factors can also be used which have units of risk/yr per pCi/cm^2 soil. When combined with site-specific media concentration data and appropriate exposure assumptions, slope factors can be used to estimate lifetime cancer risks to members of the general population due to radionuclide exposures. EPA currently provides guidance on inhalation risk assessment in RAGS Part F (Risk Assessment Guidance for Superfund Volume I: Human Health Evaluation Manual (Part F, Supplemental Guidance for Inhalation Risk Assessment). This guidance only addresses chemicals. The development of inhalation slope factors for radionuclides differs from the guidance presented in RAGS Part F for development of inhalation unit risk (IUR) values for chemicals.

The SFs from the Center for Radiation Protection Knowledge differ from the values presented in HEAST. The SFs were calculated using ORNL's DCAL software in the manner of Federal Guidance Report 12 and 13. 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 Metastable Isotopes

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

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

2.4 Radionuclide-Specific Parameters

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

2.4.1 Sources

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

1. IAEA TRS 472 (IAEA). Handbook of Parameter Values for the Prediction of Radionuclide Transfer in Terrestrial and Freshwater Environments. Technical Reports Series No. 472. International Atomic Energy Agency, Vienna. 2010. (IAEA TRS 364. Handbook of Parameter Values for the Prediction of Radionuclide Transfer in Temperate Environments (Technical Reports Series No. 364), 1994 was used to supplement egg, poultry and swine transfer factors.) Spreadsheet of values.

2. Environment Agency (EA). Initial radiological assessment methodology - part 2 methods and input data. Spreadsheet of values.

3. NCRP 123 (NCRP). NCRP Report No. 123, Screening Models for Releases of Radionuclides to the Atmosphere, Surface Water, and Ground. National Council on Radiation Protection and Measurements. January 22, 1996. Spreadsheet of values.

4. EPA Radionuclide Soil Screening Level (SSL). Soil Screening Guidance for Radionuclides: User's Guide. Office of Solid Waste and Emergency Response (OSWER) Directive 9355.4-16A. October 2000. Spreadsheet of values.

5. RESRAD. User's Manual for RESRAD Version 6. Environmental Assessment Division, Argonne National Laboratory. July 2001. Spreadsheet of values.

6. BAES. A Review and Analysis of Parameters for Assessing Transport of Environmentally Released Radionuclides through Agriculture. C. F. Baes III, R. D. Sharp, A. L. Sjoreen, R.W. Shor. Oak Ridge National Laboratory 1984. Spreadsheet of values.

7. ICRP 107. Nuclear Decay Data for Dosimetric Calculations. International Commission on Radiological Protection Publication 107. Ann. ICRP 38 (3), 2008.

8. EPAKD. Understanding Variation in Partition Coefficient, 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, BAES. 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, BAES. 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$_{po}$ (day/kg). IAEA, EA, RESRAD. TF$_{po}$ 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, EA, RESRAD. 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$_{sw}$ (day/kg). IAEA, EA, RESRAD. TF$_{sw}$ 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$_{dairy}$ (day/L). IAEA, NCRP, RESRAD, BAES. 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$_{beef}$ (day/kg). IAEA, EA, NCRP, RESRAD, BAES. 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$_{dairy}$ (day/L). IAEA, NCRP, RESRAD, BAES. 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$_{beef}$ (day/kg). IAEA, NCRP, RESRAD, BAES. 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 PRGs that make up the default produce PRG. Each individual PRG 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 PRGs are then summed by inverse reciprocal to determine a total produce PRG. The MLFs and intake rates used in the determination of the default biota PRGs are based on fresh weight. Intake rates, MLFs, and tranfer factors were updated in July 2016. A pdf of the Technical Memorandum, released for this update, can be found here. This file is engineered for 2 sided printing.

2.5.1.1 Intake Rates (g/day)

Table 2.4.1-A provides all of the default produce intake rates that are used to determine the total produce PRG. The delineation of (FW) in the column header indicates that the intake rates are for fresh weight, these are the intake rates used when the tool is run in default mode. In site-specific mode, the user may choose between Fresh Weight (FW) or Cooked Weight (CPW), which takes cooking and 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 2.4.1-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. In addition, a local food survey can be

conducted. Much of the methodology in the Guidance for Conducting Fish and Wildlife Consumption Surveys may be useful for surveying produce consumption.

