## Dose Compliance Concentrations for Radionuclides in Outdoor Surfaces (SDCC)

Topic for Key OSWER Radiation Guidances and Reports

# User's Guide

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## Purpose

**This guidance document sets forth recommended approaches based upon the current available and relevant science 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 recommended guidance). The use of this recommended guidance or of alternate approaches in the consideration or selection of remedial or removal actions on CERCLA sites should be reflected in the Administrative Records for such sites. 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 Dose Compliance Concentrations for Radionuclides in Outdoor Surfaces (SDCCs) for Superfund electronic calculator User's Guide provide recommended guidance to EPA staff. They also provide recommended guidance to the public and regulated community on how EPA intends the National Oil and Hazardous Substances Pollution Contingency Plan (NCP) be implemented. EPA may change this recommended 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 human radiological SDCC addresses neither human cancer risk from nonradiological (chemical) contaminants, 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 radiological contaminants which include uranium, it may also be necessary to consider the noncancer toxicity of uranium. 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. Human cancer risk evaluation of radionuclides in soil should be conducted using the EPA's PRG calculator, EPA's BPRG calculator should be used for inside buildings and the EPA's SPRG calculator should be used for evaluation of outdoor hard surfaces. EPA's DCC calculator may be used to assess radionuclide dose in soil and water.**

## 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 residential 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 SDCC is a tool that the U.S. Environmental Protection Agency developed to help standardize the evaluation and cleanup of radioactively contaminated sites at which 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 supercedes 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). A third 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 type of dose methodology used for purposes conducting dose assessment to demonstrate ARAR compliance.

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

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

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

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

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

This website combines current EPA DCFs with "standard" exposure factors to estimate contaminant concentrations 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 activities that correspond to fixed levels of dose (e.g., mrem) inside a building. Dose conversion factors (DCFs), or "dose coefficients", for a given radionuclide represent the dose equivalent per unit intake (i.e., ingestion or inhalation) or external exposure of that radionuclide. These DCFs are used to convert a radionuclide concentration in soil, air, water, or foodstuffs to a radiation 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 equivalent to the receptor.

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 dose conversion factor value tabulated in the Radionuclide Table for each radionuclide have been selected based on the following guidelines: (1) For those elements where Table 4.1 of Federal Guidance Report No. 13 (and Table 2 of ICRP Publication 72) specifies a recommended default lung absorption type for particulates, the inhalation dose conversion 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 dose conversion 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. (3) Where Federal Guidance Report No. 13 specifies risk coefficients for multiple chemical forms of certain elements (tritium, carbon, sulfur, iodine, and mercury), the inhalation dose conversion 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 specific information physical characteristics of the aerosol. Where appropriate, radionuclides may be present in gas or vapor form, are designated by "G" and "V", respectively; such radionuclides include tritium, carbon, sulfur, nickel, ruthenium, iodine, tellurium, and mercury.

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

The recommended SDCCs are generated with standard exposure route equations using EPA DCFs and exposure parameters.

### 2.2 Dose Conversion Factors (DCFs)

Users of this calculator tool should choose the DCFs (International Commission on Radiological Protection (ICRP) 30 or 60) 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 60 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 risk based upon its best scientific judgment. For further discussion of the scientific differences between ICRP 30 and 60 methodologies, see "Dosimetric Significance of the ICRP's Updated Guidance and Models, 1989-2003, and Implications for U.S. Federal Guidance" (August 2003, ORNL/TM-2003/207). http://ordose.ornl.gov/documents/ornltm2003-207.pdf

#### 2.2.1 ICRP 30

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

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

#### 2.2.2 ICRP 60

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

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

The use of dose conversion factors of ICRP 60/72 is mandated in the European Union by European Council Directive 96/29 of May 13, 1996. If requested, NRC can grant a licensee an exemption to use the new dosimetric data of the ICRP; e.g. ICRP 68 for occupational exposures. In accordance with a June 8, 2007 Federal Register notice, DOE no longer requires a facility to get an exception and they are able to use ICRP 68 dosimetric data for occupational exposure. Non-regulatory studies (e.g., 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.

