SDCC User's Guide

SDCCs for Radionuclides

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PDF of User's Guide.

Welcome to the EPA's "Dose Compliance Concentrations for Radionuclides in Outdoor Surfaces at Superfund Sites" (SDCC) user's guide. This guide includes descriptions, equations and default exposure parameters used to calculate the dose-based SDCCs. Additional guidance is also provided on sources of parameters and proper SDCC use. It is suggested that users read the SDCC 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, if 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 SDCC 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) to 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 SDCC addresses neither human cancer risk, 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 DCC Calculator should be used to assess radionuclide dose in soil, water, and air 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 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.

1. Introduction

Generally, these recommended Dose Compliance Concentrations for Radionuclides in outdoor surfaces (SDCCs) are reasonable maximum exposure (RME) concentrations derived from standardized equations that combine exposure information and toxicity information in the form of dose conversion factors (DCFs). Recommended SDCCs are presented for resident and worker exposure.

The intent of this calculator is to address hard outside surfaces, such as building slabs, outside building walls, sidewalks, and roads.

The U.S. Environmental Protection Agency developed the SDCC tool to help standardize the evaluation and cleanup of radioactively contaminated sites where doses are being assessed. This guidance provides a methodology for radiation professionals to calculate dose-based, site-specific, dose compliance concentrations (SDCCs) for radionuclides in outdoor hard surfaces while 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/yr to the whole body and 75 mrem/yr to any critical organ (including the thyroid). Another set of standards consists of a single limit (e.g., 10 mrem/yr). The type of dose limit used in the standard would be the same dose methodology used for conducting dose assessment to demonstrate ARAR compliance.

The approach to dose limitation and the methods used to calculate doses have evolved over time. 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.

Later, standards were 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). While similar to the effective dose equivalent approach, the effective dose quantity incorporates updated scientific information in the dose conversion factors. Effective dose quantity incorporates a greater number of organs, updated information on organ-specific risk, and age-specific dose coefficients for internal exposure that incorporate new physiologically-based biokinetic models.

ICRP Publication 107 (ICRP 2008) provides an electronic database of the physical data for 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 to guide EPA personnel in calculating 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 RPMs in making decisions at these sites.

Note: 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: https://www.epa.gov/superfund/radiation-superfund-sites

This website combines current EPA DCFs with “standard” exposure factors to estimate contaminant concentrations inside buildings that attain compliance with a dose-based ARAR. Exceeding a SDCC usually suggests that further evaluation of the potential dose is appropriate. The SDCC concentrations presented on this website can be used to screen pollutants in hard surfaces, trigger further investigation, and provide initial cleanup goals, if applicable. SDCCs should be applied in accordance with guidance from EPA Regions.

2. Understanding the SDCC Website

2.1 General Considerations

SDCCs are isotope concentrations that correspond to certain levels of risk in dust, streets, sidewalks, finite slabs and building materials. 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 SDCCs 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 risk 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 slope factor value tabulated in the Radionuclide Table for each radionuclide has been selected based on the following guidelines: (1) For those elements where Table 4.1 of Federal Guidance Report No. 13 (and Table 2 of ICRP Publication 72) specifies a recommended default lung absorption type for particulates, the inhalation slope factor for that type is tabulated in the Radionuclide Table for each radioisotope of that element; (2) For those elements where no specific lung absorption type is recommended and multiple types are indicated as plausible choices, the inhalation slope factor reported in the Radionuclide Table for each radioisotope of that element is the maximum of the values for each of the plausible lung absorption types; and (3) If Federal Guidance Report No. 13 specifies risk coefficients for multiple chemical forms of certain elements (tritium, carbon, sulfur, iodine, and mercury), the inhalation slope factor value for the form estimated to pose the maximum risk is reported in the Radionuclide Table, in most cases.

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

The most likely exposure scenarios and exposure assumptions are included in the equations on this website: Resident, Composite Worker, Outdoor Worker and Indoor Worker.

The recommended SDCCs are generated with standard exposure route equations using EPA DCFs and exposure parameters. For the calculation of oral dose coefficients and area correction factors, a standard soil density of 1.6 g/cm^3 has been used.

2.2 SDCC Output Options

The calculator offers three options for calculating SDCCs. 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 SDCC calculation.

2.2.1 SDCC Output Option #1: Assumes Secular Equilibrium Throughout the Chain (no decay - parent and progeny in constant equilibrium)

This is the preferred SDCC 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 SDCCs 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 SDCC 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 SDCC provided in the output would be the inverse sum of the reciprocal SDCCs of the parent and all the progeny. Currently, all the soil SDCC 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 SDCC option as the assumption of secular equilibrium is that the parent is continually being renewed.

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

- A total SDCC is calculated using the following formula.

Total secular equilibrium SDCC for parent isotope;

$$SDCC_{SE\text{-}tot} = \frac{1}{\left(\sum_{i=1}^{n} \frac{1}{SDCC_{SE\text{-}route_i}}\right)}$$

where:

n = total number of exposure routes;

Route secular equilibrium SDCC for parent isotope:

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

where:

n = total number of isotopes in decay chain;

FC = fractional contribution of isotope in decay chain;

SDCC = SDCC for isotope in decay chain without decay.

2.2.2 SDCC Output Option #2: Does Not Assume Secular Equilibrium, Provides Results for Progeny Throughout Chain (with decay where appropriate)

This option displays the SDCCs calculated with half-life decay as identified in the SDCC equation images. In addition to the selected isotope, all the individual progeny SDCCs are displayed. Each SDCC is determined with each isotope's respective half-life and not that of its parent isotope. This option does not assume secular equilibrium and presents all the individual progeny SDCCs, so that the risk assessor can identify any isotopes that will be present and those that have no data. Users can alter progeny half-life to match the parent isotope or other progeny or to account for ingrowth and decay over a chain.

2.2.3 SDCC Output Option #3: Does Not Assume Secular Equilibrium, Selected Isotopes Only (with decay where appropriate)

This option displays SDCCs, with half-life decay as identified in the SDCC equation images, for only the selected isotopes. In this output, secular equilibrium is not assumed, progeny SDCCs are not displayed, and progeny contribution is not combined into the SDCC for the selected isotope. This option is useful when contamination is from one radionuclide with a very long half-life, where secular equilibrium would be too conservative.

2.3 Dose Conversion Factors (DCFs)

Users 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). 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 that 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 DCF per se, ICRP 30 does present DCFs that 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 that have specific weighting factors, namely the gonads, breast, red marrow, lungs, thyroid, and bone surfaces. Organ DCFs are also given for the remainder, which include the five remaining tissues that 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. Most of the world's radiation standards are based on this document. ICRP 60 is similar to ICRP 30, except it is based on more recent findings. ICRP 60 risk estimates increased due to cancers in Japanese populations exposed to radiation from World War II bombings. There were also reevaluations of the radiation dose calculations. These values are also presented in Federal Guidance Report No. 13.

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

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 to use ICRP 68 dosimetric data for occupational exposure. Non-regulatory studies (e.g., risk 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 for 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 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 allows users to 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.

2.3.7 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 min and 96 min, respectively, and the energy emitted per decay is 1.30 MeV, 0.080 MeV, and 0.14 MeV, respectively.

2.4 SDCC in Context of Superfund Modeling Framework

This SDCC calculator focuses on the application of a generic and simple site-specific approach that is part of a larger framework for calculating concentration levels for complying with dose-based ARARs. Generic SDCCs for a 1 mrem/year standard are provided in the Download Area tables or by running the SDCC Search with the "Get Default ARAR Concentrations" option.

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

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 site-specific reason to use another model, then justification should be provided in the administrative record, including specific supporting data and information. The justification would normally include the model runs, using both the recommended EPA SDCC model and the alternative model. Users are cautioned that they should have a thorough understanding of both the SDCC 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 SDCC 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 SDCC 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).

2.5 Understanding Dose Output on the DCC Website

The SDCC calculator provides an option to select dose output. Selecting dose output requires the calculator to be run in "Site Specific" mode. 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.

2.5.1 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, an SDCC, the dose limit used to calculate the SDCC, and a concentration entered by the user are all that is required to calculate dose.

$$DL / SDCC = Dose / C$$

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

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

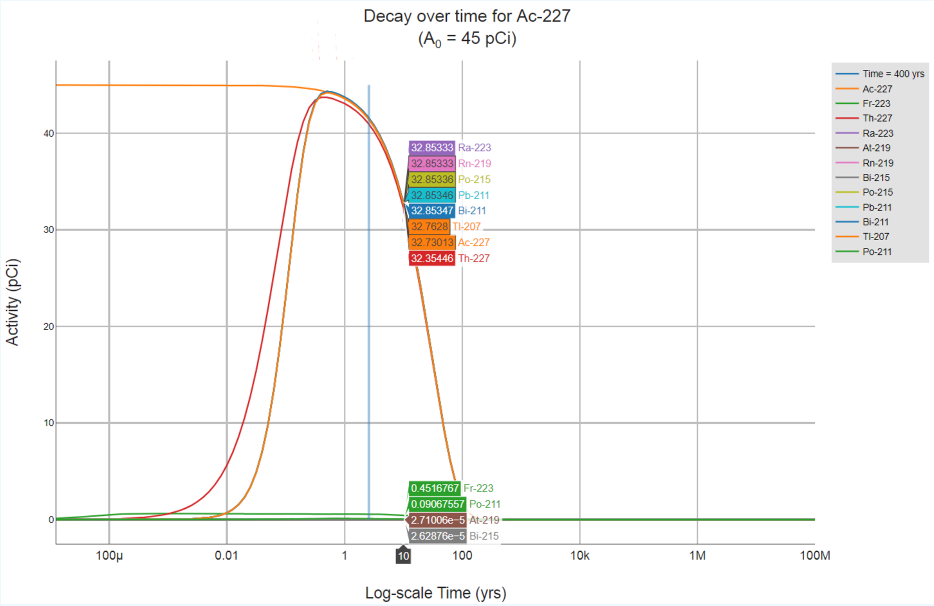
where:

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]
SDCC = Surfaces Dose Compliance Concentration, determined by the values entered by the user in site-specific mode [pCi/g ; pCi/m^3]

2.5.2 General Considerations for Entering Site Data

As presented in the previous section, the dose output is dependent on the SDCC calculated. Section 2.2 discusses the SDCC output options. To summarize section 2.2, the SDCC 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 only enters 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 SDCC calculator to calculate dose using the second and third SDCC Output options.



3. Using the SDCC Table

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

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

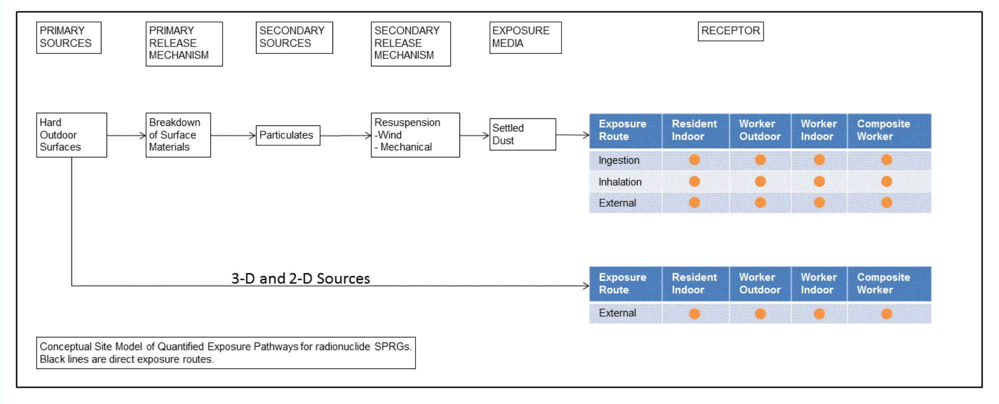
3.1 Developing a Conceptual Site Model

When using SDCCs, 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 and represent conditions that might occur at the site in the future.) Thus, it generally 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 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 (U.S. EPA 2000a) contains the recommended steps for developing a CSM.

Existing EPA documents with additional CSM guidance are:

1. Risk Assessment Guidance for Superfund: Volume I Human Health Evaluation Manual (Part D, Standardized Planning, Reporting, and Review of Superfund Risk Assessments). See Planning Table 1; and
2. Soil Screening Guidance for Radionuclides: User's Guide. See Attachment A.

CSMs can be tabular, graphical or stem-and-leaf. Section 4 of the user guide presents links to graphical CSMs for each scenario. Below is a stem-and-leaf CSM showing the exposure routes quantified and not quantified in this calculator.



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

- Are there potential ecological concerns?
- Is there potential for land use other than those listed in the SDCC calculator (e.g., recreational, agricultural or trespasser)?
- Are there other likely human exposure pathways that were not considered in development of the SDCCs?
- Are there unusual site conditions (e.g., large areas of contamination, high fugitive dust levels, potential for indoor air

contamination)?

The SDCCs may need to be adjusted to reflect the answers to these questions, and additional tools or assessment methodologies may need to be considered (e.g., if there may be potentially significant ecological risk). The recommended default scenarios in this calculator are the same default scenarios EPA addresses in its guidance. Other scenarios may be investigated, using the recommended SDCC calculator, by altering site-specific exposure parameters.

3.2 Background Radiation

Natural background radiation should be considered prior to applying SDCCs as cleanup levels. Background and site-related levels of radiation should be addressed similar to 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. Additional information on radioactive materials present in building materials can be found in Volume 105, Number 2, March-April 2000, Journal of Research of the National Institute of Standards and Technology, Radioactivity Measurements on Glazed Ceramic Surfaces.

3.3 Potential Problems

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

- Adequately develop a conceptual site model that identifies relevant exposure pathways and exposure scenarios before applying recommended SDCC levels to a site.
- Consider other relevant criteria before using recommended SDCC levels as cleanup levels
- Verify numbers with a health physicist/risk assessor before using recommended SDCC levels as cleanup levels
- Ensure use of the latest recommended SDCC tables (outdated tables may have been superseded by more recent publications)
- Consider the effects from the presence of multiple isotopes

4. Land Use Descriptions, Equations, and Technical Documentation

The recommended SDCCs consider human exposure from direct contact with contaminated outdoor dust on solid surfaces and external exposure to contaminated streets, sidewalks, finite slabs, and building materials. The equations and technical discussion are aimed at developing concentration levels for risk-based SDCCs. Calculation of the recommended SDCCs are based on the SDCC calculator. The following text presents the recommended land use equations and their exposure routes. Table 1 presents the suggested definitions of the variables and their default values. Any alternative values or assumptions used in remedy evaluation or selection on a CERCLA site should be presented with supporting rationale in the Administrative Record.

For a graphical representation and brief description of the routes of exposure for each exposure scenario, click on the name of the exposure scenarios below:

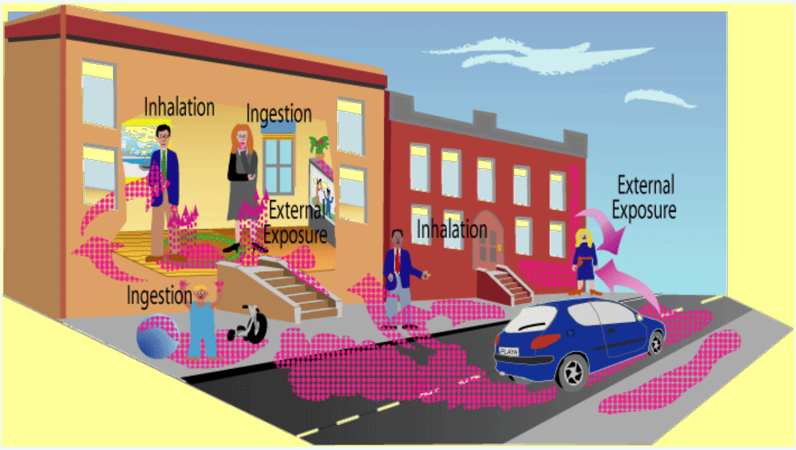
4.1 Resident

The recommended resident land use equation for outside surfaces, presented here, contains the following exposure pathways and exposure routes:

Exposure to Contamination Deposited on Streets and Sidewalks

The resident is exposed to contaminated dust settled on outdoor surfaces. The resident spends some time inside and some time outside. Three exposure routes are presented: (1) exposure to contamination deposited on surfaces via incidental ingestion, (2) inhalation of resuspended particulates, and (3) external exposure to ionizing radiation from dust settled on contaminated surfaces. For the portion of the time that the resident is indoors, this equation includes an indoor air dilution factor for inhalation and a gamma shielding factor for external exposure.

Graphical Representation



Equations

(age-adjusted incidental ingestion, age-adjusted inhalation of particulates, and external exposure to ionizing radiation from settled dust using ground plane toxicity values)

Ingestion

$$SDCC_{res\text{-}dust\text{-}ing}\left(pCi/cm^2\right) = \frac{DL\left(\frac{mrem}{year}\right)\times t_{res}\,(year)\times\lambda\left(\frac{1}{year}\right)}{\left(\frac{1-e^{-kt_{res}}}{kt_{res}}\right)\times\left(1-e^{-\lambda t_{res}}\right)\times DCF_o\left(\frac{risk}{pCi}\right)\times IFD_{res\text{-}adj}\left(\frac{39{,}291\ cm^2}{year}\right)}$$

where:

$$IFD_{res\text{-}adj}\left(\frac{39{,}291\ cm^2}{year}\right) = \left[\begin{array}{l}\left(FTSS_h\,(0.5)\times ET_{res\text{-}c,h}\left(\frac{4\ hours}{day}\right)\times EF_{res\text{-}c}\left(\frac{350\ days}{year}\right)\times SE\,(0.5)\times AAF_{res\text{-}c}\,(0.23)\times SA_{res\text{-}c}\left(\frac{16\ cm^2}{event}\right)\times FQ_{res\text{-}c}\left(\frac{10\ events}{hour}\right)\right)+\\ \left(FTSS_h\,(0.5)\times ET_{res\text{-}a,h}\left(\frac{4\ hours}{day}\right)\times EF_{res\text{-}a}\left(\frac{350\ days}{year}\right)\times SE\,(0.5)\times AAF_{res\text{-}a}\,(0.77)\times SA_{res\text{-}a}\left(\frac{49\ cm^2}{event}\right)\times FQ_{res\text{-}a}\left(\frac{2\ events}{hour}\right)\right)\end{array}\right]$$

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 with PEF $_{wind}$

$$SDCC_{res\text{-}dust\text{-}inhw}\left(pCi/cm^2\right) = \frac{DL\left(\frac{mrem}{year}\right)\times t_{res}\,(year)\times\lambda\left(\frac{1}{year}\right)}{\left(\frac{1-e^{-kt_{res}}}{kt_{res}}\right)\times\left(1-e^{-\lambda t_{res}}\right)\times DCF_i\left(\frac{mrem}{pCi}\right)\times IFA_{res\text{-}adj}\left(\frac{6{,}195\ m^3}{year}\right)\times\frac{1}{PEF_w\left(\frac{m^3}{kg}\right)}\times SLF\left(\frac{6.\bar{6}\ E{+}08\ cm^2}{kg}\right)\times\left[ET_{res\text{-}o}\left(\frac{1.752\ hours}{day}\right)+ET_{res\text{-}i}\left(\frac{16.4\ hours}{day}\right)\right]\times\left(\frac{1\ day}{24\ hours}\right)}$$

where:

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

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 with PEF $_{mechanical}$

$$SDCC_{res\text{-}dust\text{-}inhm}\left(pCi/cm^2\right) = \frac{DL\left(\frac{mrem}{year}\right)\times t_{res}\,(year)\times\lambda\left(\frac{1}{year}\right)}{\left(\frac{1-e^{-kt_{res}}}{kt_{res}}\right)\times\left(1-e^{-\lambda t_{res}}\right)\times DCF_i\left(\frac{mrem}{pCi}\right)\times IFA_{res\text{-}adj}\left(\frac{6{,}195\ m^3}{year}\right)\times\frac{1}{PEF_m\left(\frac{m^3}{kg}\right)}\times SLF\left(\frac{6.\bar{6}\ E{+}08\ cm^2}{kg}\right)\times\left[ET_{res\text{-}o}\left(\frac{1.752\ hours}{day}\right)+ET_{res\text{-}i}\left(\frac{16.4\ hours}{day}\right)\right]\times\left(\frac{1\ day}{24\ hours}\right)}$$

where:

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

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 with PEF $_{wind}$ for State-Specific

$$SDCC_{res\text{-}dust\text{-}inhw\text{-}state}\left(pCi/cm^2\right) = \frac{DL\left(\frac{mrem}{year}\right)\times t_{res}\,(year)\times\lambda\left(\frac{1}{year}\right)}{\left(\frac{1-e^{-kt_{res}}}{kt_{res}}\right)\times\left(1-e^{-\lambda t_{res}}\right)\times DCF_i\left(\frac{mrem}{pCi}\right)\times IFA_{res\text{-}adj}\left(\frac{6{,}195\ m^3}{year}\right)\times\frac{1}{PEF_w\left(\frac{m^3}{kg}\right)}\times SLF\left(\frac{cm^2}{kg}\right)\times\left[ET_{res\text{-}o}\left(\frac{1.752\ hours}{day}\right)+ET_{res\text{-}i}\left(\frac{16.4\ hours}{day}\right)\right]\times\left(\frac{1\ day}{24\ hours}\right)}$$

where:

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

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 with PEF $_{mechanical}$ for State-Specific

$$SDCC_{res\text{-}dust\text{-}inhm\text{-}state}\left(pCi/cm^2\right) = \frac{DL\left(\frac{mrem}{year}\right) \times t_{res}(year) \times \lambda\left(\frac{1}{year}\right)}{\left(\frac{1-e^{-kt_{res}}}{kt_{res}}\right) \times \left(1-e^{-\lambda t_{res}}\right) \times DCF_i\left(\frac{mrem}{pCi}\right) \times IFA_{res\text{-}adj}\left(\frac{6{,}195\ m^3}{year}\right) \times \frac{1}{PEF_m\left(\frac{m^3}{kg}\right)} \times SLF\left(\frac{cm^2}{kg}\right) \times \left[ET_{res\text{-}o}\left(\frac{1.752\ hours}{day}\right) + ET_{res\text{-}i}\left(\frac{16.4\ hours}{day}\right)\right] \times \left(\frac{1\ day}{24\ hours}\right)}$$

where:

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

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

$$SDCC_{res\text{-}dust\text{-}ext}\left(pCi/cm^2\right) = \frac{DL\left(\frac{mrem}{year}\right) \times t_{res}(year) \times \lambda\left(\frac{1}{year}\right)}{\left(\frac{1-e^{-kt_{res}}}{kt_{res}}\right) \times \left(1-e^{-\lambda t_{res}}\right) \times DCF_{ext\text{-}gp}\left(\frac{mrem/year}{pCi/cm^2}\right) \times F_{AM} \times F_{OFF\text{-}SET} \times EF_{res}\left(\frac{350\ days}{year}\right) \times \left(\frac{1\ year}{365\ days}\right) \times ACF_{ext\text{-}gp} \times \left[\left(ET_{res\text{-}o}\left(\frac{1.752\ hours}{day}\right) \times GSF_s(1.0)\right) + \left(ET_{res\text{-}i}\left(\frac{16.416\ hours}{day}\right) \times GSF_i(0.4)\right)\right] \times \left(\frac{1\ day}{24\ hours}\right)}$$

Total

$$SDCC_{res\text{-}dust\text{-}tot}\left(pCi/cm^2\right) = \frac{1}{\frac{1}{SDCC_{res\text{-}dust\text{-}ing}} + \frac{1}{SDCC_{res\text{-}dust\text{-}inh}} + \frac{1}{SDCC_{res\text{-}dust\text{-}ext}}}$$

The resulting units for this recommended SDCC are in pCi/cm^2. The units are based on area, because the SF used is the ground plane for external exposure and the ingestion route is based on hand surface area contacting dust on surfaces and subsequent hand to mouth transfer events. This equation is for values of k that are greater than 0; when k=0, the dissipation term is not quantified to avoid division by zero.