Table 2.4.1-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

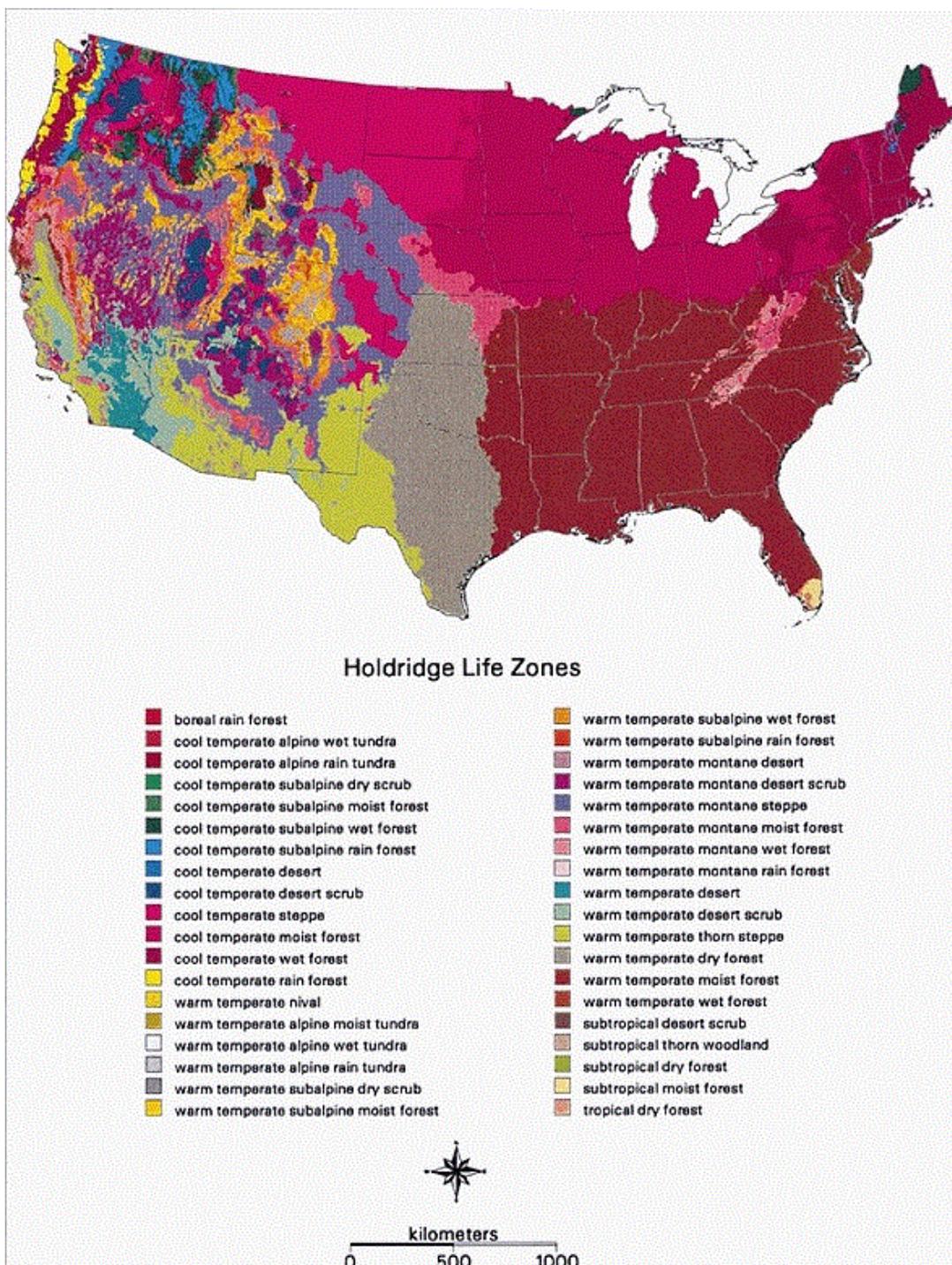| Table 2.4.1-B	Intake Rate for Farmer Child (g/day) (DW)	Intake Rate for Farmer Adult (g/day) (DW)	Intake Rate for Resident Child (g/day) (DW)	Intake Rate for Resident Adult (g/day) (DW)
Rice	34.8	88.5	28.8	73.2
Cereal Grain	46.0	91.9	38.0	76.0

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.

Holdridge Life Zones

■ boreal rain forest		■ warm temperate subalpine wet forest	
■ cool temperate alpine wet tundra		■ warm temperate subalpine rain forest	
■ cool temperate alpine rain tundra		■ warm temperate montane desert	
■ cool temperate subalpine dry scrub		■ warm temperate montane desert scrub	
■ cool temperate subalpine moist forest		■ warm temperate montane steppe	
■ cool temperate subalpine wet forest		■ warm temperate montane moist forest	
■ cool temperate subalpine rain forest		■ warm temperate montane wet forest	
■ cool temperate desert		■ warm temperate montane rain forest	
■ cool temperate desert scrub		■ warm temperate desert	
■ cool temperate steppe		■ warm temperate desert scrub	
■ cool temperate moist forest		■ warm temperate thorn steppe	
■ cool temperate wet forest		■ warm temperate dry forest	
■ cool temperate rain forest		■ warm temperate moist forest	
■ warm temperate nival		■ warm temperate wet forest	
■ warm temperate alpine moist tundra		■ subtropical desert scrub	
■ warm temperate alpine wet tundra		■ subtropical thorn woodland	
■ warm temperate alpine rain tundra		■ subtropical dry forest	
■ warm temperate subalpine dry scrub		■ subtropical moist forest	
■ warm temperate subalpine moist forest		■ tropical dry forest	