#### 2.2.3 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.

#### 2.2.4 When To Use "+D" SDCCs

Several of the isotopes are listed with a “+D” designation. This designation indicates that the DCF includes the contribution from ingrowth of daughter isotopes out to 100 years. The intention of this designation is to make realistic SDCCs by including the contributions from their short-lived decay products, assuming equal activity concentrations (i.e. ,secular equilibrium) with the principal or parent nuclide in the environment. (Note that there is one exception to the assumption of secular equilibrium. For the inhalation dose conversion factor for Rn-222+D reported in the table, EPA assumes a 50% equilibrium value for radon decay products (Po-218, Pb-214, Bi-214 and Po-214) in air.) Before applying SDCCs to a site, it should be determined if the isotopes present are in secular equilibrium. If the isotopes are found to be in secular equilibrium, the +D SDCCs should be used for the parent isotope and the daughters included in the +D can be ignored. If the isotopes are not in secular equilibrium, SDCCs should be applied for each daughter isotope. However, in the absence of empirical data, the "+D" values for radionuclides should be used unless there are compelling reasons not to.

For example, if analytical data from a site reveal that Th-228, Ra-224, Rn-220 are detected at a site and that they are in secular equilibrium, the SDCC for Th-228+D should be applied and the Ra-224 and Rn-220 can be ignored.

Another example could concern a decay chain in secular equilibrium like Th-232. Even though the decay chain for Th-232 is very long, there is no Th-232+D dose conversion factor. In this case the SDCCs for Th-232, Ra-228+D, and Th-228+D should be used. If no part of the decay chain is in secular equilibrium, the user should use each of the SDCCs for isotopes in the decay chain that have dose conversion factors (e.g., Th-232, Ra-228, Ac-228, Th-228, Ra-224, Rn-220, Po-216, Pb-212, Bi-212, Po-212, and Tl-208). If part of the decay chain is in secular equilibrium, then the user may use that particular +D dose conversion factor that covers that part of the decay chain, while using the dose conversion factors for the other radionuclides.

#### 2.2.5 When To Use "+E" SDCCs

Similar to the discussion in Section 2.2.4, "+E" DCFs account for the ingrowth of daughters out to 1,000 years.

#### 2.2.6 Associated Decay Chains for "+D" SDCCs

Selected radionuclides and radioactive decay chain products are designated with the suffix "+D" to indicate that cancer risk estimates for these radionuclides include the contributions from their short-lived decay products, assuming equal activity concentrations (i.e., secular equilibrium) with the principal or parent nuclide in the environment. For all radionuclides without the "+D" suffix, only intake or external exposure to the single radionuclide is considered. Most radionuclides with a +D designation include the entire decay chain to the stable terminal nuclide in the dose conversion factors. HEAST provides a table of +D radionuclides that decay for longer than 100 years. This table provides the associated decay chain included and the terminal radionuclide used in the dose conversion factors. This table is reproduced below.

| Principal Radionuclide (half-life in years) | Associated decay chain | Terminal Radionuclide | Half-life (years) |
|---|---|---|---|
| Am-242m+D (152) | Am-242, Cm-242, Np-238 | Pu-238 | 87.7 |
| Am-243+D (7.4E+03) | Np-239 | Pu-239 | 2.40E+04 |
| Np-237+D (2.1E+06) | Pa-233 | U-233 | 1.6E+05 |
| Pu-244+D (8.3E+07) | U-240, Np-240m | Pu-240 | 6.50E+03 |
| Ra-226+D (1.6E+03) | Rn-222, Po-218, Pb-214, At-218, Bi-214, Po-214, Tl-210 | Pb-210 | 22 |
| Ra-228+D (6) | Ac-228 | Th-228 | 2 |
| U-235+D (7.0E+08) | Th-231 | Pa-231 | 3.3E+04 |
| U-238+D (4.5E+09) | Th-234, Pa-234m, Pa-234 | U-234 | 2.4E+05 |

Ingestion and inhalation dose conversion factors are missing for some of the +D isotopes. These have not been derived yet. Use caution when selecting a SDCC to make sure that as many routes of exposure are accounted for.