3-D Direct External Exposure

The only pathway considered is external exposure to ionizing radiation. It is assumed that the street (horizontal) and the building walls (vertical) on both sides of the street are radioactively contaminated.

Graphical Representation

Resident - 3-D External Exposure to Contaminated Building Materials in Outdoor Surfaces. The resident is exposed to contaminated building materials in outdoor surfaces.

Resident - 3-D External Exposure to Outdoor Surfaces. The resident is exposed to gamma radiation from outdoor surfaces.

Equations

(Materials with fixed contamination at infinite depth in outside walls, streets, and sidewalks using infinite soil volume toxicity values)

$$SDCC_{res\text{-}3D\text{-}ext\text{-}sv}\left(\frac{pCi}{g}\right) = \frac{DL\left(\frac{mrem}{year}\right) \times t_{res}\,(year) \times \lambda\left(\frac{1}{year}\right)}{\left(1-e^{-\lambda t_{res}}\right) \times DCF_{ext\text{-}sv}\left(\frac{mrem/year}{pCi/g}\right) \times F_{AM} \times F_{OFF\text{-}SET} \times F_{s\text{-}surf} \times EF_{res}\left(\frac{350\ days}{year}\right) \times \left(\frac{1\ year}{365\ days}\right) \times \left[\left(ET_{res\text{-}o}\left(\frac{1.752\ hours}{day}\right) \times GSF_{s}\,(1.0)\right) + \left(ET_{res\text{-}i}\left(\frac{16.416\ hours}{day}\right) \times GSF_{i}\,(0.4)\right)\right] \times \left(\frac{1\ day}{24\ hours}\right)}$$

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

(Materials with fixed contamination at 1cm in outside walls, streets, and sidewalks using 1cm soil volume toxicity values)

$$SDCC_{res\text{-}3D\text{-}ext\text{-}1cm}\left(\frac{pCi}{g}\right) = \frac{DL\left(\frac{mrem}{year}\right) \times t_{res}\,(year) \times \lambda\left(\frac{1}{year}\right)}{\left(1-e^{-\lambda t_{r}}\right) \times DCF_{ext\text{-}1cm}\left(\frac{mrem/year}{pCi/g}\right) \times F_{AM} \times F_{OFF\text{-}SET} \times F_{s\text{-}surf} \times EF_{res}\left(\frac{350\ days}{year}\right) \times \left(\frac{1\ year}{365\ days}\right) \times \left[\left(ET_{res\text{-}o}\left(\frac{1.752\ hours}{day}\right) \times GSF_{s}\,(1.0)\right) + \left(ET_{res\text{-}i}\left(\frac{16.416\ hours}{day}\right) \times GSF_{i}\,(0.4)\right)\right] \times \left(\frac{1\ day}{24\ hours}\right)}$$

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

(Materials with fixed contamination at 5cm in outside walls, streets, and sidewalks using 5cm soil volume toxicity values)

$$SDCC_{res\text{-}3D\text{-}ext\text{-}5cm}\left(\frac{pCi}{g}\right) = \frac{DL\left(\frac{mrem}{year}\right) \times t_{res}\,(year) \times \lambda\left(\frac{1}{year}\right)}{\left(1-e^{-\lambda t_{res}}\right) \times DCF_{ext\text{-}5cm}\left(\frac{mrem/year}{pCi/g}\right) \times F_{AM} \times F_{OFF\text{-}SET} \times F_{s\text{-}surf} \times EF_{res}\left(\frac{350\ days}{year}\right) \times \left(\frac{1\ year}{365\ days}\right) \times \left[\left(ET_{res\text{-}o}\left(\frac{1.752\ hours}{day}\right) \times GSF_{s}\,(1.0)\right) + \left(ET_{res\text{-}i}\left(\frac{16.416\ hours}{day}\right) \times GSF_{i}\,(0.4)\right)\right] \times \left(\frac{1\ day}{24\ hours}\right)}$$

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

(Materials with fixed contamination at 15cm in outside walls, streets, and sidewalks using 15cm soil volume toxicity values)

$$SDCC_{res\text{-}3D\text{-}ext\text{-}15cm}\left(\frac{pCi}{g}\right) = \frac{DL\left(\frac{mrem}{year}\right) \times t_{res}\,(year) \times \lambda\left(\frac{1}{year}\right)}{\left(1-e^{-\lambda t_{res}}\right) \times DCF_{ext\text{-}15cm}\left(\frac{mrem/year}{pCi/g}\right) \times F_{AM} \times F_{OFF\text{-}SET} \times F_{s\text{-}surf} \times EF_{res}\left(\frac{350\ days}{year}\right) \times \left(\frac{1\ year}{365\ days}\right) \times \left[\left(ET_{res\text{-}o}\left(\frac{1.752\ hours}{day}\right) \times GSF_{s}\,(1.0)\right) + \left(ET_{res\text{-}i}\left(\frac{16.416\ hours}{day}\right) \times GSF_{i}\,(0.4)\right)\right] \times \left(\frac{1\ day}{24\ hours}\right)}$$

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

(Fixed contaminated dust on surface of outside walls, streets, and sidewalks using ground plane toxicity values)

$$SDCC_{res\text{-}3D\text{-}ext\text{-}gp}\left(pCi/cm^{2}\right) = \frac{DL\left(\frac{mrem}{year}\right) \times t_{res}\,(year) \times \lambda\left(\frac{1}{year}\right)}{\left(1-e^{-\lambda t_{res}}\right) \times DCF_{ext\text{-}gp}\left(\frac{mrem/year}{pCi/cm^{2}}\right) \times F_{AM} \times F_{OFF\text{-}SET} \times F_{s\text{-}surf} \times EF_{res}\left(\frac{350\ days}{year}\right) \times \left(\frac{1\ year}{365\ days}\right) \times \left[\left(ET_{res\text{-}o}\left(\frac{1.752\ hours}{day}\right) \times GSF_{s}\,(1.0)\right) + \left(ET_{res\text{-}i}\left(\frac{16.416\ hours}{day}\right) \times GSF_{i}\,(0.4)\right)\right] \times \left(\frac{1\ day}{24\ hours}\right)}$$

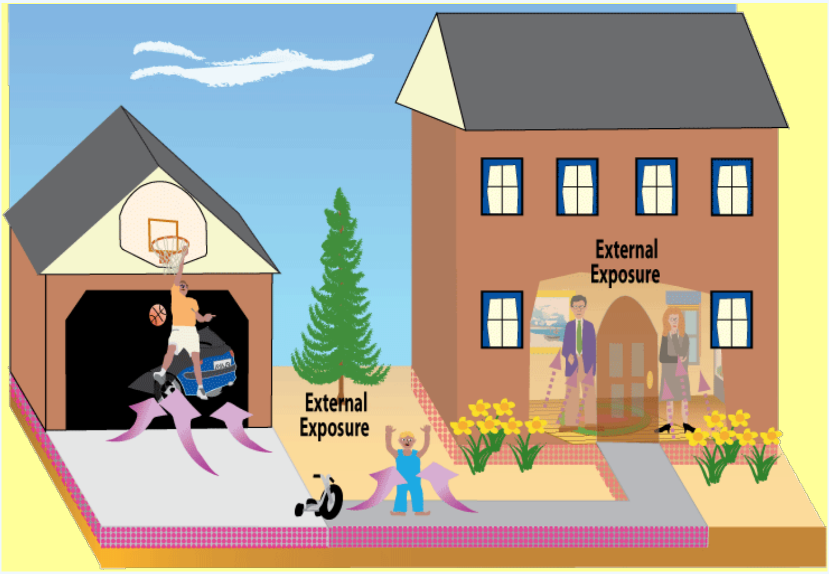
The resulting units for this recommended SDCC are in pCi/cm^2. The units are based on area, because the SF used is the ground plane for external exposure.

2-D Direct External Exposure

The resident is exposed to contaminated finite slabs. The only pathway considered is external exposure to ionizing radiation. It is assumed the resident lives in a structure built on top of the middle of the slab.

Graphical Representation

Resident - 2-D External Exposure to Contaminated Finite Slabs. It is assumed that the finite slab (horizontal) is constructed with contaminated materials.



Resident - 2-D External Exposure to Settled Dust on Finite Slabs. It is assumed that the dust on the finite slab (horizontal) is radioactively contaminated.

Equations

(Materials with fixed contamination in a finite slab using infinite soil volume toxicity values)

$$SDCC_{res\text{-}2D\text{-}ext\text{-}sv}\left(\frac{pCi}{g}\right) = \frac{DL\left(\frac{mrem}{year}\right)\times t_{res}\,(year)\times\lambda\left(\frac{1}{year}\right)}{\left(1-e^{-\lambda t_{res}}\right)\times DCF_{ext\text{-}sv}\left(\frac{mrem/year}{pCi/g}\right)\times F_{AM}\times F_{OFF\text{-}SET}\times EF_{res}\left(\frac{350\ days}{year}\right)\times\left(\frac{1\ year}{365\ days}\right)\times ACF_{ext\text{-}sv}\times\left[\left(ET_{res\text{-}o}\left(\frac{1.752\ hours}{day}\right)\times GSF_s\,(1.0)\right)+\left(ET_{res\text{-}i}\left(\frac{16.416\ hours}{day}\right)\times GSF_i\,(0.4)\right)\right]\times\left(\frac{1\ day}{24\ hours}\right)}$$

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

(Materials with fixed contamination in a finite slab at 1cm depth using 1cm soil volume toxicity values)

$$SDCC_{res\text{-}2D\text{-}ext\text{-}1cm}\left(\frac{pCi}{g}\right)=\frac{DL\left(\frac{mrem}{year}\right)\times t_{res}\,(year)\times\lambda\left(\frac{1}{year}\right)}{\left(1\text{-}e^{-\lambda t_{res}}\right)\times DCF_{ext\text{-}1cm}\left(\frac{mrem/year}{pCi/g}\right)\times F_{AM}\times F_{OFF\text{-}SET}\times EF_{res}\left(\frac{350\ days}{year}\right)\times\left(\frac{1\ year}{365\ days}\right)\times ACF_{ext\text{-}1cm}\times\left[\left(ET_{res\text{-}o}\left(\frac{1.752\ hours}{day}\right)\times GSF_s\,(1.0)\right)+\left(ET_{res\text{-}i}\left(\frac{16.416\ hours}{day}\right)\times GSF_i\,(0.4)\right)\right]\times\left(\frac{1\ day}{24\ hours}\right)}$$

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

(Materials with fixed contamination in a finite slab at 5cm depth using 5cm soil volume toxicity values)

$$SDCC_{res\text{-}2D\text{-}ext\text{-}5cm}\left(\frac{pCi}{g}\right)=\frac{DL\left(\frac{mrem}{year}\right)\times t_{res}\,(year)\times\lambda\left(\frac{1}{year}\right)}{\left(1\text{-}e^{-\lambda t_{res}}\right)\times DCF_{ext\text{-}5cm}\left(\frac{mrem/year}{pCi/g}\right)\times F_{AM}\times F_{OFF\text{-}SET}\times EF_{res}\left(\frac{350\ days}{year}\right)\times\left(\frac{1\ year}{365\ days}\right)\times ACF_{ext\text{-}5cm}\times\left[\left(ET_{res\text{-}o}\left(\frac{1.752\ hours}{day}\right)\times GSF_s\,(1.0)\right)+\left(ET_{res\text{-}i}\left(\frac{16.416\ hours}{day}\right)\times GSF_i\,(0.4)\right)\right]\times\left(\frac{1\ day}{24\ hours}\right)}$$

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

(Materials with fixed contamination in a finite slab at 15cm depth using 15cm soil volume toxicity values)

$$SDCC_{res\text{-}2D\text{-}ext\text{-}15cm}\left(\frac{pCi}{g}\right)=\frac{DL\left(\frac{mrem}{year}\right)\times t_{res}\,(year)\times\lambda\left(\frac{1}{year}\right)}{\left(1\text{-}e^{-\lambda t_{res}}\right)\times DCF_{ext\text{-}15cm}\left(\frac{mrem/year}{pCi/g}\right)\times F_{AM}\times F_{OFF\text{-}SET}\times EF_{res}\left(\frac{350\ days}{year}\right)\times\left(\frac{1\ year}{365\ days}\right)\times ACF_{ext\text{-}15cm}\times\left[\left(ET_{res\text{-}o}\left(\frac{1.752\ hours}{day}\right)\times GSF_s\,(1.0)\right)+\left(ET_{res\text{-}i}\left(\frac{16.416\ hours}{day}\right)\times GSF_i\,(0.4)\right)\right]\times\left(\frac{1\ day}{24\ hours}\right)}$$

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

(Materials with fixed contamination in a finite slab using ground plane toxicity values)

$$SDCC_{res\text{-}2D\text{-}ext\text{-}gp}\left(pCi/cm^2\right)=\frac{DL\left(\frac{mrem}{year}\right)\times t_{res}\,(year)\times\lambda\left(\frac{1}{year}\right)}{\left(1\text{-}e^{-\lambda t_{res}}\right)\times DCF_{ext\text{-}gp}\left(\frac{mrem/year}{pCi/g}\right)\times F_{AM}\times F_{OFF\text{-}SET}\times EF_{res}\left(\frac{350\ days}{year}\right)\times\left(\frac{1\ year}{365\ days}\right)\times ACF_{ext\text{-}gp}\times\left[\left(ET_{res\text{-}o}\left(\frac{1.752\ hours}{day}\right)\times GSF_s\,(1.0)\right)+\left(ET_{res\text{-}i}\left(\frac{16.416\ hours}{day}\right)\times GSF_i\,(0.4)\right)\right]\times\left(\frac{1\ day}{24\ hours}\right)}$$

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

4.2 Composite Worker

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

Exposure to Contamination Deposited on Streets and Sidewalks

The composite worker is exposed to contaminated dust settled on outdoor surfaces. The composite worker uses the most protective exposure parameters from the indoor and outdoor worker land uses. Three exposure routes are presented: (1) exposure to contamination deposited on surfaces via incidental ingestion, (2) inhalation of particulates, and (3) external exposure to ionizing radiation from dust settled on contaminated surfaces.

Graphical Representation

Equations

(incidental ingestion, inhalation of particulates, and external exposure to ionizing radiation from settled dust using ground plane toxicity values)

Ingestion

$$SDCC_{ind\text{-}dust\text{-}ing}\left(\frac{pCi}{cm^2}\right)=\frac{DL\left(\frac{mrem}{year}\right)\times t_w\,(year)\times\lambda\left(\frac{1}{year}\right)}{\left(\frac{1-e^{-kt_w}}{kt_w}\right)\times\left(1-e^{-\lambda t_w}\right)\times DCF_{oa}\left(\frac{mrem}{pCi}\right)\times IFD_w\left(\frac{196\ cm^2}{day}\right)\times EF_w\left(\frac{250\ days}{year}\right)}$$

where:

$$IFD_w\left(\frac{196\ cm^2}{day}\right)=\left(FTSS_h\,(0.5)\times ET_w\left(\frac{8\ hours}{day}\right)\times SE\,(0.5)\times SA_w\left(\frac{49\ cm^2}{event}\right)\times FQ_w\left(\frac{2\ events}{hour}\right)\right)$$

Inhalation with PEF $_{wind}$

$$SDCC_{ind\text{-}dust\text{-}inhw}\left(\frac{pCi}{cm^2}\right)=\frac{DL\left(\frac{mrem}{year}\right)\times t_w\,(year)\times\lambda\left(\frac{1}{year}\right)}{\left(\frac{1-e^{-kt_w}}{kt_w}\right)\times\left(1-e^{-\lambda t_w}\right)\times DCF_{inh}\left(\frac{mrem}{pCi}\right)\times IRA_w\left(\frac{2.5\ m^3}{hour}\right)\times ET_w\left(\frac{8\ hours}{day}\right)\times EF_w\left(\frac{250\ days}{year}\right)\times\frac{1}{PEF_w\left(\frac{m^3}{kg}\right)}\times SLF\left(\frac{6.6\ E+08\ cm^2}{kg}\right)}$$

Inhalation with PEF $_{mechanical}$

$$SDCC_{ind\text{-}dust\text{-}inhm}\left(\frac{pCi}{cm^2}\right)=\frac{DL\left(\frac{mrem}{year}\right)\times t_w\,(year)\times\lambda\left(\frac{1}{year}\right)}{\left(\frac{1-e^{-kt_w}}{kt_w}\right)\times\left(1-e^{-\lambda t_w}\right)\times DCF_{inh}\left(\frac{mrem}{pCi}\right)\times IRA_w\left(\frac{2.5\ m^3}{hour}\right)\times ET_w\left(\frac{8\ hours}{day}\right)\times EF_w\left(\frac{250\ days}{year}\right)\times\frac{1}{PEF_m\left(\frac{m^3}{kg}\right)}\times SLF\left(\frac{6.6\ E+08\ cm^2}{kg}\right)}$$

Inhalation with PEF $_{wind}$ for State-Specific

$$SDCC_{ind\text{-}dust\text{-}inhw\text{-}state}\left(\frac{pCi}{cm^2}\right)=\frac{DL\left(\frac{mrem}{year}\right)\times t_w\,(year)\times\lambda\left(\frac{1}{year}\right)}{\left(\frac{1-e^{-kt_w}}{kt_w}\right)\times\left(1-e^{-\lambda t_w}\right)\times DCF_{inh}\left(\frac{mrem}{pCi}\right)\times IRA_w\left(\frac{2.5\ m^3}{hour}\right)\times ET_w\left(\frac{8\ hours}{day}\right)\times EF_w\left(\frac{250\ days}{year}\right)\times\frac{1}{PEF_w\left(\frac{m^3}{kg}\right)}\times SLF\left(\frac{cm^2}{kg}\right)}$$

Inhalation with PEF $_{mechanical}$ for State-Specific

$$SDCC_{ind\text{-}dust\text{-}inhm\text{-}state}\left(\frac{pCi}{cm^2}\right)=\frac{DL\left(\frac{mrem}{year}\right)\times t_w\,(year)\times\lambda\left(\frac{1}{year}\right)}{\left(\frac{1-e^{-kt_w}}{kt_w}\right)\times\left(1-e^{-\lambda t_w}\right)\times DCF_{inh}\left(\frac{mrem}{pCi}\right)\times IRA_w\left(\frac{2.5\ m^3}{hour}\right)\times ET_w\left(\frac{8\ hours}{day}\right)\times EF_w\left(\frac{250\ days}{year}\right)\times\frac{1}{PEF_m\left(\frac{m^3}{kg}\right)}\times SLF\left(\frac{cm^2}{kg}\right)}$$

External

$$SDCC_{ind\text{-}dust\text{-}ext}\left(\frac{pCi}{cm^2}\right)=\frac{DL\left(\frac{mrem}{year}\right)\times t_w\,(year)\times\lambda\left(\frac{1}{year}\right)}{\left(\frac{1-e^{-kt_w}}{kt_w}\right)\times\left(1-e^{-\lambda t_w}\right)\times DCF_{ext\text{-}gp}\left(\frac{mrem/year}{pCi/cm^2}\right)\times F_{AM}\times F_{OFF\text{-}SET}\times ACF_{ext\text{-}gp}\times EF_{iw}\left(\frac{250\ days}{year}\right)\times\left(\frac{1\ year}{365\ days}\right)\times GSF_s\,(1.0)\times ET_{iw}\left(\frac{8\ hours}{day}\right)\times\left(\frac{1\ day}{24\ hours}\right)}$$

Total

$$SDCC_{ind\text{-}dust\text{-}tot}\left(pCi/cm^2\right)=\frac{1}{\frac{1}{SDCC_{ind\text{-}dust\text{-}ing}}+\frac{1}{SDCC_{ind\text{-}dust\text{-}inh}}+\frac{1}{SDCC_{ind\text{-}dust\text{-}ext}}}$$

The resulting units for this recommended SDCC are in pCi/cm^2. The units are based on area, because the SF used is the ground plane for external exposure and the ingestion route is based on hand surface area contacting dust on surfaces and subsequent hand to mouth transfer events. This equation is for values of k that are greater than 0; when k=0, the dissipation term is not quantified to avoid division by zero.

3-D Direct External Exposure

The only pathway considered is external exposure to ionizing radiation. It is assumed that the street (horizontal) and the building walls (vertical) on both sides of the street are radioactively contaminated.

Graphical Representation

Composite Worker - 3-D External Exposure to Contaminated Building Materials in Outdoor Surfaces. The composite worker is exposed to contaminated building materials in outdoor surfaces.

Composite Worker - 3-D External Exposure to Outdoor Surfaces. The composite worker is exposed to settled dust on outdoor surfaces.