kilometers

0   500   1000

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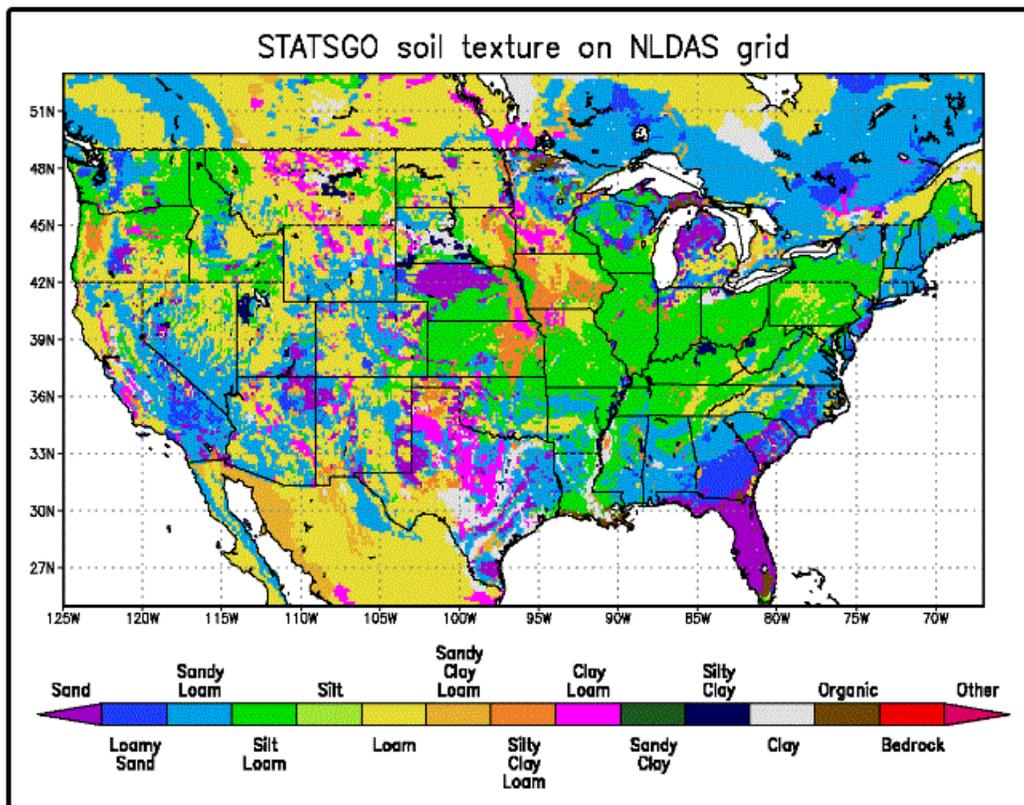
Soil Types

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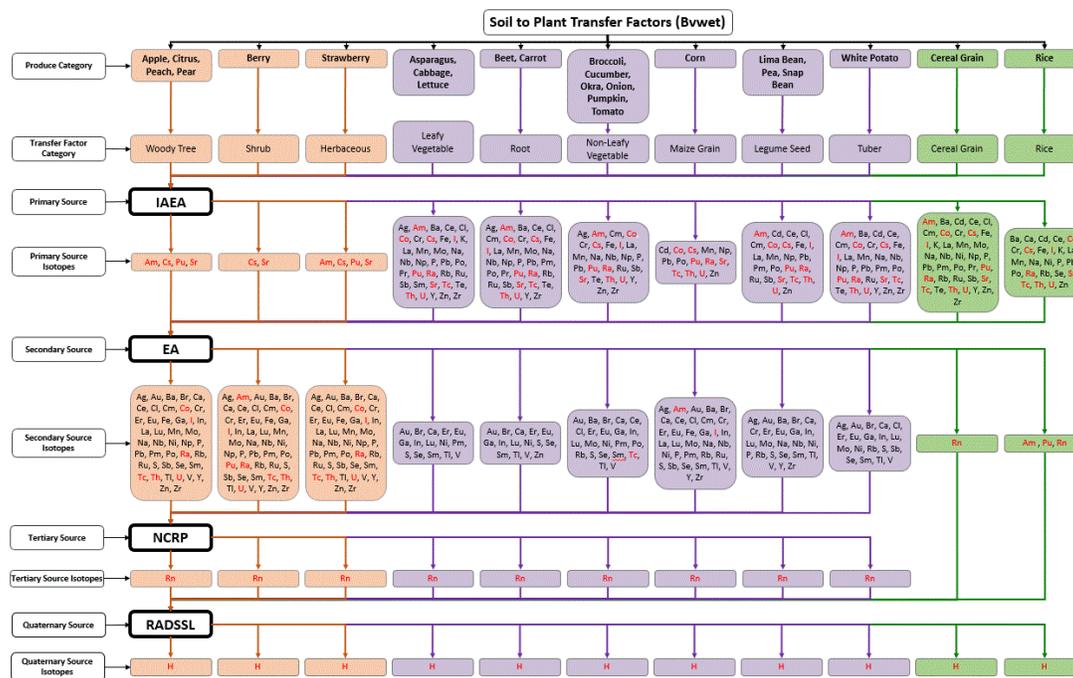
- The red text elements are on the from the 'Common Isotopes' list on the calculator page.