### 2.3 SDCC in Context of Superfund Modeling Framework

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

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

## 3. Using the SDCC Table

The SDCC "Download Area" table provides 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

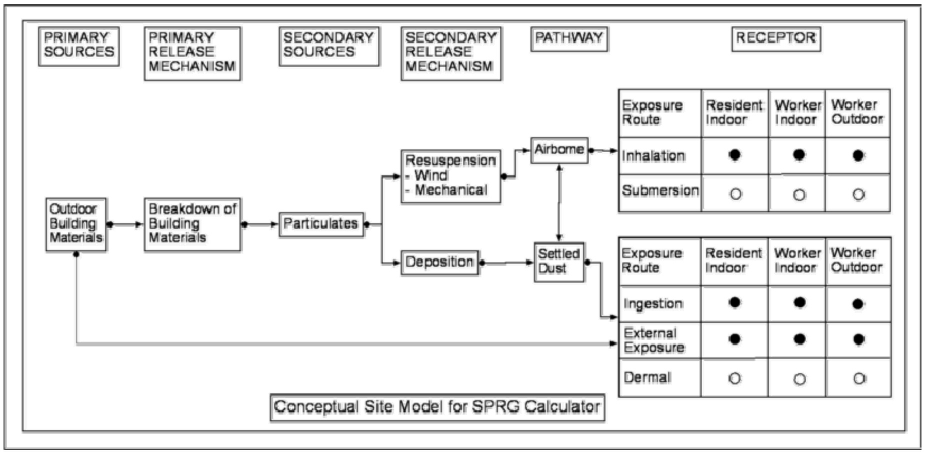
### 3.1 Developing a Conceptual Site Model

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 as conditions which 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 (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 Radionuclide Background

Natural background radiation should be considered prior to applying sdccs as cleanup levels. Background and site-related levels of radiation should be addressed as they are for other contaminants at CERCLA sites. For further information see EPA's guidance "Role of Background in the CERCLA Cleanup Program", April 2002, (OSWER 9285.6-07P). It should be noted that certain ARARs specifically address how to factor background into cleanup levels. For example, some radiation ARAR levels are established as increments above background concentrations. In these circumstances, background should be addressed in the manner prescribed by the ARAR. 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, the following should be avoided:

- Applying recommended SDCC levels to a site without adequately developing a conceptual site model that identifies relevant exposure pathways and exposure scenarios.
- Use of recommended SDCC levels as cleanup levels without the consideration of other relevant criteria such as ARARs.
- Use of recommended SDCC levels as cleanup levels without verifying numbers with a health physicist/risk assessor.
- Use of outdated SDCC tables that have been superseded by more recent publications.
- Not considering the effects from the presence of multiple isotopes.

## 4. Technical Support 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. 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:

Resident - Exposure to Settled Dust on Outdoor Surfaces
Resident - 3-D Direct External Exposure to Fixed Contaminated Building Materials
Resident - 3-D Direct External Exposure to Fixed Settled Dust on Outdoor Surfaces
Resident - 2-D Direct External Exposure to Fixed Contaminated Finite Slabs
Resident - 2-D Direct External Exposure to Fixed Settled Dust on Finite Slabs
Outdoor Worker - Exposure to Settled Dust on Outdoor Surfaces
Outdoor Worker - 3-D Direct External Exposure to Fixed Contaminated Building Materials
Outdoor Worker - 3-D Direct External Exposure to Fixed Settled Dust on Outdoor Surfaces
Outdoor Worker - 2-D Direct External Exposure to Fixed Contaminated Finite Slabs
Outdoor Worker - 2-D Direct External Exposure to Fixed Settled Dust on Finite Slabs
Indoor Worker - Exposure to Settled Dust on Outdoor Surfaces
Indoor Worker - 3-D Direct External Exposure to Fixed Contaminated Building Materials
Indoor Worker - 3-D Direct External Exposure to Fixed Settled Dust on Outdoor Surfaces
Indoor Worker - 2-D Direct External Exposure to Fixed Contaminated Finite Slabs
Indoor Worker - 2-D Direct External Exposure to Fixed Settled Dust on Finite Slabs