Equations

(Materials with fixed contamination at infinite depth in outside walls, streets, and sidewalks using infinite soil volume toxicity values)

$$SDCC_{ind\text{-}3D\text{-}ext\text{-}sv}\left(\frac{pCi}{g}\right)=\frac{DL\left(\frac{mrem}{year}\right)\times t_w\,(year)\times\lambda\left(\frac{1}{year}\right)}{\left(1-e^{-\lambda t_w}\right)\times DCF_{ext\text{-}sv}\left(\frac{mrem/year}{pCi/g}\right)\times F_{AM}\times F_{OFF\text{-}SET}\times F_{s\text{-}surf}\times EF_w\left(\frac{250\ days}{year}\right)\times\left(\frac{1\ year}{365\ days}\right)\times GSF_s\,(1.0)\times ET_w\left(\frac{8\ hours}{day}\right)\times\left(\frac{1\ day}{24\ hours}\right)}$$

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

(Materials with fixed contamination at 1cm in outside walls, streets, and sidewalks using 1cm soil volume toxicity values)

$$SDCC_{ind\text{-}3D\text{-}ext\text{-}1cm}\left(\frac{pCi}{g}\right)=\frac{DL\left(\frac{mrem}{year}\right)\times t_w\,(year)\times\lambda\left(\frac{1}{year}\right)}{\left(1-e^{-\lambda t_w}\right)\times DCF_{ext\text{-}1cm}\left(\frac{mrem/year}{pCi/g}\right)\times F_{AM}\times F_{OFF\text{-}SET}\times F_{s\text{-}surf}\times EF_w\left(\frac{250\ days}{year}\right)\times\left(\frac{1\ year}{365\ days}\right)\times GSF_s\,(1.0)\times ET_w\left(\frac{8\ hours}{day}\right)\times\left(\frac{1\ day}{24\ hours}\right)}$$

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

(Materials with fixed contamination at 5cm in outside walls, streets, and sidewalks using 5cm soil volume toxicity values)

$$SDCC_{ind\text{-}3D\text{-}ext\text{-}5cm}\left(\frac{pCi}{g}\right)=\frac{DL\left(\frac{mrem}{year}\right)\times t_w\,(year)\times\lambda\left(\frac{1}{year}\right)}{\left(1-e^{-\lambda t_w}\right)\times DCF_{ext\text{-}5cm}\left(\frac{mrem/year}{pCi/g}\right)\times F_{AM}\times F_{OFF\text{-}SET}\times F_{s\text{-}surf}\times EF_w\left(\frac{250\ days}{year}\right)\times\left(\frac{1\ year}{365\ days}\right)\times GSF_s\,(1.0)\times ET_w\left(\frac{8\ hours}{day}\right)\times\left(\frac{1\ day}{24\ hours}\right)}$$

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

(Materials with fixed contamination at 15cm in outside walls, streets, and sidewalks using 15cm soil volume toxicity values)

$$SDCC_{ind\text{-}3D\text{-}ext\text{-}15cm}\left(\frac{pCi}{g}\right) = \frac{DL\left(\frac{mrem}{year}\right)\times t_w\,(year)\times\lambda\left(\frac{1}{year}\right)}{\left(1-e^{-\lambda t_w}\right)\times DCF_{ext\text{-}15cm}\left(\frac{mrem/year}{pCi/g}\right)\times F_{AM}\times F_{OFF\text{-}SET}\times F_{s\text{-}surf}\times EF_w\left(\frac{250\ days}{year}\right)\times\left(\frac{1\ year}{365\ days}\right)\times GSF_s\,(1.0)\times ET_w\left(\frac{8\ hours}{day}\right)\times\left(\frac{1\ day}{24\ hours}\right)}$$

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

(Fixed contaminated dust on outside walls, streets, and sidewalks using ground plane toxicity values)

$$SDCC_{ind\text{-}3D\text{-}ext\text{-}gp}\left(\frac{pCi}{cm^2}\right) = \frac{DL\left(\frac{mrem}{year}\right)\times t_w\,(year)\times\lambda\left(\frac{1}{year}\right)}{\left(1-e^{-\lambda t_w}\right)\times DCF_{ext\text{-}gp}\left(\frac{mrem/year}{pCi/cm^2}\right)\times F_{AM}\times F_{OFF\text{-}SET}\times F_{s\text{-}surf}\times EF_w\left(\frac{250\ days}{year}\right)\times\left(\frac{1\ year}{365\ days}\right)\times GSF_s\,(1.0)\times ET_w\left(\frac{8\ hours}{day}\right)\times\left(\frac{1\ day}{24\ hours}\right)}$$

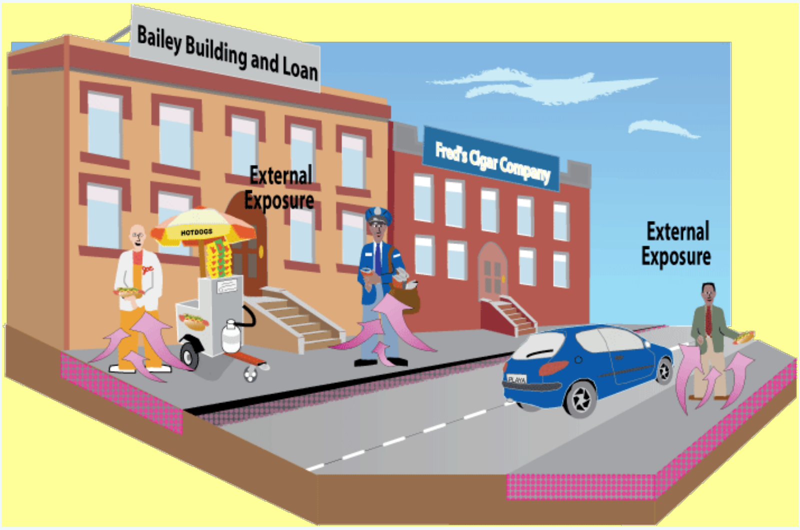
The resulting units for this recommended SDCC are in pCi/cm^2. The units are based on area, because the SF used is the ground plane for external exposure.

2-D Direct External Exposure

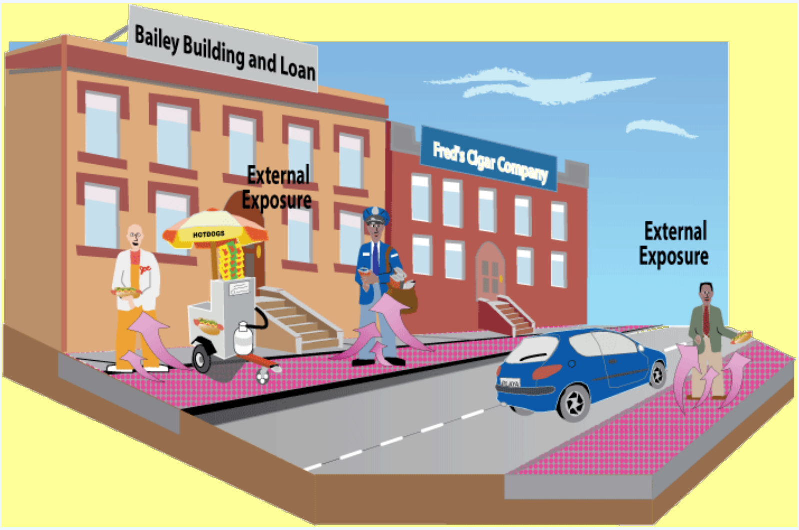
The only pathway considered is external exposure to ionizing radiation.

Graphical Representation

Composite Worker - 2-D External Exposure to Contaminated Finite Slabs. The composite worker is exposed to contaminated finite slabs. It is assumed that the finite slab (horizontal) is constructed with contaminated materials.



Composite Worker - 2-D External Exposure to Settled Dust on Finite Slabs. The composite worker is exposed to settled dust on finite slabs. It is assumed that the dust on the finite slab (horizontal) is radioactively contaminated.



Equations

(Materials with fixed contamination in a finite slab using infinite soil volume toxicity values)

$$SDCC_{ind\text{-}2D\text{-}ext\text{-}sv}\left(\frac{pCi}{g}\right) = \frac{DL\left(\frac{mrem}{year}\right)\times t_w\,(year)\times\lambda\left(\frac{1}{year}\right)}{\left(1-e^{-\lambda t_w}\right)\times DCF_{ext\text{-}sv}\left(\frac{mrem/year}{pCi/g}\right)\times F_{AM}\times F_{OFF\text{-}SET}\times ACF_{ext\text{-}sv}\times EF_w\left(\frac{250\ days}{year}\right)\times\left(\frac{1\ year}{365\ days}\right)\times GSF_s\,(1.0)\times ET_w\left(\frac{8\ hours}{day}\right)\times\left(\frac{1\ day}{24\ hours}\right)}$$

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

(Materials with fixed contamination in a finite slab at 1cm depth using 1cm soil volume toxicity values)

$$SDCC_{ind\text{-}2D\text{-}ext\text{-}1cm}\left(\frac{pCi}{g}\right) = \frac{DL\left(\frac{mrem}{year}\right)\times t_w\,(year)\times\lambda\left(\frac{1}{year}\right)}{\left(1-e^{-\lambda t_w}\right)\times DCF_{ext\text{-}1cm}\left(\frac{mrem/year}{pCi/g}\right)\times F_{AM}\times F_{OFF\text{-}SET}\times ACF_{ext\text{-}1cm}\times EF_w\left(\frac{250\ days}{year}\right)\times\left(\frac{1\ year}{365\ days}\right)\times GSF_s\,(1.0)\times ET_w\left(\frac{8\ hours}{day}\right)\times\left(\frac{1\ day}{24\ hours}\right)}$$

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

(Materials with fixed contamination in a finite slab at 5cm depth using 5cm soil volume toxicity values)

$$SDCC_{ind\text{-}2D\text{-}ext\text{-}5cm}\left(\frac{pCi}{g}\right) = \frac{DL\left(\frac{mrem}{year}\right)\times t_w\,(year)\times\lambda\left(\frac{1}{year}\right)}{\left(1-e^{-\lambda t_w}\right)\times DCF_{ext\text{-}5cm}\left(\frac{mrem/year}{pCi/g}\right)\times F_{AM}\times F_{OFF\text{-}SET}\times ACF_{ext\text{-}5cm}\times EF_w\left(\frac{250\ days}{year}\right)\times\left(\frac{1\ year}{365\ days}\right)\times GSF_s\,(1.0)\times ET_w\left(\frac{8\ hours}{day}\right)\times\left(\frac{1\ day}{24\ hours}\right)}$$

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

(Materials with fixed contamination in a finite slab at 15cm depth using 15cm soil volume toxicity values)

$$SDCC_{ind\text{-}2D\text{-}ext\text{-}15cm}\left(\frac{pCi}{g}\right) = \frac{DL\left(\frac{mrem}{year}\right)\times t_w\,(year)\times\lambda\left(\frac{1}{year}\right)}{\left(1-e^{-\lambda t_w}\right)\times DCF_{ext\text{-}15cm}\left(\frac{mrem/year}{pCi/g}\right)\times F_{AM}\times F_{OFF\text{-}SET}\times ACF_{ext\text{-}15cm}\times EF_w\left(\frac{250\ days}{year}\right)\times\left(\frac{1\ year}{365\ days}\right)\times GSF_s\,(1.0)\times ET_w\left(\frac{8\ hours}{day}\right)\times\left(\frac{1\ day}{24\ hours}\right)}$$

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

(Materials with fixed contamination in a finite slab using ground plane toxicity values)

$$SDCC_{ind\text{-}2D\text{-}ext\text{-}gp}\left(\frac{pCi}{cm^2}\right) = \frac{DL\left(\frac{mrem}{year}\right)\times t_w\,(year)\times\lambda\left(\frac{1}{year}\right)}{\left(1-e^{-\lambda t_w}\right)\times DCF_{ext\text{-}gp}\left(\frac{mrem/year}{pCi/cm^2}\right)\times F_{AM}\times F_{OFF\text{-}SET}\times ACF_{ext\text{-}gp}\times EF_w\left(\frac{250\ days}{year}\right)\times\left(\frac{1\ year}{365\ days}\right)\times GSF_s\,(1.0)\times ET_w\left(\frac{8\ hours}{day}\right)\times\left(\frac{1\ day}{24\ hours}\right)}$$

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

4.3 Outdoor Worker

The outdoor worker land use equation, presented here, contains the following exposure pathways and exposure routes:

Exposure to Contamination Deposited on Streets and Sidewalks

The outdoor worker is exposed to contaminated dust settled on outdoor surfaces. The outdoor worker spends his entire shift outside. Three exposure routes are presented: (1) exposure to contamination deposited on surfaces via incidental ingestion, (2) inhalation of particulates, and (3) external exposure to ionizing radiation from dust settled on contaminated surfaces.

Graphical Representation

Equations

(incidental ingestion, inhalation of particulates, and external exposure to ionizing radiation from settled dust using ground plane toxicity values)

Ingestion:

$$SDCC_{odw\text{-}dust\text{-}ing}\left(pCi/cm^2\right) = \frac{DL\left(\frac{mrem}{year}\right)\times t_{ow}\,(1\ year)\times\lambda\left(\frac{1}{year}\right)}{\left(\frac{1-e^{-kt_{ow}}}{kt_{ow}}\right)\times\left(1-e^{-\lambda t_{ow}}\right)\times DCF_{oa}\left(\frac{mrem}{pCi}\right)\times IFD_{ow}\left(\frac{196\ cm^2}{day}\right)\times EF_{ow}\left(\frac{225\ days}{year}\right)}$$

where:

$$IFD_{ow}\left(\frac{196\ cm^2}{day}\right) = \left[FTSS_h\,(0.5)\times ET_{ow}\left(\frac{8\ hours}{day}\right)\times SE\,(0.5)\times SA_{ow}\left(\frac{49\ cm^2}{event}\right)\times FQ_{ow}\left(\frac{2\ events}{hour}\right)\right]$$

Inhalation with PEF $_{wind}$

$$SDCC_{odw\text{-}dust\text{-}inhw}\left(pCi/cm^2\right) = \frac{DL\left(\frac{mrem}{year}\right)\times t_{ow}\,(1\ year)\times\lambda\left(\frac{1}{year}\right)}{\left(\frac{1-e^{-kt_{ow}}}{kt_{ow}}\right)\times\left(1-e^{-\lambda t_{ow}}\right)\times DCF_i\left(\frac{mrem}{pCi}\right)\times IRA_{ow}\left(\frac{2.5\ m^3}{hour}\right)\times ET_{ow}\left(\frac{8\ hours}{day}\right)\times EF_{ow}\left(\frac{225\ days}{year}\right)\times\frac{1}{PEF_w\left(\frac{m^3}{kg}\right)}\times SLF\left(\frac{6.\bar{6}\ E{+}08\ cm^2}{kg}\right)}$$

Inhalation with PEF $_{mechanical}$

$$SDCC_{odw\text{-}dust\text{-}inhm}\left(pCi/cm^2\right) = \frac{DL\left(\frac{mrem}{year}\right)\times t_{ow}\,(1\ year)\times\lambda\left(\frac{1}{year}\right)}{\left(\frac{1-e^{-kt_{ow}}}{kt_{ow}}\right)\times\left(1-e^{-\lambda t_{ow}}\right)\times DCF_i\left(\frac{mrem}{pCi}\right)\times IRA_{ow}\left(\frac{2.5\ m^3}{hour}\right)\times ET_{ow}\left(\frac{8\ hours}{day}\right)\times EF_{ow}\left(\frac{225\ days}{year}\right)\times\frac{1}{PEF_m\left(\frac{m^3}{kg}\right)}\times SLF\left(\frac{6.\bar{6}\ E{+}08\ cm^2}{kg}\right)}$$

Inhalation with PEF $_{wind}$ for State-Specific

$$SDCC_{odw\text{-}dust\text{-}inhw\text{-}state}\left(pCi/cm^2\right) = \frac{DL\left(\frac{mrem}{year}\right)\times t_{ow}\,(1\ year)\times\lambda\left(\frac{1}{year}\right)}{\left(\frac{1-e^{-kt_{ow}}}{kt_{ow}}\right)\times\left(1-e^{-\lambda t_{ow}}\right)\times DCF_i\left(\frac{mrem}{pCi}\right)\times IRA_{ow}\left(\frac{2.5\ m^3}{hour}\right)\times ET_{ow}\left(\frac{8\ hours}{day}\right)\times EF_{ow}\left(\frac{225\ days}{year}\right)\times\frac{1}{PEF_w\left(\frac{m^3}{kg}\right)}\times SLF\left(\frac{cm^2}{kg}\right)}$$

Inhalation with PEF $_{mechanical}$ for State-Specific

$$SDCC_{odw\text{-}dust\text{-}inhm\text{-}state}\left(pCi/cm^2\right) = \frac{DL\left(\frac{mrem}{year}\right)\times t_{ow}\,(1\ year)\times\lambda\left(\frac{1}{year}\right)}{\left(\frac{1-e^{-kt_{ow}}}{kt_{ow}}\right)\times\left(1-e^{-\lambda t_{ow}}\right)\times DCF_i\left(\frac{mrem}{pCi}\right)\times IRA_{ow}\left(\frac{2.5\ m^3}{hour}\right)\times ET_{ow}\left(\frac{8\ hours}{day}\right)\times EF_{ow}\left(\frac{225\ days}{year}\right)\times\frac{1}{PEF_m\left(\frac{m^3}{kg}\right)}\times SLF\left(\frac{cm^2}{kg}\right)}$$

External:

$$SDCC_{odw\text{-}dust\text{-}ext}\left(\frac{pCi}{cm^2}\right) = \frac{DL\left(\frac{mrem}{year}\right)\times t_{ow}\,(1\ year)\times\lambda\left(\frac{1}{year}\right)}{\left(\frac{1-e^{-kt_{ow}}}{kt_{ow}}\right)\times\left(1-e^{-\lambda t_{ow}}\right)\times DCF_{ext\text{-}gp}\left(\frac{mrem/year}{pCi/cm^2}\right)\times F_{AM}\times F_{OFF\text{-}SET}\times ACF_{ext\text{-}gp}\times EF_{ow}\left(\frac{225\ days}{year}\right)\times\left(\frac{1\ year}{365\ days}\right)\times GSF_s\,(1.0)\times ET_{ow}\left(\frac{8\ hours}{day}\right)\times\left(\frac{1\ day}{24\ hours}\right)}$$

Total:

$$SDCC_{odw\text{-}dust\text{-}tot}\left(pCi/cm^2\right) = \frac{1}{\frac{1}{SDCC_{odw\text{-}dust\text{-}ing}}+\frac{1}{SDCC_{odw\text{-}dust\text{-}inh}}+\frac{1}{SDCC_{odw\text{-}dust\text{-}ext}}}$$

The resulting units for this recommended SDCC are in pCi/cm^2. The units are based on area, because the SF used is the ground plane for external exposure and the ingestion route is based on hand surface area contacting dust on surfaces and subsequent hand to mouth transfer events. This equation is for values of k that are greater than 0; when k=0, the dissipation term is not quantified to avoid division by zero.

3-D Direct External Exposure

The only pathway considered is external exposure to ionizing radiation. It is assumed that the street (horizontal) and the building walls (vertical) on both sides of the street are radioactively contaminated.

Graphical Representation

Outdoor Worker - 3-D External Exposure to Contaminated Building Materials in Outdoor Surfaces. The outdoor worker is exposed to contaminated building materials in outdoor surfaces.

Outdoor Worker - 3-D External Exposure to Outdoor Surfaces. The outdoor worker is exposed to settled dust on outdoor surfaces.

Equations

(Materials with fixed contamination at infinite depth in outside walls, streets, and sidewalks using infinite soil volume toxicity values)

$$SDCC_{odw\text{-}3D\text{-}ext\text{-}sv}\left(\frac{pCi}{g}\right)=\frac{DL\,(mrem)\times t_{ow}\,(1\ year)\times\lambda\left(\frac{1}{year}\right)}{\left(1\text{-}e^{-\lambda t_{ow}}\right)\times DCF_{ext\text{-}sv}\left(\frac{mrem/year}{pCi/g}\right)\times F_{AM}\times F_{OFF\text{-}SET}\times F_{s\text{-}surf}\times EF_{ow}\left(\frac{225\ days}{year}\right)\times\left(\frac{1\ year}{365\ days}\right)\times GSF_{s}\,(1.0)\times ET_{ow}\left(\frac{8\ hours}{day}\right)\times\left(\frac{1\ day}{24\ hours}\right)}$$

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

(Materials with fixed contamination at 1cm in outside walls, streets, and sidewalks using 1cm soil volume toxicity values)

$$SDCC_{odw\text{-}3D\text{-}ext\text{-}1cm}\left(\frac{pCi}{g}\right)=\frac{DL\left(\frac{mrem}{year}\right)\times t_{ow}\,(year)\times\lambda\left(\frac{1}{year}\right)}{\left(1\text{-}e^{-\lambda t_{ow}}\right)\times DCF_{ext\text{-}1cm}\left(\frac{mrem/year}{pCi/g}\right)\times F_{AM}\times F_{OFF\text{-}SET}\times F_{s\text{-}surf}\times EF_{ow}\left(\frac{225\ days}{year}\right)\times\left(\frac{1\ year}{365\ days}\right)\times GSF_{s}\,(1.0)\times ET_{ow}\left(\frac{8\ hours}{day}\right)\times\left(\frac{1\ day}{24\ hours}\right)}$$

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

(Materials with fixed contamination at 5cm in outside walls, streets, and sidewalks using 5cm soil volume toxicity values)

$$SDCC_{odw\text{-}3D\text{-}ext\text{-}5cm}\left(\frac{pCi}{g}\right)=\frac{DL\left(\frac{mrem}{year}\right)\times t_{ow}\,(1\ year)\times\lambda\left(\frac{1}{year}\right)}{\left(1-e^{-\lambda t_{ow}}\right)\times DCF_{ext\text{-}5cm}\left(\frac{mrem/year}{pCi/g}\right)\times F_{AM}\times F_{OFF\text{-}SET}\times F_{s\text{-}surf}\times EF_{ow}\left(\frac{225\ days}{year}\right)\times\left(\frac{1\ year}{365\ days}\right)\times GSF_{s}\,(1.0)\times ET_{ow}\left(\frac{8\ hours}{day}\right)\times\left(\frac{1\ day}{24\ hours}\right)}$$

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

(Materials with fixed contamination at 15cm in outside walls, streets, and sidewalks using 15cm soil volume toxicity values)

$$SDCC_{odw\text{-}3D\text{-}ext\text{-}15cm}\left(\frac{pCi}{g}\right)=\frac{DL\left(\frac{mrem}{year}\right)\times t_{ow}\,(year)\times\lambda\left(\frac{1}{year}\right)}{\left(1-e^{-\lambda t_{ow}}\right)\times DCF_{ext\text{-}15cm}\left(\frac{mrem/year}{pCi/g}\right)\times F_{AM}\times F_{OFF\text{-}SET}\times F_{s\text{-}surf}\times EF_{ow}\left(\frac{225\ days}{year}\right)\times\left(\frac{1\ year}{365\ days}\right)\times GSF_{s}\,(1.0)\times ET_{ow}\left(\frac{8\ hours}{day}\right)\times\left(\frac{1\ day}{24\ hours}\right)}$$

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

(Fixed contaminated dust on surfaces of outside walls, streets, and sidewalks using ground plane toxicity values)

$$SDCC_{odw\text{-}3D\text{-}ext\text{-}gp}\left(\frac{pCi}{cm^2}\right)=\frac{DL\left(\frac{mrem}{year}\right)\times t_{ow}\,(year)\times\lambda\left(\frac{1}{year}\right)}{\left(1-e^{-\lambda t_{ow}}\right)\times DCF_{ext\text{-}gp}\left(\frac{mrem/year}{pCi/cm^2}\right)\times F_{AM}\times F_{OFF\text{-}SET}\times F_{s\text{-}surf}\times EF_{ow}\left(\frac{225\ days}{year}\right)\times\left(\frac{1\ year}{365\ days}\right)\times GSF_{s}\,(1.0)\times ET_{ow}\left(\frac{8\ hours}{day}\right)\times\left(\frac{1\ day}{24\ hours}\right)}$$

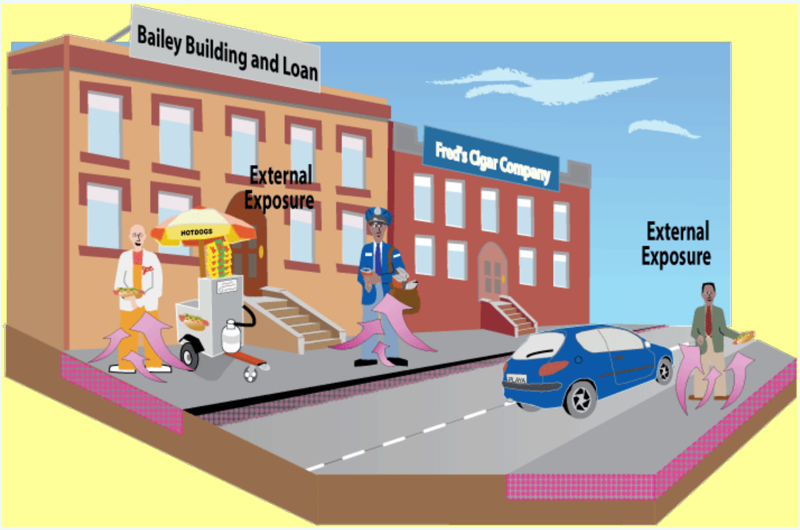
The resulting units for this recommended SDCC are in pCi/cm^2. The units are based on area, because the SF used is the ground plane for external exposure

2-D Direct External Exposure

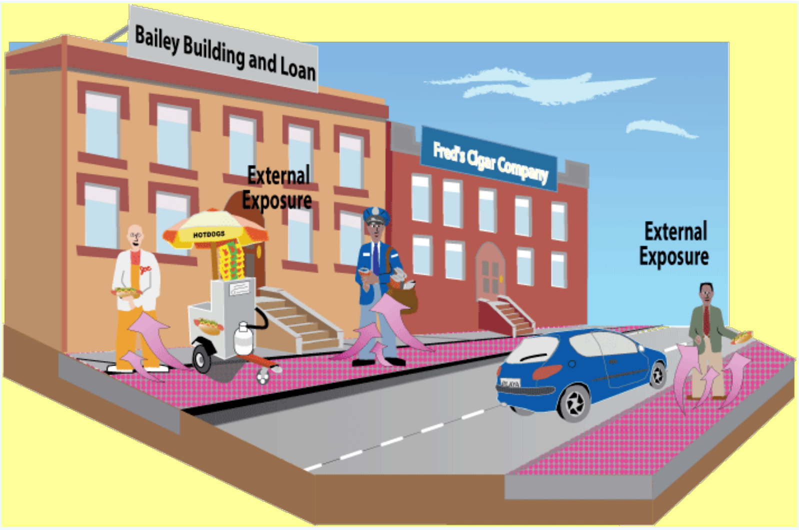
The only pathway considered is external exposure to ionizing radiation.