• 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 PRG calculator.

2.5.2 Animal Product Modeling

In default mode, the (FW) intake rates from Table 2.4.2-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 2.4.2-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 2.4.2-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 2.4.2-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

2.5.3 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 2.4.3-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 PRGs in Context of Superfund Modeling Framework

This PRG calculator focuses on the application of generic and simple site-specific approaches that are part of a larger framework for calculating concentration levels for complying with risk-based criteria. Generic PRGs for a 1 × 10⁻⁶ cancer risk standard are provided by viewing either the tables in the PRG Download Area section of this calculator or by running the PRG Calculator section of this website with the "Defaults" option. Part 3 of the Soil Screening Guidance for Radionuclides: Technical Background Document provides more information about 5 more detailed soil to groundwater models that are part of the same framework.

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

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

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

2.7 Understanding Risk Output on the PRG Website

The PRG calculator provides an option to select risk output. In the calculator, select yes if risk output is desired. Selecting risk output requires the calculator to be run in "Site Specific" mode. The "Soil to Groundwater" medium does not have risk output and the risk option will become disabled when selected. The risk values presented on this site are radionuclide-specific values for individual contaminants in air, water, soil and biota that may warrant further investigation or site cleanup.

2.7.1 General Considerations for the Risk Output

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

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

TR / PRG = Risk / C

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

Risk = (C × TR) / PRG

where:

Risk = a unitless probability of an individual developing cancer over a lifetime, determined with the equation above;

C = Concentration entered by the user in site-specific mode [pCi/g ; pCi/cm^2 ; pCi/m^3 ; pCi/L]

TR = Target Risk provided by the user in site-specific mode

PRG = Preliminary Remediation Goal, 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 One-Hit Rule

The linear risk equation, listed above, are valid only at low risk levels (below estimated risks of 0.01). For sites where radiological exposure might be high (estimated risks above 0.01, an alternate calculation should be used. The one-hit equation, which is consistent with the linear low-dose model, should be used instead (RAGS, part A, ch. 8). The results presented on the PRG use this rule. In the following instances, the one-hit rule is used independently in the risk output tables:

• Risk from a single exposure route for a single radionuclide.

• Summation of single radionuclide risk (without one-hit rule applied to single radionuclide results) for multiple exposure routes (right of each row).

• Summation of risk (without one-hit rule applied to single radionuclide results) from a single exposure route for multiple radionuclides (bottom of each column).

• Summation of total risk (without one-hit rule applied to single radionuclide results or summations listed above) from multiple radionuclides across multiple exposure routes (bottom right hand cell).
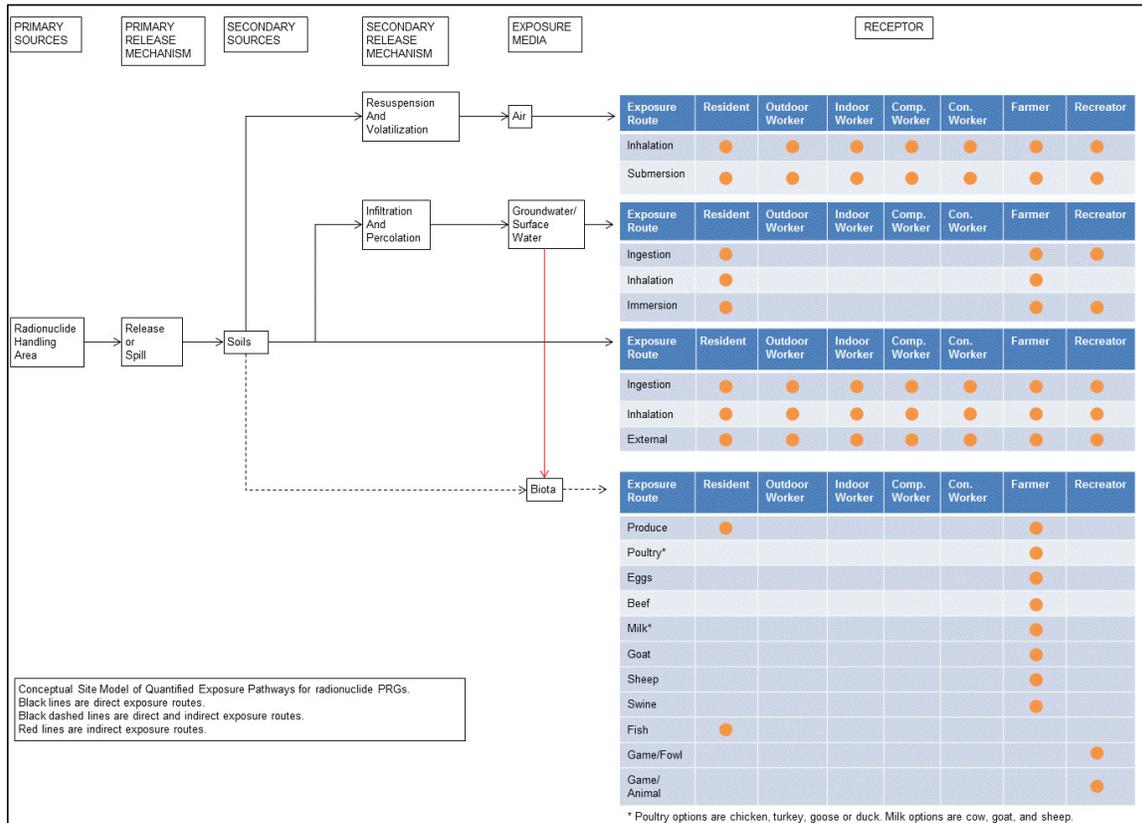
3. Using the PRG Table