### 4.1 Residential Surfaces

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

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

$$SDCC_{dr\text{-}total}\left(\frac{pCi}{cm^2}\right)=\frac{DL\,(mrem)\times t_r\,(yrs)\times\lambda\left(\frac{1}{years}\right)}{\left(\frac{1-e^{-kt_r}}{kt_r}\right)\times\left(1-e^{-\lambda t_r}\right)\times EF_r\left(\frac{350\ d}{yr}\right)\times ED_r\,(1\ yr)\times\left[\begin{array}{l}\left(DCF_{d\text{-}oral}\left(\frac{mrem}{pCi}\right)\times IF_r\left(\frac{64.5\ cm^2}{d}\right)\right)+\\ \left(DCF_{inh}\left(\frac{mrem}{pCi}\right)\times HF_r\left(\frac{18\ m^3}{d}\right)\times\left(\frac{1\ d}{24\ hr}\right)\times\frac{1}{PEF\left(\frac{m^3}{Kg}\right)}\times SLF\left(\frac{6.\bar{6}E{+}08\ cm^2}{Kg}\right)\times\left[ET_{o,r}\left(\frac{1.752\ hr}{d}\right)+ET_{i,r}\left(\frac{16.4\ hr}{d}\right.\right.\right.\\ \left(DCF_{d\text{-}ext}\left[\frac{\left(mrem/yr\right)}{\left(pCi/cm^2\right)}\right]\times F_{AM}\times F_{OFF\text{-}SET}\times ACF\,(1.0)\times\left(\frac{1\ d}{24\ hr}\right)\times\left[ET_{o,r}\left(\frac{1.752\ hr}{d}\right)\times GSF_o\,(1.0)+ET_{i,r}\left(\frac{16.4\ hr}{d}\right)\times\right.\right.\end{array}\right.}$$

where

$$IF_r\left(\frac{64.5\ cm^2}{day}\right)=\left[\begin{array}{l}\left(FTSS_h\,(0.5)\times ET_{h,c}\left(\frac{4\ hrs}{day}\right)\times SE\,(0.5)\times ED_c\,(1\ yrs)\times AAF_c\,(0.2)\times SA_c\left(\frac{15\ cm^2}{event}\right)\times FQ_c\left(\frac{9.5\ events}{hour}\right)\right)+\\ \left(FTSS_h\,(0.5)\times ET_{h,a}\left(\frac{4\ hrs}{day}\right)\times SE\,(0.5)\times ED_a\,(1\ yrs)\times AAF_a\,(0.8)\times SA_a\left(\frac{45\ cm^2}{event}\right)\times FQ_a\left(\frac{1\ event}{hour}\right)\right)\end{array}\right]/ED_r\,(1\ yrs)\ \text{and}$$

$$HF_r\left(\frac{18\ m^3}{day}\right)=\left[\left(HR_a\left(\frac{20\ m^3}{day}\right)\times ED_a\,(1\ yrs)\times AAF_a\,(0.8)\right)+\left(HR_c\left(\frac{10\ m^3}{day}\right)\times ED_c\,(1\ yrs)\times AAF_c\,(0.2)\right)\right]/ED_r\,(1\ yrs)$$

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

$$SDCC_{3\text{-}Dr\text{-}sv}\left(\frac{pCi}{g}\right)=\frac{DL\,(mrem)\times t_r\,(years)\times\lambda\left(\frac{1}{years}\right)}{SF_{ext}\left[\left(\frac{mrem}{year}\right)/\left(\frac{pCi}{g}\right)\right]\times F_{CD}\times F_{AM}\times F_{OFF\text{-}SET}\times EF_r\left(\frac{350\ days}{year}\right)\times ED_r\,(1\ year)\times\left(\frac{1day}{24hours}\right)\times\left(1-e^{-\lambda t_r}\right)\times\left[ET_{o,r}\left(\frac{1.752\ hours}{day}\right)\times GSF_o\,(1.0)+ET_{i,r}\left(\frac{16.4\ hours}{day}\right)\times GSF_i\,(0.4)\right]\times\left(\frac{1year}{365days}\right)\times F_{SURF}}$$

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.