Graphical Representation

Outdoor Worker - 2-D External Exposure to Contaminated Finite Slabs. The outdoor worker is exposed to contaminated finite slabs. It is assumed that the finite slab (horizontal) is constructed with contaminated materials.



Outdoor Worker - 2-D External Exposure to Settled Dust on Finite Slabs. The outdoor worker is exposed to settled dust on finite slabs. It is assumed that the dust on the finite slab (horizontal) is radioactively contaminated.



Equations

(Materials with fixed contamination in a finite slab using infinite soil volume toxicity values)

$$SDCC_{odw\text{-}2D\text{-}ext\text{-}sv}\left(\frac{pCi}{g}\right)=\frac{DL\,(mrem)\times t_{ow}\,(1\ year)\times\lambda\left(\frac{1}{year}\right)}{\left(1-e^{-\lambda t_{ow}}\right)\times DCF_{ext\text{-}sv}\left(\frac{mrem/year}{pCi/g}\right)\times F_{AM}\times F_{OFF\text{-}SET}\times ACF_{ext\text{-}sv}\times EF_{ow}\left(\frac{225\ days}{year}\right)\times\left(\frac{1\ year}{365\ days}\right)\times GSF_{s}\,(1.0)\times ET_{ow}\left(\frac{8\ hours}{day}\right)\times\left(\frac{1\ day}{24\ hours}\right)}$$

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

(Materials with fixed contamination in a finite slab at 1cm depth using 1cm soil volume toxicity values)

$$SDCC_{odw\text{-}2D\text{-}ext\text{-}1cm}\left(\frac{pCi}{g}\right)=\frac{DL\left(\frac{mrem}{year}\right)\times t_{ow}\,(year)\times\lambda\left(\frac{1}{year}\right)}{\left(1-e^{-\lambda t_{ow}}\right)\times DCF_{ext\text{-}1cm}\left(\frac{mrem/year}{pCi/g}\right)\times F_{AM}\times F_{OFF\text{-}SET}\times ACF_{ext\text{-}1cm}\times EF_{ow}\left(\frac{225\ days}{year}\right)\times\left(\frac{1\ year}{365\ days}\right)\times GSF_{s}\,(1.0)\times ET_{ow}\left(\frac{8\ hours}{day}\right)\times\left(\frac{1\ day}{24\ hours}\right)}$$

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

(Materials with fixed contamination in a finite slab at 5cm depth using 5cm soil volume toxicity values)

$$SDCC_{odw\text{-}2D\text{-}ext\text{-}5cm}\left(\frac{pCi}{g}\right)=\frac{DL\left(\frac{mrem}{year}\right)\times t_{ow}\,(1\ year)\times\lambda\left(\frac{1}{year}\right)}{\left(1-e^{-\lambda t_{ow}}\right)\times DCF_{ext\text{-}5cm}\left(\frac{mrem/year}{pCi/g}\right)\times F_{AM}\times F_{OFF\text{-}SET}\times ACF_{ext\text{-}5cm}\times EF_{ow}\left(\frac{225\ days}{year}\right)\times\left(\frac{1\ year}{365\ days}\right)\times GSF_{s}\,(1.0)\times ET_{ow}\left(\frac{8\ hours}{day}\right)\times\left(\frac{1\ day}{24\ hours}\right)}$$

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

(Materials with fixed contamination in a finite slab at 15cm depth using 15cm soil volume toxicity values)

$$SDCC_{odw\text{-}2D\text{-}ext\text{-}15cm}\left(\frac{pCi}{g}\right)=\frac{DL\left(\frac{mrem}{year}\right)\times t_{ow}\,(year)\times\lambda\left(\frac{1}{year}\right)}{\left(1-e^{-\lambda t_{ow}}\right)\times DCF_{ext\text{-}15cm}\left(\frac{mrem/year}{pCi/g}\right)\times F_{AM}\times F_{OFF\text{-}SET}\times ACF_{ext\text{-}15cm}\times EF_{ow}\left(\frac{225\ days}{year}\right)\times\left(\frac{1\ year}{365\ days}\right)\times GSF_{s}\,(1.0)\times ET_{ow}\left(\frac{8\ hours}{day}\right)\times\left(\frac{1\ day}{24\ hours}\right)}$$

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

(Materials with fixed contamination in a finite slab using ground plane toxicity values)

$$SDCC_{odw\text{-}2D\text{-}ext\text{-}gp}\left(\frac{pCi}{cm^2}\right)=\frac{DL\left(\frac{mrem}{year}\right)\times t_{ow}\,(year)\times\lambda\left(\frac{1}{year}\right)}{\left(1-e^{-\lambda t_{ow}}\right)\times DCF_{ext\text{-}gp}\left(\frac{mrem/year}{pCi/cm^2}\right)\times F_{AM}\times F_{OFF\text{-}SET}\times ACF_{ext\text{-}gp}\times EF_{ow}\left(\frac{225\ days}{year}\right)\times\left(\frac{1\ year}{365\ days}\right)\times GSF_{s}\,(1.0)\times ET_{ow}\left(\frac{8\ hours}{day}\right)\times\left(\frac{1\ day}{24\ hours}\right)}$$

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

4.4 Indoor Worker

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

Exposure to Contamination Deposited on Streets and Sidewalks

The indoor worker is exposed to contaminated dust settled on outdoor surfaces. The indoor worker spends his entire shift inside. Three exposure routes are presented: (1) exposure to contamination deposited on surfaces via incidental ingestion, (2) inhalation of particulates, and (3) external exposure to ionizing radiation from dust settled on contaminated surfaces. This indoor worker equation includes an indoor air dilution factor for inhalation and a gamma shielding factor for external exposure.

Graphical Representation

Equations

(incidental ingestion, inhalation of particulates, and external exposure to ionizing radiation from settled dust using ground plane toxicity values)

Ingestion

$$SDCC_{idw\text{-}dust\text{-}ing}\left(\frac{pCi}{cm^2}\right) = \frac{DL\left(\frac{mrem}{year}\right) \times t_{iw}\,(year) \times \lambda\left(\frac{1}{year}\right)}{\left(\frac{1-e^{-kt_{iw}}}{kt_{iw}}\right) \times \left(1-e^{-\lambda t_{iw}}\right) \times DCF_{oa}\left(\frac{mrem}{pCi}\right) \times IFD_{iw}\left(\frac{294\ cm^2}{day}\right) \times EF_{iw}\left(\frac{250\ days}{year}\right)}$$

where:

$$IFD_{iw}\left(\frac{294\ cm^2}{day}\right) = \left(FTSS_h\,(0.5) \times ET_{iw}\left(\frac{8\ hours}{day}\right) \times SE\,(0.5) \times SA_{iw}\left(\frac{49\ cm^2}{event}\right) \times FQ_{iw}\left(\frac{3\ events}{hour}\right)\right)$$

Inhalation with PEF $_{wind}$

$$SDCC_{idw\text{-}dust\text{-}inhw}\left(\frac{pCi}{cm^2}\right) = \frac{DL\left(\frac{mrem}{year}\right) \times t_{iw}\,(year) \times \lambda\left(\frac{1}{year}\right)}{\left(\frac{1-e^{-kt_{iw}}}{kt_{iw}}\right) \times \left(1-e^{-\lambda t_{iw}}\right) \times DCF_i\left(\frac{mrem}{pCi}\right) \times IRA_{iw}\left(\frac{2.5\ m^3}{hour}\right) \times ET_{iw}\left(\frac{8\ hours}{day}\right) \times EF_{iw}\left(\frac{250\ days}{year}\right) \times \frac{1}{PEF_w\left(\frac{m^3}{kg}\right)} \times SLF\left(\frac{6.\bar{6}\ E+08\ cm^2}{kg}\right)}$$

Inhalation with PEF $_{mechanical}$

$$SDCC_{idw\text{-}dust\text{-}inhm}\left(\frac{pCi}{cm^2}\right) = \frac{DL\left(\frac{mrem}{year}\right) \times t_{iw}\,(year) \times \lambda\left(\frac{1}{year}\right)}{\left(\frac{1-e^{-kt_{iw}}}{kt_{iw}}\right) \times \left(1-e^{-\lambda t_{iw}}\right) \times DCF_i\left(\frac{mrem}{pCi}\right) \times IRA_{iw}\left(\frac{2.5\ m^3}{hour}\right) \times ET_{iw}\left(\frac{8\ hours}{day}\right) \times EF_{iw}\left(\frac{250\ days}{year}\right) \times \frac{1}{PEF_m\left(\frac{m^3}{kg}\right)} \times SLF\left(\frac{6.\bar{6}\ E+08\ cm^2}{kg}\right)}$$

Inhalation with PEF $_{wind}$ for State-Specific

$$SDCC_{idw\text{-}dust\text{-}inhw\text{-}state}\left(\frac{pCi}{cm^2}\right) = \frac{DL\left(\frac{mrem}{year}\right) \times t_{iw}\,(year) \times \lambda\left(\frac{1}{year}\right)}{\left(\frac{1-e^{-kt_{iw}}}{kt_{iw}}\right) \times \left(1-e^{-\lambda t_{iw}}\right) \times DCF_i\left(\frac{mrem}{pCi}\right) \times IRA_{iw}\left(\frac{2.5\ m^3}{hour}\right) \times ET_{iw}\left(\frac{8\ hours}{day}\right) \times EF_{iw}\left(\frac{250\ days}{year}\right) \times \frac{1}{PEF_w\left(\frac{m^3}{kg}\right)} \times SLF\left(\frac{cm^2}{kg}\right)}$$

Inhalation with PEF $_{mechanical}$ for State-Specific

$$SDCC_{idw\text{-}dust\text{-}inhm\text{-}state}\left(\frac{pCi}{cm^2}\right) = \frac{DL\left(\frac{mrem}{year}\right) \times t_{iw}\,(year) \times \lambda\left(\frac{1}{year}\right)}{\left(\frac{1-e^{-kt_{iw}}}{kt_{iw}}\right) \times \left(1-e^{-\lambda t_{iw}}\right) \times DCF_i\left(\frac{mrem}{pCi}\right) \times IRA_{iw}\left(\frac{2.5\ m^3}{hour}\right) \times ET_{iw}\left(\frac{8\ hours}{day}\right) \times EF_{iw}\left(\frac{250\ days}{year}\right) \times \frac{1}{PEF_m\left(\frac{m^3}{kg}\right)} \times SLF\left(\frac{cm^2}{kg}\right)}$$

External

$$SDCC_{idw\text{-}dust\text{-}ext}\left(\frac{pCi}{cm^2}\right) = \frac{DL\left(\frac{mrem}{year}\right)\times t_{iw}(year)\times\lambda\left(\frac{1}{year}\right)}{\left(\frac{1-e^{-kt_{iw}}}{kt_{iw}}\right)\times\left(1-e^{-\lambda t_{iw}}\right)\times DCF_{ext\text{-}gp}\left(\frac{mrem/year}{pCi/cm^2}\right)\times F_{AM}\times F_{OFF\text{-}SET}\times ACF_{ext\text{-}gp}\times EF_{iw}\left(\frac{250\ days}{year}\right)\times\left(\frac{1\ year}{365\ days}\right)\times GSF_i(0.4)\times ET_{iw}\left(\frac{8\ hours}{day}\right)\times\left(\frac{1\ day}{24\ hours}\right)}$$

Total

$$SDCC_{idw\text{-}dust\text{-}tot}\left(pCi/cm^2\right) = \frac{1}{\frac{1}{SDCC_{idw\text{-}dust\text{-}ing}}+\frac{1}{SDCC_{idw\text{-}dust\text{-}inh}}+\frac{1}{SDCC_{idw\text{-}dust\text{-}ext}}}$$

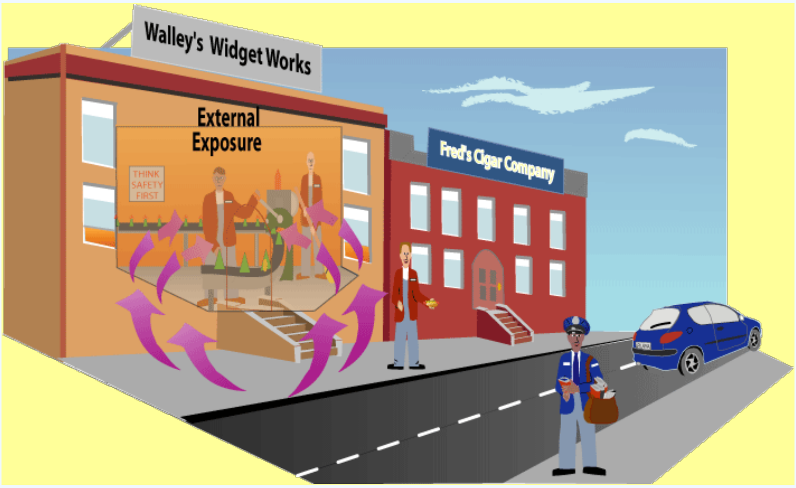
The resulting units for this recommended SDCC are in pCi/cm^2. The units are based on area, because the SF used is the ground plane for external exposure and the ingestion route is based on hand surface area contacting dust on surfaces and subsequent hand to mouth transfer events. This equation is for values of k that are greater than 0; when k=0, the dissipation term is not quantified to avoid division by zero.

3-D Direct External Exposure

The only pathway considered is external exposure to ionizing radiation. It is assumed that the street (horizontal) and the building walls (vertical) on both sides of the street are radioactively contaminated. These equations include a gamma shielding factor for external exposure.

Graphical Representation

Indoor Worker - 3-D External Exposure to Contaminated Building Materials in Outdoor Surfaces. The indoor worker is exposed to contaminated building materials in outdoor surfaces.



Indoor Worker - 3-D External Exposure to Outdoor Surfaces. The indoor worker is exposed to settled dust on outdoor surfaces.

Equations

(Materials with fixed contamination at infinite depth in outside walls, streets, and sidewalks using infinite soil volume toxicity values)

$$SDCC_{idw\text{-}3D\text{-}ext\text{-}sv}\left(\frac{pCi}{g}\right)=\frac{DL\left(\frac{mrem}{year}\right)\times t_{iw}\,(year)\times\lambda\left(\frac{1}{year}\right)}{\left(1\text{-}e^{-\lambda t_{iw}}\right)\times DCF_{ext\text{-}sv}\left(\frac{mrem/year}{pCi/g}\right)\times F_{AM}\times F_{OFF\text{-}SET}\times F_{s\text{-}surf}\times EF_{iw}\left(\frac{250\ days}{year}\right)\times\left(\frac{1\ year}{365\ days}\right)\times GSF_i\,(0.4)\times ET_{iw}\left(\frac{8\ hours}{day}\right)\times\left(\frac{1\ day}{24\ hours}\right)}$$

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

(Materials with fixed contamination at 1cm in outside walls, streets, and sidewalks using 1cm soil volume toxicity values)

$$SDCC_{idw\text{-}3D\text{-}ext\text{-}1cm}\left(\frac{pCi}{g}\right)=\frac{DL\left(\frac{mrem}{year}\right)\times t_{iw}\,(year)\times\lambda\left(\frac{1}{year}\right)}{\left(1\text{-}e^{-\lambda t_{iw}}\right)\times DCF_{ext\text{-}1cm}\left(\frac{mrem/year}{pCi/g}\right)\times F_{AM}\times F_{OFF\text{-}SET}\times F_{s\text{-}surf}\times EF_{iw}\left(\frac{250\ days}{year}\right)\times\left(\frac{1\ year}{365\ days}\right)\times GSF_i\,(0.4)\times ET_{iw}\left(\frac{8\ hours}{day}\right)\times\left(\frac{1\ day}{24\ hours}\right)}$$

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

(Materials with fixed contamination at 5cm in outside walls, streets, and sidewalks using 5cm soil volume toxicity values)

$$SDCC_{idw\text{-}3D\text{-}ext\text{-}5cm}\left(\frac{pCi}{g}\right)=\frac{DL\left(\frac{mrem}{year}\right)\times t_{iw}\,(year)\times\lambda\left(\frac{1}{year}\right)}{\left(1\text{-}e^{-\lambda t_{iw}}\right)\times DCF_{ext\text{-}5cm}\left(\frac{mrem/year}{pCi/g}\right)\times F_{AM}\times F_{OFF\text{-}SET}\times F_{s\text{-}surf}\times EF_{iw}\left(\frac{250\ days}{year}\right)\times\left(\frac{1\ year}{365\ days}\right)\times GSF_i\,(0.4)\times ET_{iw}\left(\frac{8\ hours}{day}\right)\times\left(\frac{1\ day}{24\ hours}\right)}$$

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

(Materials with fixed contamination at 15cm in outside walls, streets, and sidewalks using 15cm soil volume toxicity values)

$$SDCC_{idw\text{-}3D\text{-}ext\text{-}15cm}\left(\frac{pCi}{g}\right)=\frac{DL\left(\frac{mrem}{year}\right)\times t_{iw}\,(year)\times\lambda\left(\frac{1}{year}\right)}{\left(1\text{-}e^{-\lambda t_{iw}}\right)\times DCF_{ext\text{-}15cm}\left(\frac{mrem/year}{pCi/g}\right)\times F_{AM}\times F_{OFF\text{-}SET}\times F_{s\text{-}surf}\times EF_{iw}\left(\frac{250\ days}{year}\right)\times\left(\frac{1\ year}{365\ days}\right)\times GSF_i\,(0.4)\times ET_{iw}\left(\frac{8\ hours}{day}\right)\times\left(\frac{1\ day}{24\ hours}\right)}$$

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

(Materials with fixed contamination in a finite slab using ground plane toxicity values)

$$SDCC_{idw\text{-}3D\text{-}ext\text{-}gp}\left(\frac{pCi}{cm^2}\right)=\frac{DL\left(\frac{mrem}{year}\right)\times t_{iw}\,(year)\times\lambda\left(\frac{1}{year}\right)}{\left(1\text{-}e^{-\lambda t_{iw}}\right)\times DCF_{ext\text{-}gp}\left(\frac{mrem/year}{pCi/cm^2}\right)\times F_{AM}\times F_{OFF\text{-}SET}\times F_{s\text{-}surf}\times EF_{iw}\left(\frac{250\ days}{year}\right)\times\left(\frac{1\ year}{365\ days}\right)\times GSF_i\,(0.4)\times ET_{iw}\left(\frac{8\ hours}{day}\right)\times\left(\frac{1\ day}{24\ hours}\right)}$$

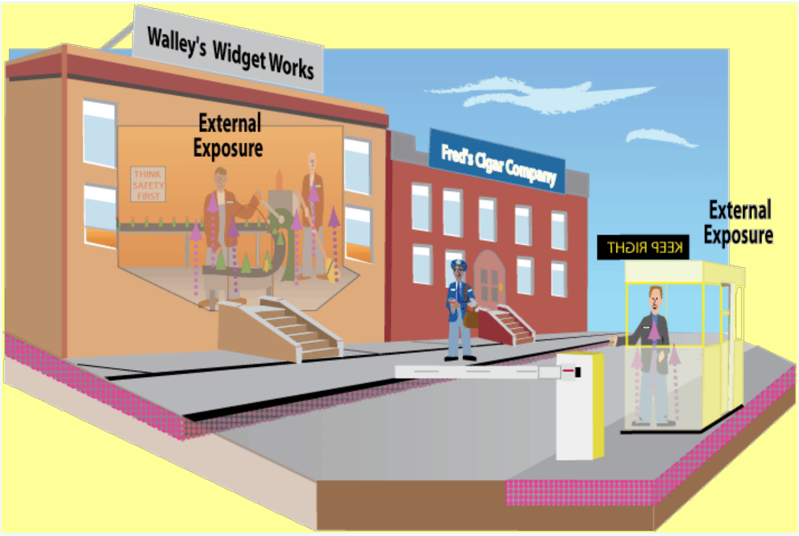
The resulting units for this recommended SDCC are in pCi/cm^2. The units are based on area, because the SF used is the ground plane for external exposure.

2-D Direct External Exposure

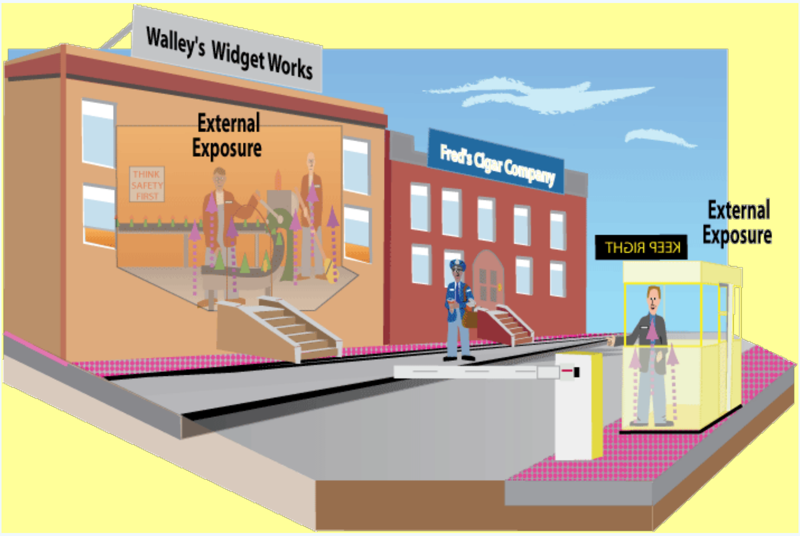
The only pathway considered is external exposure to ionizing radiation. It is assumed the worker is employed in a structure built on top of the middle of the slab.