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

• Prioritizing multiple sites within a facility or exposure units

• Prioritizing risk-based detection limits for contaminants of potential concern (COPCs)

• Focusing future risk assessment efforts

• When appropriate for the site, consideration as risk-based cleanup levels

3.1 Developing a Conceptual Site Model

When using PRGs, the exposure pathways of concern and site conditions should match those taken into account by the screening levels. (Note, however, that future uses may not match current uses. Future uses of a site should be logical as conditions which might occur at the site in the future.) Thus, it is necessary to develop a conceptual site model (CSM) to identify likely contaminant source areas, exposure pathways, and potential receptors. This information can be used to determine the applicability of screening levels at the site and the need for additional information. The final CSM diagram represents linkages among contaminant sources, release mechanisms, exposure pathways, and routes and receptors based on historical information. It summarizes the understanding of the contamination problem. A separate CSM for ecological receptors can be useful. Part 2 and Attachment A of the Soil Screening Guidance for Radionuclides: Users Guide (EPA 2000a) contains the steps for developing a CSM.

A conceptual site model for the land uses presented in this calculator is presented below.

Exposure Route	Resident	Outdoor Worker	Indoor Worker	Comp. Worker	Con. Worker	Farmer	Recreator
Inhalation	●	●	●	●	●	●	●
Submersion	●	●	●	●	●	●	●

Exposure Route	Resident	Outdoor Worker	Indoor Worker	Comp. Worker	Con. Worker	Farmer	Recreator
Ingestion	●					●	●
Inhalation	●					●	
Immersion	●					●	●

Exposure Route	Resident	Outdoor Worker	Indoor Worker	Comp. Worker	Con. Worker	Farmer	Recreator
Ingestion	●	●	●	●	●	●	●
Inhalation	●	●	●	●	●	●	●
External	●	●	●	●	●	●	●

Exposure Route	Resident	Outdoor Worker	Indoor Worker	Comp. Worker	Con. Worker	Farmer	Recreator
Produce	●					●	
Poultry*						●	
Eggs						●	
Beef						●	
Milk*						●	
Goat						●	
Sheep						●	
Swine						●	
Fish	●						
Game/Fowl							●
Game/Animal							●

Conceptual Site Model of Quantified Exposure Pathways for radionuclide PRGs.
Black lines are direct exposure routes.
Black dashed lines are direct and indirect exposure routes.
Red lines are indirect exposure routes.

* Poultry options are chicken, turkey, goose or duck. Milk options are cow, goat, and sheep.

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

• Are there potential ecological concerns?

• Is there potential for land use other than those listed in the PRG calculator (i.e. , resident and worker)?

• Are there other likely human exposure pathways that were not considered in development of the PRGs?

• Are there unusual site conditions (e.g. large areas of contamination, high fugitive dust levels, potential for indoor air contamination)?

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

3.2 Background Radiation

Natural background radiation should be considered prior to applying PRGs as cleanup levels. Background and site-related levels of radiation will be addressed as they are for other contaminants at CERCLA sites, for further information see EPA's guidance "Role of Background in the CERCLA Cleanup Program", April 2002, (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 risk-based tool, the potential exists for misapplication. In most cases, this results from not understanding the intended use of the PRGs. In order to prevent misuse of the PRGs, the following should be avoided:

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

• Use of PRG levels as cleanup levels without the consideration of other relevant criteria such as ARARs,

• Use of PRG levels as cleanup levels without verifying numbers with a health physicist/risk assessor.