- 3-D Exposure to Direct External Exposure (Materials with fixed contamination at 1cm in outside walls, streets and sidewalks using 1cm soil volume toxicity values)

$$SDCC_{3\text{-}Dr\text{-}1cm}\left(\frac{pCi}{g}\right)=\frac{DL\,(mrem)\times t_r\,(years)\times\lambda\left(\frac{1}{years}\right)}{SF_{ext\text{-}1cm}\left[\left(\frac{mrem}{year}\right)/\left(\frac{pCi}{g}\right)\right]\times F_{CD}\times F_{AM}\times F_{OFF\text{-}SET}\times EF_r\left(\frac{350\ days}{year}\right)\times ED_r\,(1\ year)\times\left(\frac{1day}{24hours}\right)\times\left(1-e^{-\lambda t_r}\right)\times\left[ET_{o,r}\left(\frac{1.752\ hours}{day}\right)\times GSF_o\,(1.0)+ET_{i,r}\left(\frac{16.4\ hours}{day}\right)\times GSF_i\,(0.4)\right]\times\left(\frac{1year}{365days}\right)\times F_{SURF}}$$

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.

- 3-D Exposure to Direct External Exposure (Materials with fixed contamination at 5cm in outside walls, streets and sidewalks using 5cm soil volume toxicity values)

$$SDCC_{3\text{-}Dr\text{-}5cm}\left(\frac{pCi}{g}\right)=\frac{DL\,(mrem)\times t_r\,(years)\times\lambda\left(\frac{1}{years}\right)}{SF_{ext\text{-}5cm}\left[\left(\frac{mrem}{year}\right)/\left(\frac{pCi}{g}\right)\right]\times F_{CD}\times F_{AM}\times F_{OFF\text{-}SET}\times EF_r\left(\frac{350\ days}{year}\right)\times ED_r\,(1\ year)\times\left(\frac{1day}{24hours}\right)\times\left(1-e^{-\lambda t_r}\right)\times\left[ET_{o,r}\left(\frac{1.752\ hours}{day}\right)\times GSF_o\,(1.0)+ET_{i,r}\left(\frac{16.4\ hours}{day}\right)\times GSF_i\,(0.4)\right]\times\left(\frac{1year}{365days}\right)\times F_{SURF}}$$

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.

- 3-D Exposure to Direct External Exposure (Materials with fixed contamination at 15cm in outside walls, streets and sidewalks using 15cm soil volume toxicity values)

$$SDCC_{3\text{-}Dr\text{-}15cm}\left(\frac{pCi}{g}\right)=\frac{DL\,(mrem)\times t_r\,(years)\times\lambda\left(\frac{1}{years}\right)}{SF_{ext\text{-}15cm}\left[\left(\frac{mrem}{year}\right)/\left(\frac{pCi}{g}\right)\right]\times F_{CD}\times F_{AM}\times F_{OFF\text{-}SET}\times EF_r\left(\frac{350\ days}{year}\right)\times ED_r\,(1\ year)\times\left(\frac{1day}{24hours}\right)\times\left(1-e^{-\lambda t_r}\right)\times\left[ET_{o,r}\left(\frac{1.752\ hours}{day}\right)\times GSF_o\,(1.0)+ET_{i,r}\left(\frac{16.4\ hours}{day}\right)\times GSF_i\,(0.4)\right]\times\left(\frac{1year}{365days}\right)\times F_{SURF}}$$

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.