Graphical Representation

Indoor Worker - 2-D External Exposure to Contaminated Finite Slabs. The indoor worker is exposed to contaminated finite slabs. It is assumed that the finite slab (horizontal) is constructed with contaminated materials.



Indoor Worker - 2-D External Exposure to Settled Dust on Finite Slabs. The indoor worker is exposed to settled dust on finite slabs. It is assumed that the dust on the finite slab (horizontal) is radioactively contaminated.



Equations

(Materials with fixed contamination in a finite slab using infinite soil volume toxicity values)

$$SDCC_{idw\text{-}2D\text{-}ext\text{-}sv}\left(\frac{pCi}{g}\right) = \frac{DL\left(\frac{mrem}{year}\right) \times t_{iw}\,(year) \times \lambda\left(\frac{1}{year}\right)}{\left(1\text{-}e^{-\lambda t_{iw}}\right) \times DCF_{ext\text{-}sv}\left(\frac{mrem/year}{pCi/g}\right) \times F_{AM} \times F_{OFF\text{-}SET} \times ACF_{ext\text{-}sv} \times EF_{iw}\left(\frac{250\ days}{year}\right) \times \left(\frac{1\ year}{365\ days}\right) \times GSF_{i}\,(0.4) \times ET_{iw}\left(\frac{8\ hours}{day}\right) \times \left(\frac{1\ day}{24\ hours}\right)}$$

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

(Materials with fixed contamination in a finite slab at 1cm depth using 1cm soil volume toxicity values)

$$SDCC_{idw\text{-}2D\text{-}ext\text{-}1cm}\left(\frac{pCi}{g}\right) = \frac{DL\left(\frac{mrem}{year}\right) \times t_{iw}\,(year) \times \lambda\left(\frac{1}{year}\right)}{\left(1\text{-}e^{-\lambda t_{iw}}\right) \times DCF_{ext\text{-}1cm}\left(\frac{mrem/year}{pCi/g}\right) \times F_{AM} \times F_{OFF\text{-}SET} \times ACF_{ext\text{-}1cm} \times EF_{iw}\left(\frac{250\ days}{year}\right) \times \left(\frac{1\ year}{365\ days}\right) \times GSF_{i}\,(0.4) \times ET_{iw}\left(\frac{8\ hours}{day}\right) \times \left(\frac{1\ day}{24\ hours}\right)}$$

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

(Materials with fixed contamination in a finite slab at 5cm depth using 5cm soil volume toxicity values)

$$SDCC_{idw\text{-}2D\text{-}ext\text{-}5cm}\left(\frac{pCi}{g}\right)=\frac{DL\left(\frac{mrem}{year}\right)\times t_{iw}(year)\times\lambda\left(\frac{1}{year}\right)}{\left(1\text{-}e^{-\lambda t_{iw}}\right)\times DCF_{ext\text{-}5cm}\left(\frac{mrem/year}{pCi/g}\right)\times F_{AM}\times F_{OFF\text{-}SET}\times ACF_{ext\text{-}5cm}\times EF_{iw}\left(\frac{250\ days}{year}\right)\times\left(\frac{1\ year}{365\ days}\right)\times GSF_i(0.4)\times ET_{iw}\left(\frac{8\ hours}{day}\right)\times\left(\frac{1\ day}{24\ hours}\right)}$$

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

(Materials with fixed contamination in a finite slab at 15cm depth using 15cm soil volume toxicity values)

$$SDCC_{idw\text{-}2D\text{-}ext\text{-}15cm}\left(\frac{pCi}{g}\right)=\frac{DL\left(\frac{mrem}{year}\right)\times t_{iw}(year)\times\lambda\left(\frac{1}{year}\right)}{\left(1\text{-}e^{-\lambda t_{iw}}\right)\times DCF_{ext\text{-}15cm}\left(\frac{mrem/year}{pCi/g}\right)\times F_{AM}\times F_{OFF\text{-}SET}\times ACF_{ext\text{-}15cm}\times EF_{iw}\left(\frac{250\ days}{year}\right)\times\left(\frac{1\ year}{365\ days}\right)\times GSF_i(0.4)\times ET_{iw}\left(\frac{8\ hours}{day}\right)\times\left(\frac{1\ day}{24\ hours}\right)}$$

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

(Materials with fixed contamination in a finite slab using ground plane toxicity values)

$$SDCC_{idw\text{-}2D\text{-}ext\text{-}gp}\left(\frac{pCi}{cm^2}\right)=\frac{DL\left(\frac{mrem}{year}\right)\times t_{iw}(year)\times\lambda\left(\frac{1}{year}\right)}{\left(1\text{-}e^{-\lambda t_{iw}}\right)\times DCF_{ext\text{-}gp}\left(\frac{mrem/year}{pCi/cm^2}\right)\times F_{AM}\times F_{OFF\text{-}SET}\times ACF_{ext\text{-}gp}\times EF_{iw}\left(\frac{250\ days}{year}\right)\times\left(\frac{1\ year}{365\ days}\right)\times GSF_i(0.4)\times ET_{iw}\left(\frac{8\ hours}{day}\right)\times\left(\frac{1\ day}{24\ hours}\right)}$$

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

4.5 Exposure Parameter Justification

The following sections describe the exposure parameter default variables and the values selected. The default parameters are listed in Table 1.

4.5.1 Exposure Time (ET)

The exposure time represents the hours per day that a receptor spends exposed to a source. The exposure times vary by exposure scenario, age of the receptor, and whether the source is located on a hard or soft surface. This calculator only calculates exposure to hard surfaces. For the resident ingestion pathway, the hard surface exposure time of 4 hours per day is used for adult and child. This value is from the EPA Office of Pesticide Programs (OPP). For inhalation and external exposure for the resident, the exposure time indoors is set at 16.4 hours per day, and the exposure time outdoors is set at 1.752 hours per day. These values are from the 1997 Exposure Factors Handbook. Note that inhalation and subsequent ingestion of dust particles trapped in mucous is not quantified in the SDCC equations due to lack of exposure information.

For the outdoor and indoor worker, exposure time for the dust ingestion exposure route is based on exposure to hard surfaces. For this calculator, the defaults were set at 8 hour/d. The exposure time for direct external exposure is the entire work day, or 8 hour/d.

4.5.2 Fraction Transferred from Surface to Skin (FTSS)

In general, this is the fraction of residue on a surface that can be transferred to skin. U.S. EPA 2003 (pg D-5) states that hand press experiments were conducted on dry skin. Transfers of 50% were observed for hard surfaces. These are considered representative of the WTC situation and were adopted for this calculator.

4.5.3 Surface Area (SA)

In general, this is the skin area contacted during the mouthing event. The OPP recommended default was based on the surface area of the 3 fingers that a child will most likely use for hand to mouth transfer. It was assumed that 3 fingers of one hand represents about 5% of the total area of both hands (U.S. EPA 2003). The exposure factor handbook (U.S. EPA 2011 Table 7.2) presents hand surface areas for adults and children. For children, the surface areas were time-weight averaged across all age groups from birth to 6 years (317 cm^2), and the 5% assumption was applied to derive the child hand surface area of 16 cm^2.

The hand surface area for the adult was also derived from data presented in the exposure factor handbook (U.S. EPA 2011 Table 7.2). The exposure factor handbook presents hand surface areas for male and female adults of 1070 and 890 cm^2, respectively. These numbers were averaged (980 cm^2, and the 5% assumption was applied to derive the adult hand surface area of 49 cm^2.

4.5.4 Frequency of Hand to Mouth (FQ)

The exposure factors handbook (U.S. EPA 2011 Table 4-1) and the world trade center report (U.S. EPA 2003) provide hand to mouth contact rates for many age groups. For the child FQ, all age groups for mean outdoor contact from birth to 6 years old were time-weight averaged from the exposure factors handbook. Missing data points were substituted with data from the nearest age group. The FQ for children was determined to be 10 times/hour.

For the adult FQ, all age groups for mean indoor contact from 6 to 26 years old were time-weight averaged from the exposure factors handbook and world trade center report to generate a value of 2 times/hour. For outdoor contact, all age groups from 6 to 26 years old were time-weight averaged from the exposure factors handbook and world trade center report to generate a value of 2 times/hour. The composite worker uses the outdoor FQ.

4.5.5 Saliva Extraction Factor (SE)

In general, the fraction transferred from skin to mouth will depend on the contaminant, mouthing time, and other behavioral patterns. The OPP default is 50%, based on pesticide studies. Michaud et al (1994) assumed that all of the residues deposited on the fingertips would be transferred to the mouth, twice per day. In the Binghamton re-entry guideline derivation, a range of factors were used: 0.05, 0.1, and 0.25 representing the fraction of residue on hand that is transferred to the mouth (Kim and Hawley, 1985). For purposes of this assessment, the OPP default of 50% was selected for all ages.

4.5.6 Age-Adjusted Dust Ingestion Rate (IF)

To account for the variability in exposure activities between children and adults, the age-adjusted dust ingestion rate equation was developed. This equation takes into account the differences in hand to mouth behavior, hand surface area, and exposure to hard and soft surfaces over the exposure durations of an adult and child.

4.5.7 Dust Ingestion Rate (IR_d)

This dust ingestion equation calculates the intake for a worker based on exposure to hard surfaces.

4.5.8 Dissipation Rate Constant (k)

In some circumstances, the load of dust on a contaminated surface to which receptors are exposed may decline over time. Dissipation of dust may result from weather, cleaning, and transfer to skin and clothing. Different surfaces may be cleaned at different rates, and any dissipation rate used should consider a representative cleaning frequency. To determine whether dissipation is a factor at a given site, the site manager should establish whether a significant reservoir of contaminated dust is present. Such reservoirs may function as sources of dust and negate the impacts of dissipation mechanisms. The first step in identifying the presence of a reservoir is to examine site history. If a waste site was created through disposal, deposition, or equipment leaks over an extended period of time, then the contaminant may have seeped deep into the surface. Porous surfaces, such as cement or wood, are also more likely to have subsurface contamination. When reservoirs are less likely to exist, such as at sites where contamination is the result of a single spill, dust cloud, or event, it may be more important to account for dissipation of surface loads. For fixed contamination in materials (outside walls, streets, and pavement) or on material surfaces in the 3-D and 2-D equations, the dissipation term is not included, as dissipation is not expected.

The recommended default value for the dissipation rate constant is 0.0. This assumes that a contaminant reservoir is present. The variable, however, is adjustable in the SDCC calculator. If a dissipation rate constant is used, it is assumed that the dust was deposited as a one-time event (i.e., dust cloud). Also, if a dissipation rate is applied, it is assumed that it is applicable from the point in time the SDCC is calculated into the future. The discussion below provides a review of literature related to this issue and provides an alternative dissipation rate constant value. Site specific outdoor dissipation rate constants can be used. This equation is for values of k that are greater than 0; when k=0, the dissipation term is not quantified to avoid division by zero. See the following text.

Based on many indoor studies presented in U.S. EPA 2003 (pg. D-5), there is strong support for considering dissipation in setting criteria for outdoor building clean-ups. A study of the Binghamton State office Building found that dioxin has dissipated over time according to first order kinetics with a 20 to 22 month half-life. Even though this was an indoor study, the same principles would apply for outdoor surfaces. This dissipation is thought to occur from a combination of cleaning, resuspension, and dilution with uncontaminated dust (and possibly some volatilization). These same physical dissipation processes would apply to other compounds addressed in this study as well. Therefore, the other compounds were assumed to dissipate at the same rate as dioxin. In summary, a 22 month half-life (dissipation rate constant of 0.38 $year^{-1}$) was adopted. Exposures were calculated in a series of time steps where the residue level was assumed to dissipate according to first order kinetics:

$CSL = CSL_{initial}\ e^{-kt}$
CSL = Contaminant Surface Load (ug/cm^2)
$CSL_{initial}$ = Initial Contaminant Surface Load (ug/cm^2)
k = Dissipation Rate Constant ($year^{-1}$)
t = Time (year)

The above equation steps are shown for completeness. This SDCC calculator computes a concentration of contaminants in dust that will not exceed a target risk. The equation above simply derives the amount of dust. For this SDCC calculator, the only parts of the above equation that are relevant are the dissipation rate constant and time. By putting these variables in the denominator of the recommended SDCC resident and worker ingestion of dust equations, a higher recommended SDCC concentration would be calculated.

Further evidence that care should be taken in selecting a dissipation rate comes from the classic example of leaded gasoline. According to "*The Role of Resuspended Soil in Lead Flows in the California South Coast Air Basin*" the soil lead concentration is still over 6 times the baseline lead level from 1919 to 1933 levels. Despite leaded gasoline being phased out from 1967 to 1970 (40 years ago), the lead dissipation rate in soil is not expected to reach a steady state for more than 100 years.

WARNING: Using a dissipation rate constant or changing the value of *t* should only be done once a complete understanding of the mathematics involved in deriving the equation is gained and the site conditions have been fully investigated. Exhibit 1 displays the results obtained by changing the value *t*. *t* is equal to ED in all equations.

In the simplified PRG equation: PRG=TR/CDI*SF*(1-$e^{(-kt)}$)/(kt), where PRG is preliminary remediation goal, TR is target risk, CDI is chronic daily intake, SF is the radionuclide-specific slope factor, and (1-$e^{(-kt)}$)/(kt) is the dissipation term, Exhibit 1 shows the results of changing t. Exhibit 2 shows the results of changing k.

Exhibit 1. Results Obtained By Changing The Value *t*.

t	k	SF	CDI	TR	(1-$e^{(-kt)}$)/(kt)	PRG
year	year-1	risk/pCi	cm^2	risk	unitless	pCi/cm^2

0	0.38	1.00E-05	400	1.00E-06	1.00E+01	2.5E-04
1	0.38	1.00E-05	400	1.00E-06	8.32E-01	3.01E-04
2	0.38	1.00E-05	400	1.00E-06	7.00E-01	3.57E-04
3	0.38	1.00E-05	400	1.00E-06	5.97E-01	4.19E-04
4	0.38	1.00E-05	400	1.00E-06	5.14E-01	4.86E-04
5	0.38	1.00E-05	400	1.00E-06	4.48E-01	5.59E-04
6	0.38	1.00E-05	400	1.00E-06	3.94E-01	6.35E-04
7	0.38	1.00E-05	400	1.00E-06	3.50E-01	7.15E-04
8	0.38	1.00E-05	400	1.00E-06	3.13E-01	7.98E-04
9	0.38	1.00E-05	400	1.00E-06	2.83E-01	8.84E-04
10	0.38	1.00E-05	400	1.00E-06	2.57E-01	9.72E-04
11	0.38	1.00E-05	400	1.00E-06	2.36E-01	1.06E-03
12	0.38	1.00E-05	400	1.00E-06	2.17E-01	1.15E-03
13	0.38	1.00E-05	400	1.00E-06	2.01E-01	1.24E-03
14	0.38	1.00E-05	400	1.00E-06	1.87E-01	1.34E-03
15	0.38	1.00E-05	400	1.00E-06	1.75E-01	1.43E-03
16	0.38	1.00E-05	400	1.00E-06	1.64E-01	1.52E-03
17	0.38	1.00E-05	400	1.00E-06	1.55E-01	1.62E-03
18	0.38	1.00E-05	400	1.00E-06	1.46E-01	1.71E-03
19	0.38	1.00E-05	400	1.00E-06	1.38E-01	1.81E-03
20	0.38	1.00E-05	400	1.00E-06	1.32E-01	1.90E-03
21	0.38	1.00E-05	400	1.00E-06	1.25E-01	2.00E-03
22	0.38	1.00E-05	400	1.00E-06	1.20E-01	2.09E-03
23	0.38	1.00E-05	400	1.00E-06	1.14E-01	2.19E-03
24	0.38	1.00E-05	400	1.00E-06	1.10E-01	2.28E-03
25	0.38	1.00E-05	400	1.00E-06	1.05E-01	2.38E-03
26	0.38	1.00E-05	400	1.00E-06	1.01E-01	2.47E-03
27	0.38	1.00E-05	400	1.00E-06	9.75E-02	2.57E-03
28	0.38	1.00E-05	400	1.00E-06	9.40E-02	2.66E-03
29	0.38	1.00E-05	400	1.00E-06	9.07E-02	2.76E-03
30	0.38	1.00E-05	400	1.00E-06	8.77E-02	2.85E-03

Exhibit 2. Results Obtained By Changing The Value k.

t	k	SF	CDI	TR	$(1-e^{(-kt)})/(kt)$	PRG
year	year-1	risk/pCi	cm^2	risk	unitless	pCi/cm^2
30	0.000001	1.00E-05	400	1.00E-06	1.00E+00	2.50E-04
30	0.033331	1.00E-05	400	1.00E-06	6.32E-01	3.95E-04

30	0.066661	1.00E-05	400	1.00E-06	4.32E-01	5.78E-04
30	0.099991	1.00E-05	400	1.00E-06	3.17E-01	7.89E-04
30	0.133321	1.00E-05	400	1.00E-06	2.45E-01	1.02E-03
30	0.166651	1.00E-05	400	1.00E-06	1.99E-01	1.26E-03
30	0.199981	1.00E-05	400	1.00E-06	1.66E-01	1.50E-03
30	0.233311	1.00E-05	400	1.00E-06	1.43E-01	1.75E-03
30	0.266641	1.00E-05	400	1.00E-06	1.25E-01	2.00E-03
30	0.299971	1.00E-05	400	1.00E-06	1.11E-01	2.25E-03
30	0.333301	1.00E-05	400	1.00E-06	1.00E-01	2.50E-03
30	0.366631	1.00E-05	400	1.00E-06	9.09E-02	2.75E-03
30	0.399961	1.00E-05	400	1.00E-06	8.33E-02	3.00E-03
30	0.433291	1.00E-05	400	1.00E-06	7.69E-02	3.25E-03
30	0.466621	1.00E-05	400	1.00E-06	7.14E-02	3.50E-03
30	0.499951	1.00E-05	400	1.00E-06	6.67E-02	3.75E-03
30	0.533281	1.00E-05	400	1.00E-06	6.25E-02	4.00E-03
30	0.566611	1.00E-05	400	1.00E-06	5.88E-02	4.25E-03
30	0.599941	1.00E-05	400	1.00E-06	5.56E-02	4.50E-03
30	0.633271	1.00E-05	400	1.00E-06	5.26E-02	4.75E-03
30	0.666601	1.00E-05	400	1.00E-06	5.00E-02	5.00E-03
30	0.699931	1.00E-05	400	1.00E-06	4.76E-02	5.25E-03
30	0.733261	1.00E-05	400	1.00E-06	4.55E-02	5.50E-03
30	0.766591	1.00E-05	400	1.00E-06	4.35E-02	5.75E-03
30	0.799921	1.00E-05	400	1.00E-06	4.17E-02	6.00E-03
30	0.833251	1.00E-05	400	1.00E-06	4.00E-02	6.25E-03
30	0.866581	1.00E-05	400	1.00E-06	3.85E-02	6.50E-03
30	0.899911	1.00E-05	400	1.00E-06	3.70E-02	6.75E-03
30	0.933241	1.00E-05	400	1.00E-06	3.57E-02	7.00E-03
30	0.966571	1.00E-05	400	1.00E-06	3.45E-02	7.25E-03
30	1	1.00E-05	400	1.00E-06	3.33E-02	7.50E-03

4.5.9 Dermal Exposure

Other possible exposure pathways that may be considered in a radiological analysis of a contaminated building would include internal contamination due to puncture wounds and dermal absorption of radionuclides deposited on the skin. The radiation doses caused by these two pathways, however, are likely to be *de minimis* and much smaller than the doses caused by the other potential pathways already considered for most radionuclides (Kennedy and Strenge 1992 in Section 3.1.2). Therefore, dermal pathways are not included in the current version of this SDCC calculator. If one desires to calculate dermal risk, one method would be to calculate the dose based on either adherence of dust/soil to dry or wet skin. The mobility of the radionuclide, the range of the emitted beta particles, and the assumed exposure parameters may be used to determine the percentage contribution of each component to the total calculated risk. The partitioning coefficient (Kd) of the beta-emitting radionuclide of concern would be used to determine the significance of the sweat layer. If this value approaches zero, then contaminated soil particulates may dissolve, and diluted concentrations should be estimated from the original soil concentrations. If Kd is greater than zero, then the range of the emitted beta particles is expected to become the most important factor in determining if the radionuclide yields an unacceptable dose. If the range exceeds the average distribution of the sweat layer, then risk calculations are likely warranted. The dry deposition scenario dominates the whole exposure interval. Otherwise, the radionuclide is shielded by the sweat layer, and the corresponding indirect deposition contributions to the total risk are negligible.

4.5.10 Silt Loading Factor

It is assumed that dust is being resuspended from the road surface. The amount of dust on an area of road is called the silt loading factor (SLF). For this calculator, a default value of 0.015 g/m^2 was selected from *2011 National Emissions Inventory, version 1 Technical Support Document June 2014 - DRAFT* , Table 63, Page 104, concerning paved roads. This value, combined with the California annual vehicle kilometers traveled by length of California interstates, resulted in the most protective PEF. Multiple SLFs were given for specific circumstances. The values range from 0.015 to 0.6 g/m^2. The Table is reproduced below. The SLFs for urban collector roadway class are used for both major and minor collector roadway classes found in annual vehicle kilometers traveled by the length of each roadway class. Also, rural interstate roadway class SLFs were used for the "other freeways and expressways" roadway class. The SLF used in the risk equations is the inverse of 0.015 g/m^2 converted to units of cm^2/kg.