• Use of outdated PRG levels tables that have been superseded by more recent publications.

• Not considering the effects from the presence of multiple isotopes.

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

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

- Risk Assessment Guidance for Superfund: Volume I, Human Health Evaluation Manual (Part B, Development of Risk-based Preliminary Remediation Goals) (RAGS Part B).
- U.S. EPA. 2005. Human Health Risk Assessment Protocol for Hazardous Waste Combustion Facilities. Washington, DC. OSWER No. 5305W. EPA530-R-05-006
- U.S. EPA. 2000a. Soil Screening Guidance for Radionuclides: User's Guide. Office of Emergency and Remedial Response and Office of Radiation and Indoor Air. Washington, DC. OSWER No. 9355.4-16A EPA/540-R-00-007
- U.S. EPA. 2000b. Soil Screening Guidance for Radionuclides: Technical Background Document. Office of Emergency and Remedial Response and Office of Radiation and Indoor Air. Washington, DC. OSWER No. 9355.4-16
- U.S. EPA 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
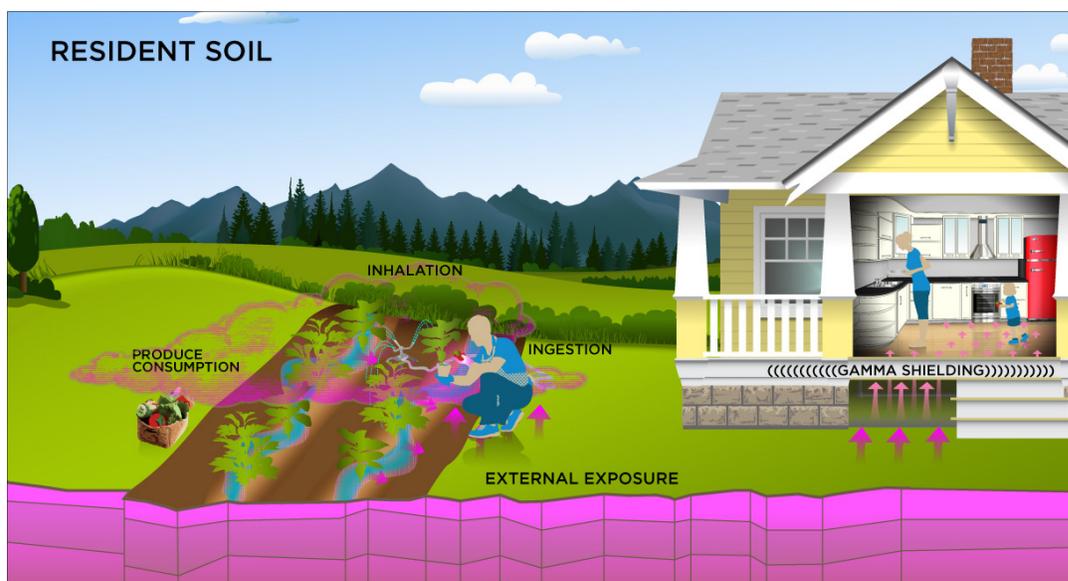
Equations

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

• incidental ingestion of soil,

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

where:

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

• inhalation of particulates emitted from soil,

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

where:

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

• external exposure to ionizing radiation, and

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

• 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.

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

where:

n = total number of produce items included

and:

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

where:

$$R_{upv} = Bv_{wet} \quad ; \quad R_{es} = MLF_{produce}$$

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

where:

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

where:

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

$$\left[\left[EF_{res\text{-}a}\left(\frac{350 \text{ days}}{year}\right)\times ED_{res\text{-}a}\,(20 \text{ years})\times IR_{res\text{-}a}\left(\frac{g}{day}\right)\right]\right]_{total}$$

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

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

RESIDENT SOIL 2-D EXTERNAL EXPOSURE
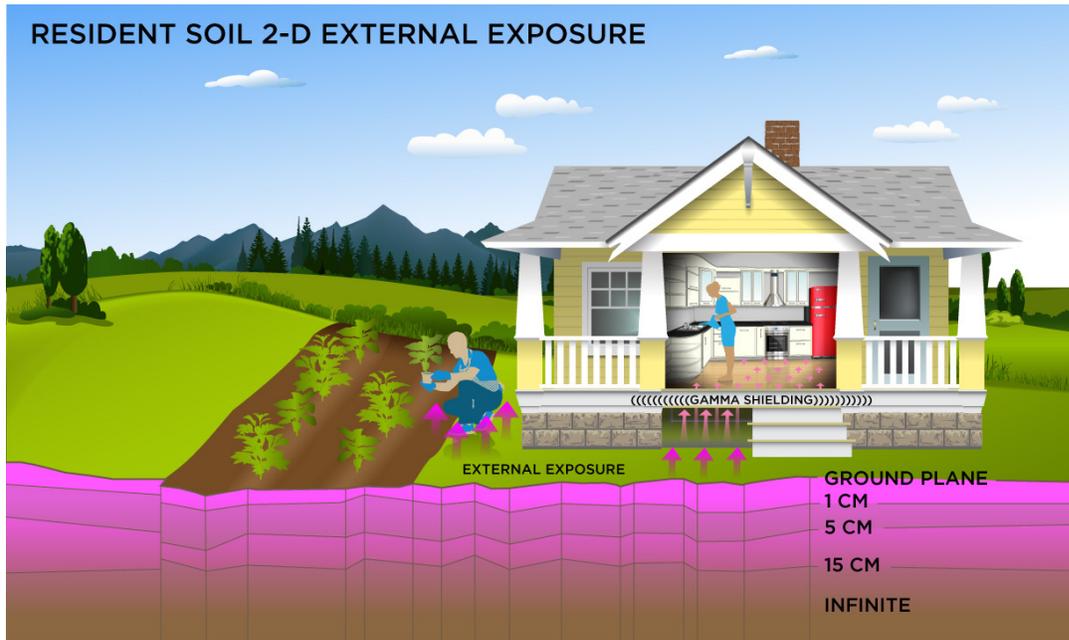
Equations