Table 63: 2011 Silt Loadings by State and Roadway Class Modeled in Paved Road Emission Factor Calculations (g/m^2)

	Rural						Urban					
State	**Interstate**	**Other Principal Arterial**	**Minor Arterial**	**Major Collector**	**Minor Collector**	**Local**	**Interstate**	**Other Freeways and Expressways**	**Other Principal Arterial**	**Minor Arterial**	**Collectors**	**Local**
Alabama	0.015	0.06	0.2	0.2	0.2	0.6	0.015	0.015	0.03	0.06	0.2	0.2
Alaska	0.015	0.2	0.2	0.2	0.6	0.6	0.015	0.015	0.03	0.03	0.2	0.6
Arizona	0.015	0.06	0.2	0.2	0.2	0.6	0.015	0.015	0.03	0.03	0.06	0.2
Arkansas	0.015	0.06	0.2	0.2	0.6	0.6	0.015	0.015	0.03	0.06	0.2	0.6
California	0.015	0.03	0.2	0.2	0.2	0.6	0.015	0.015	0.03	0.03	0.2	0.2
Colorado	0.015	0.2	0.2	0.2	0.6	0.6	0.015	0.015	0.03	0.06	0.2	0.2
Connecticut	0.015	0.06	0.06	0.2	0.2	0.6	0.015	0.015	0.03	0.06	0.2	0.2
Delaware	0.015	0.03	0.06	0.2	0.2	0.6	0.015	0.015	0.03	0.03	0.06	0.2
Dist. of Columbia	0.015	0.6	0.6	0.6	0.6	0.6	0.015	0.015	0.03	0.03	0.06	0.2
Florida	0.015	0.06	0.2	0.2	0.2	0.2	0.015	0.015	0.03	0.03	0.06	0.2
Georgia	0.015	0.06	0.2	0.2	0.2	0.6	0.015	0.015	0.03	0.06	0.2	0.2
Hawaii	0.015	0.03	0.06	0.2	0.2	0.2	0.015	0.015	0.03	0.03	0.06	0.2
Idaho	0.015	0.2	0.2	0.2	0.6	0.6	0.015	0.015	0.03	0.06	0.2	0.2
Illinois	0.015	0.2	0.2	0.2	0.6	0.6	0.015	0.015	0.03	0.06	0.2	0.2
Indiana	0.015	0.06	0.2	0.2	0.2	0.6	0.015	0.015	0.03	0.06	0.06	0.2
Iowa	0.015	0.2	0.2	0.2	0.6	0.6	0.015	0.015	0.03	0.06	0.2	0.2
Kansas	0.015	0.2	0.2	0.6	0.6	0.6	0.015	0.015	0.03	0.06	0.2	0.2
Kentucky	0.015	0.06	0.2	0.2	0.2	0.6	0.015	0.015	0.03	0.06	0.2	0.2
Louisiana	0.015	0.06	0.2	0.2	0.2	0.6	0.015	0.015	0.03	0.06	0.2	0.6
Maine	0.015	0.06	0.2	0.2	0.2	0.6	0.015	0.015	0.03	0.03	0.2	0.2
Maryland	0.015	0.03	0.06	0.2	0.2	0.6	0.015	0.015	0.03	0.03	0.06	0.2
Massachusetts	0.015	0.06	0.2	0.2	0.2	0.6	0.015	0.015	0.03	0.06	0.2	0.2
Michigan	0.015	0.2	0.2	0.2	0.2	0.6	0.015	0.015	0.03	0.06	0.2	0.2
Minnesota	0.015	0.06	0.2	0.2	0.6	0.6	0.015	0.015	0.03	0.06	0.2	0.2
Mississippi	0.015	0.06	0.2	0.2	0.2	0.6	0.015	0.015	0.03	0.06	0.2	0.2
Missouri	0.015	0.2	0.2	0.2	0.6	0.6	0.015	0.015	0.03	0.06	0.2	0.2
Montana	0.015	0.2	0.2	0.6	0.6	0.6	0.015	0.015	0.03	0.06	0.2	0.2
Nebraska	0.015	0.2	0.2	0.6	0.6	0.6	0.015	0.015	0.03	0.06	0.2	0.2
Nevada	0.015	0.2	0.2	0.2	0.6	0.6	0.015	0.015	0.03	0.03	0.06	0.2
New Hampshire	0.015	0.06	0.06	0.2	0.2	0.6	0.015	0.015	0.03	0.03	0.2	0.2
New Jersey	0.015	0.03	0.06	0.2	0.2	0.6	0.015	0.015	0.03	0.06	0.2	0.2
New Mexico	0.015	0.2	0.2	0.2	0.6	0.6	0.015	0.015	0.03	0.06	0.2	0.2
New York	0.015	0.2	0.2	0.2	0.2	0.6	0.015	0.015	0.03	0.06	0.2	0.2
North Carolina	0.015	0.03	0.06	0.2	0.2	0.6	0.015	0.015	0.03	0.03	0.06	0.2
North Dakota	0.015	0.2	0.2	0.6	0.6	0.6	0.015	0.015	0.03	0.06	0.2	0.2
Ohio	0.015	0.06	0.2	0.2	0.2	0.6	0.015	0.015	0.03	0.06	0.2	0.2
Oklahoma	0.015	0.06	0.2	0.2	0.6	0.6	0.015	0.015	0.03	0.06	0.2	0.2
Oregon	0.015	0.2	0.2	0.2	0.6	0.6	0.015	0.015	0.03	0.06	0.2	0.2
Pennsylvania	0.015	0.06	0.2	0.2	0.2	0.6	0.015	0.015	0.03	0.06	0.2	0.2
Rhode Island	0.015	0.06	0.06	0.2	0.2	0.6	0.015	0.015	0.03	0.06	0.2	0.6
South Carolina	0.015	0.06	0.2	0.2	0.6	0.6	0.015	0.015	0.03	0.03	0.2	0.2
South Dakota	0.015	0.2	0.2	0.6	0.6	0.6	0.015	0.015	0.03	0.06	0.2	0.6
Tennessee	0.015	0.06	0.2	0.2	0.2	0.6	0.015	0.015	0.03	0.06	0.2	0.2
Texas	0.015	0.06	0.2	0.2	0.6	0.6	0.015	0.015	0.03	0.06	0.2	0.6
Utah	0.015	0.2	0.2	0.2	0.6	0.6	0.015	0.015	0.03	0.03	0.2	0.2
Vermont	0.015	0.06	0.2	0.2	0.2	0.6	0.015	0.015	0.03	0.06	0.2	0.2
Virginia	0.015	0.03	0.2	0.2	0.2	0.6	0.015	0.015	0.03	0.03	0.2	0.2
Washington	0.015	0.2	0.2	0.2	0.2	0.6	0.015	0.015	0.03	0.06	0.2	0.2
West Virginia	0.015	0.06	0.2	0.2	0.6	0.6	0.015	0.015	0.03	0.06	0.2	0.6
Wisconsin	0.015	0.06	0.2	0.2	0.6	0.6	0.015	0.015	0.03	0.06	0.2	0.6
Wyoming	0.015	0.2	0.2	0.2	0.6	0.6	0.015	0.015	0.06	0.06	0.2	0.2

To obtain more accurate SDCC results, the SLF should be measured in the field. Table 13.2.1-3 from AP42 is reproduced below showing the high end typical industrial facility SLF ranges. The values range from 0.09 to 400 g/m^2. AP 42 suggests the following:

> "Limited access roadways pose severe logistical difficulties in terms of surface sampling, and few silt loading data are available for such roads. Nevertheless, the available data do not suggest great variation in silt loading for limited access roadways from one part of the country to another. For annual conditions, a default value of 0.015 g/m^2 is recommended for limited access roadways. Even fewer of the available data correspond to worst-case situations, and elevated loadings are observed to be quickly depleted because of high traffic speeds and high ADT rates. A default value of 0.2 g/m^2 is recommended for short periods of time following application of snow/ice controls to limited access roads."

13.2.1-10 EMISSION FACTORS

Table 13.2.1-3 (Metric And English Units). TYPICAL SILT CONTENT AND LOADING VALUES FOR PAVED ROADS AT INDUSTRIAL FACILITIES [a]

Industry	No. of Sites	No. Of Samples	Silt Content (%) Range	Silt Content (%) Mean	No. of Travel Lanes	Total Loading x 10^{-3} Range	Total Loading x 10^{-3} Mean	Units[b]	Silt Loading (g/m^2) Range	Silt Loading (g/m^2) Mean
Copper smelting	1	3	15.4-21.7	19.0	2	12.9 - 19.5 45.8 - 69.2	15.9 55.4	kg/km lb/mi	188-400	292
Iron and steel production	9	48	1.1-35.7	12.5	2	0.006 - 4.77 0.020 -16.9	0.495 1.75	kg/km lb/mi	0.09-79	9.7
Asphalt batching	1	3	2.6 - 4.6	3.3	1	12.1 - 18.0 43.0 - 64.0	14.9 52.8	kg/km lb/mi	76-193	120
Concrete batching	1	3	5.2 - 6.0	5.5	2	1.4 - 1.8 5.0 - 6.4	1.7 5.9	kg/km lb/mi	11-12	12
Sand and gravel processing	1	3	6.4 - 7.9	7.1	1	2.8 - 5.5 9.9 - 19.4	3.8 13.3	kg/km lb/mi	53-95	70
Municipal solid waste landfill	2	7		-	2	-			1.1-32.0	7.4
Quarry	1	6		-	2	-			2.4-14	8.2
Corn wet mills	3	15		-	2	-			0.05 – 2.9	1.1

[a] References 1-2,5-6,11-13. Values represent samples collected from *industrial* roads. Public road silt loading values are presented in Table-13.2.1-2. Dashes indicate information not available.[b] Multiply entries by 1000 to obtain stated units; kilograms per kilometer (kg/km) and pounds per mile (lb/mi).

The default state road class and road type, the California urban interstate, yields a mechanical PEF of 1.86 × 10^6 using an ADTV value of 0.015 g/m^2. This was chosen as the default for this calculator to produce more protective default SPRGs; however, selecting a site-specific state and roadway class will provide a more accurate SLF and ADTV. The United States Department of Transportation's Federal Highway Administration maintains an interactive HEPGIS website that supplies a map of the 50 States and Puerto Rico depicting functional roadway classes. The user can use the zoom controls to reach the area of interest. This resource could be consulted to apply site-specific inputs for calculating ADTV and SLF for a risk assessment. Further state-specific information can be found by consulting the contact list.

4.5.11 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).

Since the assumption of an infinite slab source will result in overly protective SDCCs for most residential settings, 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 SDCCs. 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.

4.5.12 Street Surfaces Factor $F_{s\text{-}surf}$

The 3-D direct external exposure equations (building materials and dust) without $F_{s\text{-}surf}$ are single surface equations. The surfaces factor, in the default and site-specific equations, are based on exposure to two vertical surfaces (outside building surfaces on either side of a street) and a horizontal surface (road and sidewalk). This calculator uses the relationship between the dose rate coefficients for exposures in a contaminated outdoor setting and dose rate coefficients for an infinite source to calculate a surfaces factor ($F_{s\text{-}surf}$). The dose quantity evaluated is the air kerma rate one meter above the sidewalk. The outdoor surfaces are assumed to be contaminated to the same level. Locations in the midpoint of the sidewalk, next to the buildings, and in the middle of the street for building heights of 12.5, 30, 59, 150, and 200 feet were modeled to account for the dose contribution from multiple surfaces. Further, photon energies of each radioisotope were incorporated into the modeling. Please see the attached PDF file for a detailed explanation of the process. Side Walk Dose Rate shows that building height doesn't effect the dose rate significantly after 150 feet. The above link shows a table of the $F_{s\text{-}surf}$ values used in this calculator for each radioisotope. $F_{s\text{-}surf}$ values were calculated for each position-specific and building-height specific combination.

4.5.13 Radionuclide Decay Constant (lambda; 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 SDCC 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. In the absence of empirical data, however, the secular equilibrium SDCCs will provide a protective screening value. Definitions of the input variables are in Table 1.

4.5.14 Gamma Shielding Factor for Soil (GSF)

A default gamma shielding factor for indoor exposure to ionizing radiation (GSF_i) is established at 0.4 (60% shielding).

A default gamma shielding factor for outdoor exposure to ionizing radiation on surfaces (GSF_s) is established at 1 (0% shielding).

4.6 Supporting Equations

The above land use equations require further explanation for particulate emission factors.

4.6.1 Particulate Emission Factors (PEFs)

Two types of particulate emission factors are presented in this calculator: mechanically driven and the traditional wind driven emission factor.

4.6.1.1 Mechanically Driven PEF for Paved Public Roads

These equations allow the user to change site dimensions, distance traveled, mean vehicle weight, road dimensions, particle size multiplier, time, and number of rain days. These equations can be used to simulate emission factors after an incident. The receptor is assumed to be exposed to contaminants in the form of particulate matter with an aerodynamic particle diameter of less than 10 microns (PM_{10}). Fugitive dust emissions are generated by vehicle traffic on paved roads.

The following fugitive dust emission equations represent approximations of actual emissions at a specific site. Sensitive emission model parameters include the soil silt content and mean vehicle weight. Silt is defined as soil particles smaller than 75 micrometers (Fm) in diameter and can be measured as that proportion of soil passing a 200-mesh screen, using the American Society for Testing and Materials (ASTM) Method C-136. Mean vehicle weight is presented in tons. The default value is 3.2 tons, but site-specific values can be used. In general, silt loading and mean vehicle weight are the most sensitive model parameters for which default values have been assigned; however, site-specific values will produce more accurate modeling results. Other emission model parameters have not been assigned default values and are typically defined on a site-specific basis. These parameters include the total distance traveled by vehicles, average vehicle speed, and the area of roadway.

Mean vehicle weight (W) in tons is calculated by determining vehicle weight classes and numbers in that class. An example is presented below for site-specific data. The default mean vehicle weight selected for this calculator is 3.2 tons, based on page 4-285 in *Procedures Document for National Emission Inventory, Criteria Air Pollutants 1985-1999*. EPA-454/R-01-006. There is wide variation in vehicle weights when considering industrial facilities. AP42 supporting documentation reveals in Table A1-6 that the mean vehicle weight can range up to 42 tons. Site-specific conditions should be considered or measured. The table is reproduced below.

TABLE 4-8. DETAILED INFORMATION FROM PAVED ROAD TESTS FOR REFERENCE 7

Run No.	Industrial category	Traffic	PM_{10} emission factor, lb/VMT	Duration, min.	Mean wind speed, mph	Road width, ft	No. of vehicle passes	Vehicle characteristics: Mean vehicle weight, tons	Vehicle characteristics: No. of wheels	Vehicle characteristics: Mean vehicle speed, mph	Moisture content, %	Silt loading, g/m²	Silt, %
Y-1	Asphalt Batching	Medium Duty	0.257	274	5.37	13.8	47	3.6	6	10	0.22	91	2.6
Y-2	Asphalt Batching	Medium Duty	0.401	344	4.70	14.1	76	3.7	7	10	0.51	76	2.7
Y-3	Asphalt Batching	Medium Duty	0.0801	95	6.04	14.1	100	3.8	6.5	10	0.32	193	4.6
Y-4	Asphalt Batching	Medium Duty	0.441	102	5.59	14.1	150	3.7	6	10	0.32	193	4.6
Z-1	Concrete Batching	Medium Duty	0.699	170	6.71	24.3	149	8.0	10	10	a	11.3	6.0
Z-2	Concrete Batching	Medium Duty	1.63	143	9.84	24.9	161	8.0	10	15	a	12.4	5.2
Z-3	Concrete Batching	Medium Duty	4.01	109	9.62	24.9	62	8.0	10	15	a	12.4	5.2
AC-4	Copper Smelting	Medium Duty	3.86	38	8.72	34.8	45	5.7	7.4	10	0.43	287	19.8
AC-5	Copper Smelting	Medium Duty	3.13	36	9.62	34.8	36	7.0	6.2	15	0.43	188	15.4
AC-6	Copper Smelting	Medium Duty	1.35	33	4.92	34.8	42	3.1	4.2	20	0.53	400	21.7
AD-1	Sand and Gravel	Heavy Duty	3.27	110	7.61	12.1	11	42	11	23	a	94.8	6.4
AD-2	Sand and Gravel	Heavy Duty	0.753	69	5.15	12.1	16	39	17	23	a	63.6	7.9
AD-3	Sand and Gravel	Heavy Duty	0.513	76	3.13	12.1	20	40	15	23	a	52.6	7.0

1 lb/VMT = 281.9 g/VKT.
1 g/m² = 1.434 gr/ft²
[a] Not measured

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W = [(20 cars × 2 tons/car) + (10 trucks × 20 tons/truck)]/30 vehicles = 8 tons mean vehicle weight.

Sum of vehicle kilometers traveled during the exposure duration, ∑VKT, is estimated based on the size of the area of the contamination, the configuration of the road, and amount of traffic. The default ∑VKT is based on California urban interstate statistics. The value of 2,683,117 kilometers was calculated by multiplying the length of contaminated surface(L_S) by the annual vehicle kilometers divided by the total number of kilometers of that road class. This number is then multiplied by the ED. These values resulted in the most protective PEF. The area of the site contamination is assumed to be a square. Therefore, the square root of the area gives the distance traveled in the contaminated area. A half-acre site is 0.002024 km^2. The square root is 0.045 km. For the site-specific option of the calculator, the ∑VKT is determined as presented below.

VKT = 30 vehicles × 0.045 km/trip × 1 trips/day × 26 weeks/year × 5 days/week × 30 years (ED) d = 5265 km.

The table below is taken from AP42 for Paved Roads and gives values for k.

Table 13.2.1-1. PARTICLE SIZE MULTIPLIERS FOR PAVED ROAD EQUATION

Size range[a]	Particle Size Multiplier k[b]		
	g/VKT	g/VMT	lb/VMT
PM-2.5[c]	0.15	0.25	0.00054
PM-10	0.62	1.00	0.0022
PM-15	0.77	1.23	0.0027
PM-30[d]	3.23	5.24	0.011

4.6.1.1.1 State-Specific Equation for Mechanically Driven PEF for Paved Public Roads

Below is the equation used to determine the state-specific and default mechanical PEF for public paved roads. In state-specific mode, the site dimensions, mean vehicle weight, road dimensions, particle size multiplier, time, and number of rain days can be changed. The state, geographic setting, and roadway class must be selected for the equation to operate. The default PEF is based on California data.

$$PEF_{m\text{-}pp\text{-}state}\left(\frac{m^3}{kg}\right) = \frac{Q}{C_{m\text{-}pp}}\left(\left(\frac{g}{m^2\text{-}s}\right)\Big/\left(\frac{kg}{m^3}\right)\right)\times\frac{1}{F_D}\times\frac{T(s)\times A_R\left(m^2\right)}{\Sigma\,VKT\times k\text{-}pp\left(\frac{0.62\ g}{VKT}\right)\times\left(sL\left(\frac{0.015\ g}{m^2}\right)\right)^{0.91}\times\left(W(3.2\ tons)\right)^{1.02}\times\left[1-\frac{P\left(\frac{150\ rain\ day}{year}\right)}{4\times\left(\frac{365\ day}{year}\right)}\right]}$$

where

$PEF_{m\text{-}pp}$ = paved public road mechanical particulate emission factor $\left(\frac{m^3}{kg}\right)$

$A_R\left(m^2\right) = L_R\,(length\ ft)\times W_R\,(width\ ft)\times 0.092903\ m^2/ft^2$

F_D = dispersion correction factor $= 0.1852+\frac{5.3537}{t_c\,(hour)}+\frac{-9.6318}{t_c^{\,2}\,(hour)}$

$\frac{Q}{C_m}\left(\left(\frac{g}{m^2\text{-}s}\right)\Big/\left(\frac{kg}{m^3}\right)\right) = A\times\exp\left[\frac{\left(\ln A_s\,(acre)-B\right)^2}{C}\right]$ where A, B and C are unitless dispersion constants

$L_S\,(km) = L_R\,(ft)\times 0.000304799\ \frac{km}{ft}$

$\Sigma\,VKT$ (sum of vehicle km traveled during ED) = 2,822,326 where $\Sigma\,VKT = \left(\frac{L_S\,(km)\times AKV\left(\frac{km}{year}\right)\ \text{based on California Urban Interstate}}{\text{km based on California Urban Interstate}}\times ED\,(year)\right)$

4.6.1.1.2 Site-Specific Equation for Mechanically Driven PEF for Paved Public Roads

Below is the equation used to determine the site-specific mechanical PEF for public paved roads. The site dimensions, road dimensions, particle size multiplier, number of rain days, silt loading factor, mean vehicle weight inputs, time, and ∑VKT inputs can be changed.

$$PEF_{m\text{-}pp}\left(\frac{m^3}{kg}\right) = \frac{Q}{C_{m\text{-}pp}}\left(\left(\frac{g}{m^2\text{-}s}\right)\Big/\left(\frac{kg}{m^3}\right)\right)\times\frac{1}{F_D}\times\frac{T(s)\times A_R\left(m^2\right)}{\Sigma\,VKT\times k\text{-}pp\left(\frac{0.62\ g}{VKT}\right)\times\left(sL\left(\frac{g}{m^2}\right)\right)^{0.91}\times\left(W(ton)\right)^{1.02}\times\left[1-\frac{P\left(\frac{rain\ day}{year}\right)}{4\times\left(\frac{365\ day}{year}\right)}\right]}$$

where:

$PEF_{m\text{-}pp}$ = paved public road mechanical particulate emission factor $\left(\frac{m^3}{kg}\right)$

$A_R\left(m^2\right) = L_R\,(length\ ft)\times W_R\,(width\ ft)\times 0.092903\ m^2/ft^2$

F_D = dispersion correction factor $= 0.1852+\frac{5.3537}{t_c\,(hour)}+\frac{-9.6318}{t_c^{\,2}\,(hour)}$

$\frac{Q}{C_m}\left(\left(\frac{g}{m^2\text{-}s}\right)\Big/\left(\frac{kg}{m^3}\right)\right) = A\times\exp\left[\frac{\left(\ln A_s\,(acre)-B\right)^2}{C}\right]$ where A, B and C are unitless dispersion constants

$W\ (\text{mean vehicle weight in tons}) = \frac{\left[\left(\text{Number of cars}\times\frac{ton}{car}\right)+\left(\text{Number of trucks}\times\frac{ton}{truck}\right)\right]}{\text{Total number of vehicles}}$

$\Sigma\,VKT$ (sum of vehicle km traveled during ED) $= \text{Total number of vehicles}\times\frac{km}{trip}\times\frac{trips}{day}\times\frac{days}{week}\times\frac{weeks}{year}\times ED\,(year)$

4.6.1.2 Mechanically Driven PEF for Unpaved public Roads

This equation allows the user to change emission factor for fleet exhaust, brake and tire wear, silt percentage, silt moisture content, mean vehicle speed, site dimensions, distance traveled, mean vehicle weight, road dimensions, particle size multiplier, time, and number of rain days. This equation can be used to simulate emission factors after an incident. The receptor is assumed to be exposed to contaminants in the form of particulate matter with an aerodynamic particle diameter of less than 10 microns (PM_{10}). Fugitive dust emissions are generated by vehicle traffic on unpaved public roads.

$$PEF_{m\text{-}up}\left(\frac{m^3}{kg}\right) = \frac{Q}{C_{m\text{-}up}}\left(\left(\frac{g}{m^2\text{-}s}\right)\Big/\left(\frac{kg}{m^3}\right)\right) \times \frac{1}{F_D} \times \frac{T(s) \times A_R\left(m^2\right)}{\left(\frac{k\text{-}up\left(\frac{1.8\ lb}{VMT}\right) \times \left(\frac{s(8.5\ \%)}{12}\right)^{a\text{-}p} \times \left(\frac{S\left(\frac{mi}{hour}\right)}{30}\right)^{d\text{-}p}}{\left(\frac{M\ (7.9\ \%)}{0.5}\right)^{c\text{-}p}} - C\left(\frac{0.00047\ lb}{VMT}\right)\right) \times \left[\frac{(365\text{-}p\,(rain\ day))}{365}\right] \times \left(\frac{\left(\frac{281.9\ g}{VKT}\right)}{\left(\frac{1\ lb}{VMT}\right)}\right) \times \Sigma\, VKT}$$

where

$PEF_{m\text{-}up}$ = unpaved public road mechanical particulate emission factor $\left(\frac{m^3}{kg}\right)$

F_D = dispersion correction factor $= 0.1852 + \frac{5.3537}{t_c\,(hour)} + \frac{-9.6318}{t_c^{\,2}\,(hour)}$

$$\frac{Q}{C_m}\left(\left(\frac{g}{m^2\text{-}s}\right)\Big/\left(\frac{kg}{m^3}\right)\right) = A \times \exp\left[\frac{\left(\ln A_s\,(acre) - B\right)^2}{C}\right]$$ where A, B and C are unitless dispersion constants

$A_R\left(m^2\right) = L_R\,(length\ ft) \times W_R\,(width\ ft) \times 0.092903\ m^2/ft^2$

$\Sigma\, VKT$ (sum of vehicle km traveled during ED) = Total number of vehicles $\times \frac{km}{trip} \times \frac{trips}{day} \times \frac{weeks}{year} \times \frac{days}{week} \times ED\,(year)$

k-up, a-p, c-p and d-p are constants based on the stated aerodynamic particle sizes

The fugitive dust emission equation represents approximations of actual emissions at a specific site. Sensitive emission model parameters include the soil silt percentage, silt moisture content, and mean vehicle speed. Silt is defined as soil particles smaller than 75 micrometers (Fm) in diameter and can be measured as that proportion of soil passing a 200-mesh screen, using the American Society for Testing and Materials (ASTM) Method C-136. Soil moisture content is defined on a percent gravimetric basis [(g-water/g-soil) x 100] and should be approximated as the mean value for the duration of the construction project. In general, soil silt and moisture content are the most sensitive model parameters for which default values have been assigned; however, site-specific values will produce more accurate modeling results. Other emission model parameters have not been assigned default values and are typically defined on a site-specific basis. These parameters include the site dimensions and average vehicle speed.

The silt moisture content default is 7.9%, but moisture can range from 0.03 to 13% according to AP42 section on unpaved roads. There is wide variation in moisture content when considering industrial facilities. Table 13.2.2-3 is presented below.

Table 13.2.2-3. RANGE OF SOURCE CONDITIONS USED IN DEVELOPING EQUATION 1a AND 1b

Emission Factor	Surface Silt Content, %	Mean Vehicle Weight		Mean Vehicle Speed		Mean No. of Wheels	Surface Moisture Content, %
		Mg	ton	km/hr	mph		
Industrial Roads (Equation 1a)	1.8-25.2	1.8-260	2-290	8-69	5-43	4-17[a]	0.03-13
Public Roads (Equation 1b)	1.8-35	1.4-2.7	1.5-3	16-88	10-55	4-4.8	0.03-13

Sum of vehicle kilometers traveled during the ED, ∑VKT, is estimated based on the size of the area of the contamination, the configuration of the road and amount of traffic. There is not a default value for this equation. This equation is only accessible in the site-specific option. The VKT can be determined on a site-specific basis by following the example presented below.

VKT = 30 vehicles ×0.045 km/trip×1 trips/day ×26 weeks/year ×5 days/week ×30 years (ED) d = 5265 km.

The table below is taken from AP42 for Unpaved Roads and gives values for k.

Table 13.2.2-2. CONSTANTS FOR EQUATIONS 1a AND 1b

Constant	Industrial Roads (Equation 1a)			Public Roads (Equation 1b)		
	PM-2.5	PM-10	PM-30*	PM-2.5	PM-10	PM-30*
k (lb/VMT)	0.15	1.5	4.9	0.18	1.8	6.0
a	0.9	0.9	0.7	1	1	1
b	0.45	0.45	0.45	-	-	-
c	-	-	-	0.2	0.2	0.3
d	-	-	-	0.5	0.5	0.3
Quality Rating	B	B	B	B	B	B

The table below is taken from AP42 for Unpaved Roads and gives values for C.

Table 13.2.2-4. EMISSION FACTOR FOR 1980'S VEHICLE FLEET EXHAUST, BRAKE WEAR AND TIRE WEAR

Particle Size Range[a]	C, Emission Factor for Exhaust, Brake Wear and Tire Wear[b] lb/VMT
$PM_{2.5}$	0.00036
PM_{10}	0.00047
PM_{30}[c]	0.00047

The table below is taken from AP42 for Unpaved Roads and gives values for S.

Table 13.2.2-3. RANGE OF SOURCE CONDITIONS USED IN DEVELOPING EQUATION 1a AND 1b

Emission Factor	Surface Silt Content, %	Mean Vehicle Weight		Mean Vehicle Speed		Mean No. of Wheels	Surface Moisture Content, %
		Mg	ton	km/hr	mph		
Industrial Roads (Equation 1a)	1.8-25.2	1.8-260	2-290	8-69	5-43	4-17[a]	0.03-13
Public Roads (Equation 1b)	1.8-35	1.4-2.7	1.5-3	16-88	10-55	4-4.8	0.03-13

4.6.1.3 Mechanically Driven PEF for Unpaved Industrial Roads

This equation allows the user to change silt percentage, site dimensions, distance traveled, mean vehicle weight, road dimensions, particle size multiplier, time, and number of rain days. This equation can be used to simulate emission factors after an incident. The receptor is assumed to be exposed to contaminants in the form of particulate matter with an aerodynamic particle diameter of less than 10 microns (PM_{10}). Fugitive dust emissions are generated by vehicle traffic on unpaved industrial roads.

The following fugitive dust emission equation represents approximations of actual emissions at a specific site. Sensitive emission model parameters include the silt percentage and mean vehicle weight. Silt is defined as soil particles smaller than 75 micrometers (Fm) in diameter and can be measured as that proportion of soil passing a 200-mesh screen, using the American Society for Testing and Materials (ASTM) Method C-136. Site-specific values for mean vehicle weight and silt percentage will produce more accurate modeling results. Other emission model parameters have not been assigned default values and are typically defined on a site-specific basis. These parameters include the total distance traveled by vehicles, mean vehicle weight, and the area of the site.

The silt percentage default is 8.5%; however, percentage can range from 1.8 to 25.2% according to AP42 section on unpaved roads. There is wide variation in silt percentage content when considering industrial facilities. Table 13.2.2-3 is presented below.

Table 13.2.2-3. RANGE OF SOURCE CONDITIONS USED IN DEVELOPING EQUATION 1a AND 1b

Emission Factor	Surface Silt Content, %	Mean Vehicle Weight		Mean Vehicle Speed		Mean No. of Wheels	Surface Moisture Content, %
		Mg	ton	km/hr	mph		
Industrial Roads (Equation 1a)	1.8-25.2	1.8-260	2-290	8-69	5-43	4-17[a]	0.03-13
Public Roads (Equation 1b)	1.8-35	1.4-2.7	1.5-3	16-88	10-55	4-4.8	0.03-13

W = [(20 cars × 2 tons/car) + (10 trucks × 20 tons/truck)]/30 vehicles = 8 tons mean vehicle weight.

Sum of vehicle kilometers traveled, VKT, is estimated based on the size of the area of the contamination, the configuration of the road, and amount of traffic. There is not a default value for this equation. This equation is only accessible in the site-specific option. The VKT can be determined on a site-specific basis by following the example presented below.

VKT = 30 vehicles × 0.045 km/trip× 1 trips/day × 26 weeks/year × 5 days/week × 30 years (ED) d = 5265 km.

$$PEF_{m\text{-}ui}\left(\frac{m^3}{kg}\right) = \frac{Q}{C_{m\text{-}ui}}\left(\left(\frac{g}{m^2\text{-}s}\right)\Big/\left(\frac{kg}{m^3}\right)\right)\times\frac{1}{F_D}\times\frac{T(s)\times A_R\left(m^2\right)}{k\text{-}ui\left(\frac{1.5\ lb}{VMT}\right)\times\left(\frac{s(8.5\ \%)}{12}\right)^{a\text{-}i}\times\left(\frac{W(ton)}{3}\right)^{b\text{-}i}\times\left[\frac{365\text{-}p(rain\ day)}{365}\right]\times\left(\frac{\left(\frac{281.9\ g}{VKT}\right)}{\left(\frac{lb}{VMT}\right)}\right)\times\Sigma\ VKT}$$

where

$PEF_{m\text{-}ui}$ = unpaved industrial road mechanical particulate emission factor $\left(\frac{m^3}{kg}\right)$

F_D = dispersion correction factor = $0.1852+\frac{5.3537}{t_c(hour)}+\frac{-9.6318}{t_c^{\,2}(hour)}$

$\frac{Q}{C_m}\left(\left(\frac{g}{m^2\text{-}s}\right)\Big/\left(\frac{kg}{m^3}\right)\right) = A\times exp\left[\frac{\left(lnA_s(acre)\text{-}B\right)^2}{C}\right]$ where A, B and C are unitless dispersion constants

$A_R\left(m^2\right) = L_R(length\ ft)\times W_R(width\ ft)\times 0.092903\ m^2/ft^2$

$W\ (mean\ vehicle\ weight\ in\ tons) = \frac{\left[\left(Number\ of\ cars\times\frac{ton}{car}\right)+\left(Number\ of\ trucks\times\frac{ton}{truck}\right)\right]}{Total\ number\ of\ vehicles}$

ΣVKT (sum of vehicle km traveled during ED) = Total number of vehicles $\times\frac{km}{trip}\times\frac{trips}{day}\times\frac{weeks}{year}\times\frac{days}{week}\times ED(year)$

k-ui, a-i, and b-i are constants based on the stated aerodynamic particle sizes

The table below is taken from AP42 for Unpaved Roads and gives values for k.

Table 13.2.2-2. CONSTANTS FOR EQUATIONS 1a AND 1b

Constant	Industrial Roads (Equation 1a)			Public Roads (Equation 1b)		
	PM-2.5	PM-10	PM-30*	PM-2.5	PM-10	PM-30*
k (lb/VMT)	0.15	1.5	4.9	0.18	1.8	6.0
a	0.9	0.9	0.7	1	1	1
b	0.45	0.45	0.45	-	-	-
c	-	-	-	0.2	0.2	0.3
d	-	-	-	0.5	0.5	0.3
Quality Rating	B	B	B	B	B	B

4.6.1.4 Wind Driven PEF

This equation allows the user to select geographical regions and input fraction of vegetative cover and wind speed. Inhalation of isotopes adsorbed to respirable particles (PM_{10}re) was assessed using default input parameters. 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. Regional-specific PEFs are 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.

The equation below 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:

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

and:

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

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

where:

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

4.7 Equation Sources and Parameters

This section presents details on some of the equation sources and parameters.

4.7.1 Exposure to Settled Dust on Surfaces Equations

The inadvertent ingestion from materials deposited on surfaces equation was modeled after the equation found in ANL 2001 (Fig 8.3). The ingestion rate term in this equation was modeled after U.S. EPA 2003 (pg. D-4). External exposure from deposited materials equation was modeled after the equation found in ANL 2001 (Fig 8.7).

4.7.2 Direct External Exposure Equations

The direct external exposure from a volume and surface of a large area equation was modeled after ANL 2001 (Fig 8.6). External exposure from deposited materials equation was modeled after the equation found in ANL 2001 (Fig 8.7).

4.7.2.1 External Exposure Equation Derivation

The external exposure pathway dose from exposure to an area or a volume source containing radionuclide *n* in compartment *i*,
D^n_{iv}, is expressed as:

$$D^n_{iv} = F_{in} \times F_i \times C^n_s \times DCF^n_v \times F^n_G,$$

where:

F_{in} = fraction of time spent indoors;

F_i = fraction of time spent in compartment *i*;

C^n_s = average concentration of radionuclide n;

DCF^n_v = FGR-12 dose conversion factor for infinite volume source; and

F^n_G = geometrical factor for finite area, source thickness, shielding, source material, and position of receptor relative to the source for radionuclide *n*.

The geometrical factor is the ratio of the effective dose equivalent for the actual source to the effective dose equivalent for the standard source. The standard source is a contaminated soil of infinite depth and lateral extent with no cover. The geometrical factor is expressed as the product of the depth-and-cover factor, F_{CD}, an area and material factor, F_{AM}, and the off-set factor, $F_{OFF\text{-}SET}$.

So,
F^n_G = effective dose from actual source/effective dose from standard source.

Then,
$F^n_G = F_{CD} \times F_{AM} \times F_{OFF\text{-}SET}$

4.7.2.1.1 Depth-And-Cover Factor (F_{CD})

Note: The F_{CD} would traditionally be included in this type of analysis; however, it is not included in the equations for this calculator. This calculator includes depth-specific dose conversion factors for surface (ground plane) and uniformly distributed volume sources at four specific thicknesses (1, 5, and 15 cm and effectively infinite). Inclusion of these dose conversion factors eliminates the need for the F_{CD}.

Dose conversion factors in FGR-12 (Eckerman and Ryman 1993) are given for surface and uniformly distributed volume sources at four specific thicknesses (1, 5, and 15 cm and effectively infinite) with a soil density of 1.6 g/cm^3. FGR-12 assumes that sources are infinite in lateral extent. In actual situations, sources can have any depth, shape, cover, and size. A depth and-cover factor function, F_{CD}, was developed with regression analysis to express the attenuation for radionuclides. Three independent radionuclide-specific parameters were determined by using the effective dose equivalent values of FGR-12 at different depths. Kamboj et al. (1998) describes how the depth-and-cover function was derived using the effective dose equivalent values of FGR-12 at different depths. A depth-and-cover factor function was derived from the depth factor function by considering both dose contribution and attenuation from different depths:

$$\frac{D(T_c = t_c, T_S = t_s)}{D(T_c = 0, T_S = \infty)} = Ae^{-K_A \rho_c t_c}(1 - e^{-K_A \rho_s t_s}) + Be^{-K_B \rho_c t_c}(1 - e^{-K_B \rho_s t_s}),$$

where:

A, B = fit parameters (dimensionless);

K_A, K_B = fit parameters (cm^2/g);

t_c = shielding thickness (cm) (the sum of all shielding thicknesses between the source and the receptor), the shielding is placed immediately adjacent to the source;

ρ_c= shielding density (g/cm^3)(the thickness-averaged density between the source and receptor);

t_s = source thickness (cm);

ρ_s = source density (g/cm^3);

T_c = shielding parameter (m); and

T_s = source depth parameter (m).

The following constraints were put on the four fitting parameters:

1. All the parameters were forced to be positive;

2. A + B = 1; and

3. In the limit source depth, $t_s \rightarrow$ zero, the DCF should match the contaminated surface DCF.

All the four unknown parameters (A, B, K_A, and K_B) were found for 67 radionuclides available in the RESRAD-BUILD computer code. The fitted values of A, B, K_A, and K_B for radionuclides were used in the dose calculations.

4.7.2.1.2 Area-And-Material Factor (F_{AM})

For actual geometries (finite area and different materials), the area and material factor, F_{AM}, was derived by using the point-kernel method. This factor depends not only on the lateral extent of the contamination but also on source thickness, shielding thickness, gamma energies, and source material through its attenuation and buildup factors. All energies from radionuclide decay were considered separately and weighted by its yield, y, energy, E, and an energy dependent coefficient, K, to convert from air-absorbed dose to effective dose equivalent:

$$F_{AM} = \frac{\sum_{Energies:j} y_j E_j K_j \int_{V'} \frac{B(x')e^{-\mu x'}}{(x')^2} dV'}{\sum_{Energies:j} y_j E_j K_j \int_{V} \frac{B(x)e^{-\mu x}}{(x)^2} dV},$$

where:

$(x')^2 = r^2 + (t_a + t_c + t)^2$;

$(x)^2 = r^2 + (1m + t)^2$;

$$\mu = \frac{(t_a\mu_a + t_c\mu_c + t\mu_s)}{(t_a + t_c + t)}; \quad \text{and}$$

$$B(\chi) = B_a\left(\frac{t_a}{t_a + t_c + t_s}\chi\right)B_c\left(\frac{t_c}{t_a + t_c + t_s}\chi\right)B_s\left(\frac{t_s}{t_a + t_c + t_s}\chi\right).$$

B and μ are the buildup factor and the attenuation factor, respectively, for the appropriate material (a for air, c for shield material, and s for source material or soil reference). The integration volume V' is the desired geometry of specified material with radius R, shielding thickness t_c, and air thickness t_a; whereas V is the reference geometry of soil extending infinitely laterally with no shield and the receptor midpoint located 1 m from the surface.

4.7.2.1.3 Off-set Factor ($F_{OFF-SET}$)

The off-set factor, $F_{OFF-SET}$, is the ratio of the dose estimates from a noncircular shaped contaminated material to a reference shape. The concept of the shape factor is used to calculate the off-set factor. The reference shape is a fully contaminated circular area encompassing the given shape, centered about the receptor. This factor is derived by considering the area, material factors of a series of concentric circles, and the corresponding contamination fraction of the annular regions. The off-set factor is obtained by enclosing the irregularly shaped contaminated area in a circle, multiplying the area factor of each annulus by the fraction of the contaminated annulus area, f_i, summing the products, and dividing by the area factor of a circular contaminated material that is equivalent in area:

$$F_{OFF-SET} = \frac{\sum_{i=0}^{n} f_i\left[F_{AM}(A_i) - F_A(A_{i-1})\right]}{F_{AM}\left[\sum_{i=0}^{n} f_i(A_i - A_{i-1})\right]}.$$

5. Recommended Default Exposure Parameters

Table 1 presents the definitions of the variables and their default values. The SDCC default values and exposure models are consistent with the Surface Preliminary Remediation Goals for Radionuclides (SPRG) calculator. Both the SDCC and SPRG default values are largely consistent with default values in the PRG, DCC, BPRG, and SPRG where the same pathways are addressed (e.g., ingestion of dust on hard surfaces). This calculator, and the SPRG, 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.

Table 1. Recommended Default Exposure Parameters

SDCC Units			
Symbol	Definition (units)	Default	Reference
$SDCC_{idw-2D-ext-15cm}$	2-D Indoor Worker Direct External Exposure to Finite Slabs using 15 cm soil volume (pCi/g)	Isotope-specific	Determined in this calculator
	2-D Indoor Worker Direct External Exposure		

$SDCC_{idw-2D-ext-1cm}$	to Finite Slabs using 1 cm soil volume (pCi/g)	Isotope-specific	Determined in this calculator
$SDCC_{idw-2D-ext-5cm}$	2-D Indoor Worker Direct External Exposure to Finite Slabs using 5 cm soil volume (pCi/g)	Isotope-specific	Determined in this calculator
$SDCC_{idw-2D-ext-gp}$	2-D Indoor Worker Direct External Exposure to Contaminated Dust on Finite Slabs (pCi/cm^2)	Isotope-specific	Determined in this calculator
$SDCC_{idw-2D-ext-sv}$	2-D Indoor Worker Direct External Exposure to Finite Slabs using infinite soil volume (pCi/g)	Isotope-specific	Determined in this calculator
$SDCC_{idw-3D-ext-15cm}$	3-D Indoor Worker Direct External Exposure to Contaminated Building Materials using 15 cm soil volume (pCi/g)	Isotope-specific	Determined in this calculator
$SDCC_{idw-3D-ext-1cm}$	3-D Indoor Worker Direct External Exposure to Contaminated Building Materials using 1 cm soil volume (pCi/g)	Isotope-specific	Determined in this calculator
$SDCC_{idw-3D-ext-5cm}$	3-D Indoor Worker Direct External Exposure to Contaminated Building Materials using 5 cm soil volume (pCi/g)	Isotope-specific	Determined in this calculator
$SDCC_{idw-3D-ext-gp}$	3-D Indoor Worker Direct External Exposure to Contaminated Dust (pCi/cm^2)	Isotope-specific	Determined in this calculator
$SDCC_{idw-3D-ext-sv}$	3-D Indoor Worker Direct External Exposure to Contaminated Building Materials using infinite soil volume (pCi/g)	Isotope-specific	Determined in this calculator
$SDCC_{idw-dust-ext}$	Indoor Worker External Exposure to Settled Dust on Surfaces (pCi/cm^2)	Isotope-specific	Determined in this calculator
$SDCC_{idw-dust-ing}$	Indoor Worker Ingestion Exposure to Settled Dust on Surfaces (pCi/cm^2)	Isotope-specific	Determined in this calculator
$SDCC_{idw-dust-inhm}$	Indoor Worker Inhalation Exposure to Settled Dust on Surfaces using PEF_{m-pp} , PEF_{m-ui} , or PEF_{m-up} (pCi/cm^2)	Isotope-specific	Determined in this calculator
$SDCC_{idw-dust-inhm-state}$	Indoor Worker Inhalation Exposure to Settled Dust on Surfaces using $PEF_{m-pp-state}$ (pCi/cm^2)	Isotope-specific	Determined in this calculator
$SDCC_{idw-dust-inhw}$	Indoor Worker Inhalation Exposure to Settled Dust on Surfaces using PEF (pCi/cm^2)	Isotope-specific	Determined in this calculator
$SDCC_{idw-dust-inhw-state}$	Indoor Worker Inhalation Exposure to Settled Dust on Surfaces using PEF (pCi/cm^2)	Isotope-specific	Determined in this calculator
$SDCC_{idw-dust-tot}$	Indoor Worker Exposure to Settled Dust on Surfaces (pCi/cm^2)	Isotope-specific	Determined in this calculator
$SDCC_{ind-2D-ext-15cm}$	2-D Composite Worker Direct External Exposure to Finite Slabs using 15 cm soil volume (pCi/g)	Isotope-specific	Determined in this calculator
$SDCC_{ind-2D-ext-1cm}$	2-D Composite Worker Direct External Exposure to Finite Slabs using 1 cm soil volume (pCi/g)	Isotope-specific	Determined in this calculator
$SDCC_{ind-2D-ext-5cm}$	2-D Composite Worker Direct External Exposure to Finite Slabs using 5 cm soil volume (pCi/g)	Isotope-specific	Determined in this calculator
$SDCC_{ind-2D-ext-gp}$	2-D Composite Worker Direct External Exposure to Contaminated Dust on Finite Slabs (pCi/cm^2)	Isotope-specific	Determined in this calculator