• Direct External Exposure to contamination at infinite depth

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

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

• Direct External Exposure to contamination 1 cm thick

$$PRG_{res\text{-}soil\text{-}1cm}\,(pCi/g)=\cfrac{TR\times t_{res}\,(year)\times\lambda\left(\frac{1}{year}\right)}{\left(1-e^{-\lambda t_{res}}\right)\times SF_{ext\text{-}1cm}\left(\frac{risk/year}{pCi/g}\right)\times EF_{res}\left(\frac{350 \text{ days}}{year}\right)\times\left(\frac{1 \text{ year}}{365 \text{ days}}\right)\times ED_{res}\,(26 \text{ years})\times ACF_{ext\text{-}1cm}\times\left[\left(ET\quad\left(\frac{1.752 \text{ hours}}{day}\right)\times\left(\frac{1 \text{ day}}{\quad}\right)\times GSF\right)+\left(ET\quad\left(\frac{16.416 \text{ hours}}{day}\right)\times\left(\frac{1 \text{ day}}{\quad}\right)\times GSF\right)\right]}$$

$$\left[\left(\ldots_{res-o}\left(\frac{}{day}\right)\right)\left(\frac{}{24\ hours}\right)\cdots_{o-ext-1cm}\right]\cdot\left(\ldots_{res-i}\left(\frac{}{day}\right)\right)\left(\frac{}{24\ hours}\right)\cdots_{i-total}\right)\right]$$

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

- Direct External Exposure to contamination 5 cm thick

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

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

- Direct External Exposure to contamination 15 cm thick

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

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

- Direct External Exposure to surface contamination

$$PRG_{res\text{-}soil\text{-}gp}(pCi/cm^2) = \frac{TR \times t_{res}\,(year) \times \lambda\left(\frac{1}{year}\right)}{\left(1-e^{-\lambda t_{res}}\right) \times SF_{ext\text{-}gp}\left(\frac{risk/year}{pCi/cm^2}\right) \times EF_{res}\left(\frac{350\ days}{year}\right) \times \left(\frac{1\ year}{365\ days}\right) \times ED_{res}\,(26\ years) \times ACF_{ext\text{-}gp} \times}$$
$$\left[\left(ET_{res\text{-}o}\left(\frac{1.752\ hours}{day}\right) \times \left(\frac{1\ day}{24\ hours}\right) \times GSF_{o\text{-}ext\text{-}gp}\right) + \left(ET_{res\text{-}i}\left(\frac{16.416\ hours}{day}\right) \times \left(\frac{1\ day}{24\ hours}\right) \times GSF_{i\text{-}total}\right)\right]$$

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

Definitions of the input variables are in Table 1.

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

$$PRG_{res-air-inh-decay}\left(pCi/m^3\right) = \frac{TR \times t_{res}\left(year\right) \times \lambda\left(\frac{1}{year}\right)}{\left(1-e^{-\lambda t_{res}}\right) \times SF_i\left(\frac{risk}{pCi}\right) \times IFA_{res-adj}\left(161{,}000\ m^3\right)}$$

where:

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

- external exposure to ionizing radiation

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

- total

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

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

- inhalation and

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

where:

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

- external exposure to ionizing radiation

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

- total

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

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, Ra-226, Rn-220, and Rn-222 which volatilize. External exposure to immersion in tapwater and exposure to produce irrigated with contaminated tapwater are also considered.