$SDCC_{ind\text{-}2D\text{-}ext\text{-}sv}$	2-D Composite Worker Direct External Exposure to Finite Slabs using infinite soil volume (pCi/g)	Isotope-specific	Determined in this calculator
$SDCC_{ind\text{-}3D\text{-}ext\text{-}15cm}$	3-D Composite Worker Direct External Exposure to Contaminated Building Materials using 15 cm soil volume (pCi/g)	Isotope-specific	Determined in this calculator
$SDCC_{ind\text{-}3D\text{-}ext\text{-}1cm}$	3-D Composite Worker Direct External Exposure to Contaminated Building Materials using 1 cm soil volume (pCi/g)	Isotope-specific	Determined in this calculator
$SDCC_{ind\text{-}3D\text{-}ext\text{-}5cm}$	3-D Composite Worker Direct External Exposure to Contaminated Building Materials using 5 cm soil volume (pCi/g)	Isotope-specific	Determined in this calculator
$SDCC_{ind\text{-}3D\text{-}ext\text{-}gp}$	3-D Composite Worker Direct External Exposure to Contaminated Dust (pCi/cm^2)	Isotope-specific	Determined in this calculator
$SDCC_{ind\text{-}3D\text{-}ext\text{-}sv}$	3-D Composite Worker Direct External Exposure to Contaminated Building Materials using infinite soil volume (pCi/g)	Isotope-specific	Determined in this calculator
$SDCC_{ind\text{-}dust\text{-}ext}$	Composite Worker External Exposure to Settled Dust on Surfaces (pCi/cm^2)	Isotope-specific	Determined in this calculator
$SDCC_{ind\text{-}dust\text{-}ing}$	Composite Worker Ingestion Exposure to Settled Dust on Surfaces (pCi/cm^2)	Isotope-specific	Determined in this calculator
$SDCC_{ind\text{-}dust\text{-}inhm}$	Composite Worker Inhalation Exposure to Settled Dust on Surfaces using $PEF_{m\text{-}pp}$, $PEF_{m\text{-}ui}$, or $PEF_{m\text{-}up}$ (pCi/cm^2)	Isotope-specific	Determined in this calculator
$SDCC_{ind\text{-}dust\text{-}inhm\text{-}state}$	Composite Worker Inhalation Exposure to Settled Dust on Surfaces using $PEF_{m\text{-}pp\text{-}state}$ (pCi/cm^2)	Isotope-specific	Determined in this calculator
$SDCC_{ind\text{-}dust\text{-}inhw}$	Composite Worker Inhalation Exposure to Settled Dust on Surfaces using PEF (pCi/cm^2)	Isotope-specific	Determined in this calculator
$SDCC_{ind\text{-}dust\text{-}inhw\text{-}state}$	Composite Worker Inhalation Exposure to Settled Dust on Surfaces using PEF (pCi/cm^2)	Isotope-specific	Determined in this calculator
$SDCC_{ind\text{-}dust\text{-}tot}$	Composite Worker Exposure to Settled Dust on Surfaces (pCi/cm^2)	Isotope-specific	Determined in this calculator
$SDCC_{odw\text{-}2D\text{-}ext\text{-}15cm}$	2-D Outdoor Worker Direct External Exposure to Finite Slabs using 15cm soil volume (pCi/g)	Isotope-specific	Determined in this calculator
$SDCC_{odw\text{-}2D\text{-}ext\text{-}1cm}$	2-D Outdoor Worker Direct External Exposure to Finite Slabs using 1 cm soil volume (pCi/g)	Isotope-specific	Determined in this calculator
$SDCC_{odw\text{-}2D\text{-}ext\text{-}5cm}$	2-D Outdoor Worker Direct External Exposure to Finite Slabs using 5cm soil volume (pCi/g)	Isotope-specific	Determined in this calculator
$SDCC_{odw\text{-}2D\text{-}ext\text{-}gp}$	2-D Outdoor Worker Direct External Exposure to Contaminated Dust on Finite Slabs (pCi/cm^2)	Isotope-specific	Determined in this calculator
$SDCC_{odw\text{-}2D\text{-}ext\text{-}sv}$	2-D Outdoor Worker Direct External Exposure to Finite Slabs using infinite soil volume (pCi/g)	Isotope-specific	Determined in this calculator
$SDCC_{odw\text{-}3D\text{-}ext\text{-}15cm}$	3-D Outdoor Worker Direct External Exposure to Contaminated Building Materials using 15cm soil volume (pCi/g)	Isotope-specific	Determined in this calculator
$SDCC_{odw\text{-}3D\text{-}ext\text{-}1cm}$	3-D Outdoor Worker Direct External Exposure to Contaminated Building Materials using 1 cm soil volume (pCi/g)	Isotope-specific	Determined in this calculator

$SDCC_{odw-3D-ext-5cm}$	3-D Outdoor Worker Direct External Exposure to Contaminated Building Materials using 5cm soil volume (pCi/g)	Isotope-specific	Determined in this calculator
$SDCC_{odw-3D-ext-gp}$	3-D Outdoor Worker Direct External Exposure to Contaminated Dust (pCi/cm^2)	Isotope-specific	Determined in this calculator
$SDCC_{odw-3D-ext-sv}$	3-D Outdoor Worker Direct External Exposure to Contaminated Building Materials using infinite soil volume (pCi/g)	Isotope-specific	Determined in this calculator
$SDCC_{odw-dust-ext}$	Outdoor Worker External Exposure to Settled Dust on Surfaces (pCi/cm^2)	Isotope-specific	Determined in this calculator
$SDCC_{odw-dust-ing}$	Outdoor Worker Ingestion Exposure to Settled Dust on Surfaces (pCi/cm^2)	Isotope-specific	Determined in this calculator
$SDCC_{odw-dust-inhm}$	Outdoor Worker Inhalation Exposure to Settled Dust on Surfaces using PEF_{m-pp} , PEF_{m-ui} , or PEF_{m-up} (pCi/cm^2)	Isotope-specific	Determined in this calculator
$SDCC_{odw-dust-inhm-state}$	Outdoor Worker Inhalation Exposure to Settled Dust on Surfaces using $PEF_{m-pp-state}$ (pCi/cm^2)	Isotope-specific	Determined in this calculator
$SDCC_{odw-dust-inhw}$	Outdoor Worker Inhalation Exposure to Settled Dust on Surfaces using PEF (pCi/cm^2)	Isotope-specific	Determined in this calculator
$SDCC_{odw-dust-inhw-state}$	Outdoor Worker Inhalation Exposure to Settled Dust on Surfaces using PEF (pCi/cm^2)	Isotope-specific	Determined in this calculator
$SDCC_{odw-dust-tot}$	Outdoor Worker Exposure to Settled Dust on Surfaces (pCi/cm^2)	Isotope-specific	Determined in this calculator
$SDCC_{res-2D-ext-15cm}$	2-D Resident Direct External Exposure to Finite Slabs using 15 cm soil volume (pCi/g)	Isotope-specific	Determined in this calculator
$SDCC_{res-2D-ext-1cm}$	2-D Resident Direct External Exposure to Finite Slabs using 1cm soil volume (pCi/g)	Isotope-specific	Determined in this calculator
$SDCC_{res-2D-ext-5cm}$	2-D Resident Direct External Exposure to Finite Slabs using 5 cm soil volume (pCi/g)	Isotope-specific	Determined in this calculator
$SDCC_{res-2D-ext-gp}$	Resident Direct External Exposure to Contaminated Dust on Finite Slabs (pCi/cm^2)	Isotope-specific	Determined in this calculator
$SDCC_{res-2D-ext-sv}$	2-D Resident Direct External Exposure to Finite Slabs using infinite soil volume (pCi/g)	Isotope-specific	Determined in this calculator
$SDCC_{res-3D-ext-15cm}$	3-D Resident Direct External Exposure to Contaminated Building Materials using 15 cm soil volume (pCi/g)	Isotope-specific	Determined in this calculator
$SDCC_{res-3D-ext-1cm}$	3-D Resident Direct External Exposure to Contaminated Building Materials using 1cm soil volume (pCi/g)	Isotope-specific	Determined in this calculator
$SDCC_{res-3D-ext-5cm}$	3-D Resident Direct External Exposure to Contaminated Building Materials using 5 cm soil volume (pCi/g)	Isotope-specific	Determined in this calculator
$SDCC_{res-3D-ext-gp}$	Resident Direct External Exposure to Contaminated Dust (pCi/cm^2)	Isotope-specific	Determined in this calculator
$SDCC_{res-3D-ext-sv}$	3-D Resident Direct External Exposure to Contaminated Building Materials using infinite soil volume (pCi/g)	Isotope-specific	Determined in this calculator
$SDCC_{res-dust-ext}$	Resident External Exposure to Settled Dust on Surfaces (pCi/cm^2)	Isotope-specific	Determined in this calculator

$SDCC_{res\text{-}dust\text{-}ing}$	Resident Ingestion Exposure to Settled Dust on Surfaces (pCi/cm^2)	Isotope-specific	Determined in this calculator
$SDCC_{res\text{-}dust\text{-}inhm}$	Resident Inhalation Exposure to Settled Dust on Surfaces using $PEF_{m\text{-}pp}$, $PEF_{m\text{-}ui}$, or $PEF_{m\text{-}up}$ (pCi/cm^2)	Isotope-specific	Determined in this calculator
$SDCC_{res\text{-}dust\text{-}inhm\text{-}state}$	Resident Inhalation Exposure to Settled Dust on Surfaces using $PEF_{m\text{-}pp\text{-}state}$ (pCi/cm^2)	Isotope-specific	Determined in this calculator
$SDCC_{res\text{-}dust\text{-}inhw}$	Resident Inhalation Exposure to Settled Dust on Surfaces using PEF (pCi/cm^2)	Isotope-specific	Determined in this calculator
$SDCC_{res\text{-}dust\text{-}inhw\text{-}state}$	Resident Inhalation Exposure to Settled Dust on Surfaces using PEF (pCi/cm^2)	Isotope-specific	Determined in this calculator
$SDCC_{res\text{-}dust\text{-}tot}$	Resident Exposure to Settled Dust on Surfaces (pCi/cm^2)	Isotope-specific	Determined in this calculator

Dose Conversion Factors

Symbol	Definition (units)	Default	Reference
$DCF_{ext\text{-}15cm}$	External Exposure Dose Conversion Factor - direct (mrem/year per pCi/g)	Isotope-specific	ORNL 2014c
$DCF_{ext\text{-}1cm}$	External Exposure Dose Conversion Factor - direct (mrem/year per pCi/g)	Isotope-specific	ORNL 2014c
$DCF_{ext\text{-}5cm}$	External Exposure Dose Conversion Factor - direct (mrem/year per pCi/g)	Isotope-specific	ORNL 2014c
$DCF_{ext\text{-}gp}$	External Exposure Dose Conversion Factor - dust (mrem/year per pCi/cm^2)	Isotope-specific	ORNL 2014c
$DCF_{ext\text{-}sv}$	External Exposure Dose Conversion Factor - direct (mrem/year per pCi/g)	Isotope-specific	ORNL 2014c
DCF_i	Inhalation Dose Conversion Factor - air (mrem/pCi)	Isotope-specific	ORNL 2014c
DCF_o	Dust Ingestion Dose Conversion Factor - population (mrem/pCi)	Isotope-specific	ORNL 2014c
DCF_{oa}	Dust Ingestion Dose Conversion Factor - adult only (mrem/pCi)	Isotope-specific	ORNL 2014c

Dose and Decay Constant Variables

Symbol	Definition (units)	Default	Reference
DL	Dose Limit (mrem/year)	1	User must specify dose rate
k	Dissipation Rate Constant - (year^{-1})	0.38	U.S. EPA 2003 (pg. D-8)
t_{iw}	Time - indoor worker (year)	1	U.S. EPA. 1991 (pg. 15)
t_{ow}	Time - outdoor worker (year)	1	U.S. EPA. 1991 (pg. 15)
t_{res}	Time - resident (year)	1	U.S. EPA. 1991 (pg. 15)
t_w	Time - composite worker (year)	1	U.S. EPA. 1991 (pg. 15)
λ	decay constant = 0.693/half-life (year^{-1}) where 0.693 = ln(2)	Isotope-specific	Developed for EPA's "Preliminary Remediation Goals for Radionuclide Contaminants at Superfund Sites" (NRCP 1996)

Miscellaneous Variables

Symbol	Definition (units)	Default	Reference
AAF_{res-a}	Annual Age Fraction - resident adult (unitless)	0.77	This fraction is used to compose an age-adjusted intake.
AAF_{res-c}	Annual Age Fraction - resident child (unitless)	0.23	This fraction is used to compose an age-adjusted intake.
$ACF_{ext-15cm}$	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
F_{AM}	Area and Material Factor (unitless)	1.0	ANL 2001 (Fig 8.6)
$F_{OFF-SET}$	Off-set Factor (unitless)	1.0	ANL 2001 (Fig 8.6)
F_{s-surf}	Street Surfaces Factor (unitless)	Isotope-specific	Eckerman 2007
GSF_i	Gamma Shielding Factor - indoor (unitless)	0.4 (assumes shielding)	Other GSFs are presented in these reports. U.S. EPA 2000a. (pg. 2-22). U.S. EPA 2000b. (pg. 2-18)
GSF_s	Gamma Shielding Factor - Outdoor Surfaces (unitless)	1 (assumes no shielding)	Other GSFs are presented in these reports. U.S. EPA 2000a. (pg. 2-22). U.S. EPA 2000b. (pg. 2-18)
SLF	Silt Loading Factor (cm^2/kg)	6.67E+08	Converted from 0.015 gram/m^2. A default number for California highway from Table 2, pg A-67 U.S. EPA 2005.

Inhalation and Ingestion Rates

Symbol	Definition (units)	Default	Reference
$IFA_{res-adj}$	Age-adjusted Inhalation Rate - resident (m^3/year)	6,195	Calculated Value based on U.S. EPA. 1991 (pg. 15)
IFD_{iw}	Dust Ingestion Factor - indoor worker (cm^2/day)	294	Calculated Value based on U.S. EPA 2003 (pg. D-4)
IFD_{ow}	Dust Ingestion Factor - outdoor worker (cm^2/day)	196	Calculated Value based on U.S. EPA 2003 (pg. D-4)
$IFD_{res-adj}$	Age-Adjusted Dust Ingestion Rate - resident (cm^2/year)	39,291	Calculated Value based on U.S. EPA 2003 (pg. D-4)
IFD_w	Dust Ingestion Factor - composite worker (cm^2/day)	294	Calculated Value based on U.S. EPA 2003 (pg. D-4)
IRA_{iw}	Inhalation Rate - indoor worker (m^3/hour)	2.5	U.S. EPA. 1997 (pg. 5-25)
IRA_{ow}	Inhalation Rate - outdoor worker (m^3/hour)	2.5	U.S. EPA. 1997 (pg. 5-25)
IRA_{res-a}	Inhalation Rate - resident adult (m^3/day; based on IRIS default)	20	U.S. EPA. 1991 (pg. 15)
IRA_{res-c}	Inhalation Rate - resident child (m^3/day; based on IRIS default)	10	U.S. EPA. 1991 (pg. 15)
	Inhalation Rate - composite worker		

IRA_w	(m^3/hour)	2.5	U.S. EPA. 1997 (pg. 5-25)

Ingestion Rate Variables

Symbol	Definition (units)	Default	Reference
ET_{iw}	Exposure Time - indoor worker (hour/day)	8	U.S. EPA 2003 (pg. D-4)
ET_{ow}	Exposure Time - outdoor worker (hour/day)	8	U.S. EPA 2003 (pg. D-4)
$ET_{res-a,h}$	Exposure Time - adult hard surface (hour/day)	4	U.S. EPA 2003 (pg. D-4)
$ET_{res-c,h}$	Exposure Time - child Hard Surface (hour/day)	4	U.S. EPA 2003 (pg. D-4)
ET_{res-i}	Exposure Time Indoor - resident (hour/day)	16.4	U.S. EPA. 1997 (Table 15-131)
ET_{res-o}	Exposure Time Outdoor - resident (hour/day)	1.752	U.S. EPA. 1997 (Table 15-132)
ET_w	Exposure Time - composite worker (hour/day)	8	U.S. EPA 2003 (pg. D-4)
FQ_{iw}	Frequency of Hand to Mouth - indoor worker (event/hour)	3	U.S. EPA 2011 Table 4.1 and U.S. EPA 2003. Time weighted average of all age groups from 6 to 26 years.
FQ_{ow}	Frequency of Hand to Mouth - outdoor worker (event/hour)	2	U.S. EPA 2011 Table 4.1 and U.S. EPA 2003. Time weighted average of all age groups from 6 to 26 years.
FQ_{res-a}	Frequency of Hand to Mouth - adult (event/hour)	2	U.S. EPA 2011 Table 4.1 and U.S. EPA 2003. Time weighted average of all age groups from 6 to 26 years.
FQ_{res-c}	Frequency of Hand to Mouth - child (event/hour)	10	U.S. EPA 2011 Table 4.1 and U.S. EPA 2003. Time weighted average of all age groups from birth to 6 years.
FQ_w	Frequency of Hand to Mouth - composite worker (event/hour)	2	U.S. EPA 2011 Table 4.1 and U.S. EPA 2003. Time weighted average of all age groups from 6 to 26 years.
$FTSS_h$	Fraction Transferred Surface to Skin - Hard Surface (unitless)	0.5	U.S. EPA 2003 (pg. D-3)
SA_{iw}	Surface Area of Fingers - indoor worker (cm^2)	49	U.S. EPA 2011 Table 7.2. 5% of the average of adult male and female.
SA_{ow}	Surface Area of Fingers - outdoor worker (cm^2)	49	U.S. EPA 2011 Table 7.2. 5% of the average of adult male and female.
SA_{res-a}	Surface Area of Fingers - adult (cm^2)	49	U.S. EPA 2011 Table 7.2. 5% of the average of adult male and female.
SA_{res-c}	Surface Area of Fingers - child (cm^2)	16	U.S. EPA 2011 Table 7.2. 5% of the average of adult male and female.
SA_w	Surface Area of Fingers - composite worker (cm^2)	49	U.S. EPA 2011 Table 7.2. 5% of the average of adult male and female.
SE	Saliva Extraction Factor (unitless)	0.5	U.S. EPA 2003 (pg. D-5)

Exposure Variables

Symbol	Definition (units)	Default	Reference
ED_{iw}	Exposure Duration - indoor worker (year)	1	U.S. EPA 1991 (pg. 15)

ED_{ow}	Exposure Duration - outdoor worker (year)	1	U.S. EPA 1991 (pg. 15)
ED_{res}	Exposure Duration - resident (year)	26	U.S. EPA 1991 (pg. 15)
ED_{res-a}	Exposure Duration - adult resident (year)	20	U.S. EPA 1991 (pg. 15)
ED_{res-c}	Exposure Duration - child resident (year)	6	U.S. EPA 1991 (pg. 15)
ED_{w}	Exposure Duration - composite worker (year)	1	U.S. EPA 1991 (pg. 15)
EF_{iw}	Exposure Frequency - indoor worker (day/year)	250	U.S. EPA 1991 (pg. 15)
EF_{ow}	Exposure Frequency - outdoor worker (day/year)	225	U.S. EPA 1991 (pg. 15)
EF_{res}	Exposure Frequency - resident (day/year)	350	U.S. EPA 1991 (pg. 15)
EF_{res-a}	Exposure Frequency - resident (day/year)	350	U.S. EPA 1991 (pg. 15)
EF_{res-c}	Exposure Frequency - resident (day/year)	350	U.S. EPA 1991 (pg. 15)
EF_{w}	Exposure Frequency - composite worker (day/year)	250	U.S. EPA 1991 (pg. 15)

Particulate Emission Factor Variables

Symbol	Definition (units)	Default	Reference
A	Dispersion constant - wind (unitless) region-specific Dispersion constant - mechanical (unitless)	16.2302 - wind default 12.9351 - mechanical	wind - U.S. EPA 2002 (pg. D-6) mechanical - U.S. EPA 2002 (Eq. E-19)
a-i	Constants based on the stated aerodynamic particle size for industrial unpaved roads (unitless)	0.9 for PM-10	AP42 for Unpaved Roads Table 13.2.2-2
a-p	Constants based on the stated aerodynamic particle size for public unpaved roads (unitless)	1.0 for PM-10	AP42 for Unpaved Roads Table 13.2.2-2
A_R	Surface area of contaminated road segment (m^2), $AR = L_R \times W_R \times 0.092903\ m^2/ft^2$	274.2	U.S. EPA 2002 (Equation E-18)
A_s	Areal extent of the site or contamination (acres)	0.5 (range 0.5 to 500)	U.S. EPA 2002 (pg. D-2)
AVK	Annual vehicle kilometers traveled	roadclass-specific	U.S. DOT 2018 (hm20 and vm2)
B	Dispersion constant - wind (unitless) region-specific Dispersion constant - mechanical (unitless)	18.7762 - wind default 5.7383 - mechanical	wind - U.S. EPA 2002 (pg. D-6) mechanical - U.S. EPA 2002 (Eq. E-19)
b-i	Constants based on the stated aerodynamic particle size for industrial unpaved roads (unitless)	0.45 for PM-10	AP42 for Unpaved Roads Table 13.2.2-2
C	Dispersion constant - wind (unitless) region-specific Dispersion constant - mechanical (unitless)	216.108 - wind default 71.7711 - mechanical	wind - U.S. EPA 2002 (pg. D-6) mechanical - U.S. EPA 2002 (Eq. E-19)
c-p	Constants based on the stated aerodynamic particle size for public unpaved roads (unitless)	0.2 for PM-10	AP42 for Unpaved Roads Table 13.2.2-2

d-p	Constants based on the stated aerodynamic particle size for public unpaved roads (unitless)	0.5 for PM-10	AP42 for Unpaved Roads Table 13.2.2-2
F(x)	function dependent on 0.886 × (U_t/U_m) unitless	0.194	U.S. EPA 1996, Appendix D Table 2
k-pp	Particle size multiplier for public paved road (g/VKT)	Size-specific (0.62 for PM-10)	AP42 for Paved Roads Table 13.2-1.1
k-ui	Particle size multiplier for industrial unpaved road (lb/VMT)	Size-specific (1.5 for PM-10)	AP42 for Unpaved Roads Table 13.2.2-2
k-up	Particle size multiplier for public unpaved road (lb/VMT)	Size-specific (1.8 for PM-10)	AP42 for Unpaved Roads Table 13.2.2-2
L_R	Length of road segment (ft) L_R = square root of site surface contamination used for $A_{s=}$=0.5 acres	147.6	U.S. EPA 2002 (Equation E-18)
L_S	Length of road segment (km) L_S = L_R×0.0003048 km/ft	0.045	U.S. EPA 2002 (Equation E-18)
M	Road surface material moisture content (%)	7.9 % (default)	U.S. EPA 2002 (Equation E-18)
p	Number of days per year with at least 0.01 inches of precipitation	Region-specific (150)	U.S. EPA 2002 (Exhibit E-4)
PEF	Wind Particulate Emission Factor - Minneapolis (m^3/kg)	1.36×10^9 Minneapolis-specific	U.S. EPA 1996a (pg. 23), U.S. EPA 1996b (pg. 31)
$PEF_{m\text{-}pp}$	Mechanical Particulate Emission Factor - paved public roads(m^3/kg)	1.86×10^6	U.S. EPA 2002 (Equation E-18)
$PEF_{m\text{-}pp\text{-}state}$	Mechanical Particulate Emission Factor - paved public state roads (m^3/kg)	state-specific	U.S. EPA 2002 (Equation E-18)
$PEF_{m\text{-}ui}$	Mechanical Particulate Emission Factor - unpaved industrial roads(m^3/kg)	site-specific	U.S. EPA 2002 (Equation E-18)
$PEF_{m\text{-}up}$	Mechanical Particulate Emission Factor - unpaved public roads(m^3/kg)	site-specific	U.S. EPA 2002 (Equation E-18)
Q/C_m	Inverse of the ratio of the 1-h. geometric mean air concentration to the emission flux along a straight road segment bisecting a square site, (g/m^2-s per kg/m^3)	23.02	U.S. EPA 2002 (Equation E-18)
Q/C_w	Inverse of the Mean Concentration at the Center of a 0.5-Acre-Square Source - wind(g/m^2-s per kg/m^3)	93.77 Minneapolis-specific	U.S. EPA 1996a (pg. 23), U.S. EPA 1996b (pg. 31)
s	Road surface silt content (%)	8.5	U.S. EPA 2002 (Equation E-18)
sL	Road surface silt loading (g/m^2)	Region-specific (0.015)	U.S. EPA 2014 (Table 63)
T	Total time over which exposure occurs. equal to ED (s)	31,536,000 (1 year)	U.S. EPA 2002 (Equation E-18)
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 1999b, U.S. EPA 1996a (pg. 23), U.S. EPA 1996b (pg. 31)
	Sum of fleet vehicle kilometers traveled	(based on annualized urban	

VKT	during the exposure duration (km/year)	California road and traffic data)	U.S. DOT 2018 (hm20 and vm2)
W	Mean vehicle weight (tons)	3.2	U.S. EPA 2001 (Page 4-285)
W_R	Width of road segment (ft)	20	U.S. EPA 2002 (Equation E-18)

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