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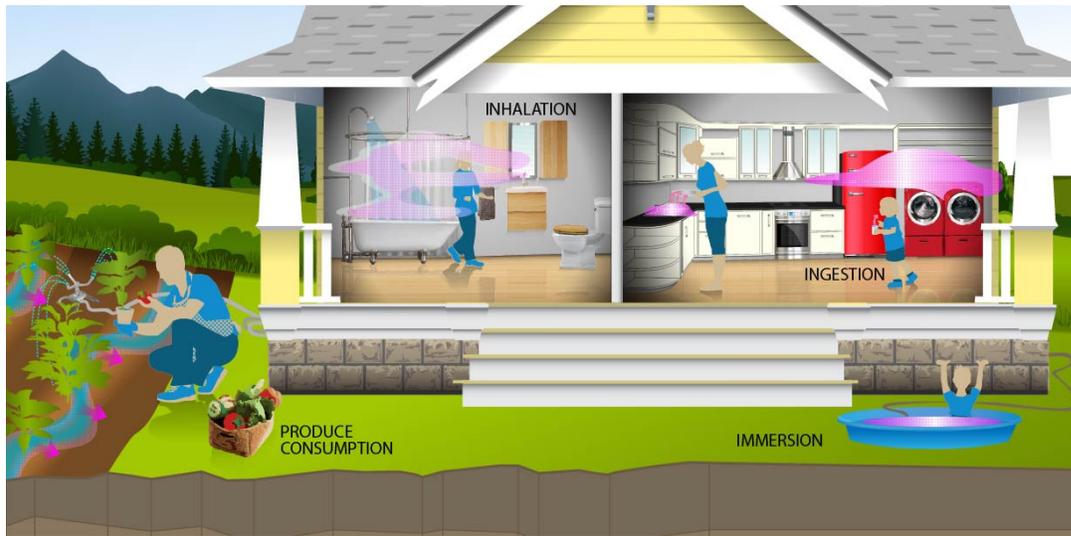
$$PRG_{water\text{-}ing}\left(pCi/L\right) = \dfrac{TR}{SF_w\left(\frac{risk}{pCi}\right) \times IFW_{res\text{-}adj}\left(19{,}138\ L\right)}$$

where:

$$IFW_{res\text{-}adj}\left(19{,}138\ L\right) = \begin{pmatrix} \left(EF_{res\text{-}c}\left(\dfrac{350\ days}{year}\right) \times ED_{res\text{-}c}\left(6\ years\right) \times IRW_{res\text{-}c}\left(\dfrac{0.78\ L}{day}\right)\right) + \\[2ex] \left(EF_{res\text{-}a}\left(\dfrac{350\ days}{year}\right) \times ED_{res\text{-}a}\left(20\ years\right) \times IRW_{res\text{-}a}\left(\dfrac{2.5\ L}{day}\right)\right) \end{pmatrix}$$

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

where:

$$IFA_{res\text{-}adj}\left(161{,}100\ m^3\right) = \begin{pmatrix} \left(EF_{res\text{-}c}\left(\dfrac{350\ days}{year}\right) \times ED_{res\text{-}c}\left(6\ years\right) \times ET_{res\text{-}c}\left(\dfrac{24\ hours}{day}\right) \times \left(\dfrac{1\ day}{24\ hours}\right) \times IRA_{res\text{-}c}\left(\dfrac{10\ m^3}{day}\right)\right) + \\[2ex] \left(EF_{res\text{-}a}\left(\dfrac{350\ days}{year}\right) \times ED_{res\text{-}a}\left(20\ years\right) \times ET_{res\text{-}a}\left(\dfrac{24\ hours}{day}\right) \times \left(\dfrac{1\ day}{24\ hours}\right) \times IRA_{res\text{-}a}\left(\dfrac{20\ m^3}{day}\right)\right) \end{pmatrix}$$

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

where:

$$DFA_{res\text{-}adj}\left(6104\ hours\right) = \begin{pmatrix} \left(EF_{res\text{-}c}\left(\dfrac{350\ days}{year}\right) \times ED_{res\text{-}c}\left(6\ years\right) \times EV_{res\text{-}c}\left(\dfrac{1\ event}{day}\right) \times ET_{event\text{-}res\text{-}c}\left(\dfrac{0.54\ hours}{event}\right)\right) + \\[2ex] \left(EF_{res\text{-}a}\left(\dfrac{350\ days}{year}\right) \times ED_{res\text{-}a}\left(20\ years\right) \times EV_{res\text{-}a}\left(\dfrac{1\ event}{day}\right) \times ET_{event\text{-}res\text{-}a}\left(\dfrac{0.71\ hours}{event}\right)\right) \end{pmatrix}$$

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

where:
  n = total number of produce items included

and:

$$PRG_{water\text{-}res\text{-}produce\text{-}ing}\left(pCi/L\right) = \dfrac{PRG_{res\text{-}produce\text{-}ing}\left(pCi/g\right)}{\left(\dfrac{1\ kg}{\ }\right)\left(\ \left(\dfrac{L}{\ }\right)+\left(\dfrac{L}{\ }\right)+\left(\dfrac{L}{\ }\right)\right)}$$

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ERROR: stackunderflow
OFFENDING COMMAND: ~

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