- 3-D Exposure to Direct External Exposure (Fixed contaminated dust on surface of outside walls, streets and sidewalks using ground plane toxicity values)

$$SDCC_{3\text{-}Dr\text{-}gp}\left(\frac{pCi}{cm^2}\right)=\frac{DL\,(mrem)\times t_r\,(years)\times\lambda\left(\frac{1}{years}\right)}{SF_{ext}\left[\left(\frac{mrem}{year}\right)/\left(\frac{pCi}{cm^2}\right)\right]\times F_{CD}\times F_{AM}\times F_{OFF\text{-}SET}\times EF_r\left(\frac{350\ days}{year}\right)\times ED_r\,(1\ year)\times\left(\frac{1day}{24hours}\right)\times ACF\,(1.0)\times\left(1-e^{-\lambda t_r}\right)\times\left[ET_{o,r}\left(\frac{1.752\ hours}{day}\right)\times GSF_o\,(1.0)+ET_{i,r}\left(\frac{16.4\ hours}{day}\right)\times GSF_i\,(0.4)\right]\times\left(\frac{1year}{365days}\right)\times F_{SURF}}$$

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

$$SDCC_{2\text{-}Dr\text{-}sv}\left(\frac{pCi}{g}\right)=\frac{DL\,(mrem)\times t_r\,(years)\times\lambda\left(\frac{1}{years}\right)}{SF_{ext}\left[\left(\frac{mrem}{year}\right)/\left(\frac{pCi}{g}\right)\right]\times F_{CD}\times F_{AM}\times F_{OFF\text{-}SET}\times EF_r\left(\frac{350\ days}{year}\right)\times ED_r\,(1\ year)\times\left(\frac{1day}{24hours}\right)\times ACF\times\left(1-e^{-\lambda t_r}\right)\times\left[ET_{o,r}\left(\frac{1.752\ hours}{day}\right)\times GSF_o\,(1.0)+ET_{i,r}\left(\frac{16.4\ hours}{day}\right)\times GSF_i\,(0.4)\right]\times\left(\frac{1year}{365days}\right)}$$

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.

- 2-D Exposure to Direct External Exposure (Materials with fixed contamination in a finite slab at 1cm depth using 1cm soil volume toxicity values)

$$SDCC_{2\text{-}Dr\text{-}1cm}\left(\frac{pCi}{g}\right)=\frac{DL\,(mrem)\times t_r\,(years)\times\lambda\left(\frac{1}{years}\right)}{SF_{ext\text{-}1cm}\left[\left(\frac{mrem}{year}\right)\Big/\left(\frac{pCi}{g}\right)\right]\times F_{CD}\times F_{AM}\times F_{OFF\text{-}SET}\times EF_r\left(\frac{350\ days}{year}\right)\times ED_r\,(1\ year)\times\left(\frac{1day}{24hours}\right)\times ACF\times\left(1-e^{-\lambda t_r}\right)\times\left[ET_{o,r}\left(\frac{1.752\ hours}{day}\right)\times GSF_o\,(1.0)+ET_{i,r}\left(\frac{16.4\ hours}{day}\right)\times GSF_i\,(0.4)\right]\times\left(\frac{1year}{365days}\right)}$$

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.

- 2-D Exposure to Direct External Exposure (Materials with fixed contamination in a finite slab at 5cm depth using 5cm soil volume toxicity values)

$$SDCC_{2\text{-}Dr\text{-}5cm}\left(\frac{pCi}{g}\right)=\frac{DL\,(mrem)\times t_r\,(years)\times\lambda\left(\frac{1}{years}\right)}{SF_{ext\text{-}5cm}\left[\left(\frac{mrem}{year}\right)\Big/\left(\frac{pCi}{g}\right)\right]\times F_{CD}\times F_{AM}\times F_{OFF\text{-}SET}\times EF_r\left(\frac{350\ days}{year}\right)\times ED_r\,(1\ year)\times\left(\frac{1day}{24hours}\right)\times ACF\times\left(1-e^{-\lambda t_r}\right)\times\left[ET_{o,r}\left(\frac{1.752\ hours}{day}\right)\times GSF_o\,(1.0)+ET_{i,r}\left(\frac{16.4\ hours}{day}\right)\times GSF_i\,(0.4)\right]\times\left(\frac{1year}{365days}\right)}$$

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.

- 2-D Exposure to Direct External Exposure (Materials with fixed contamination in a finite slab at 15cm depth using 15cm soil volume toxicity values)

$$SDCC_{2\text{-}Dr\text{-}15cm}\left(\frac{pCi}{g}\right)=\frac{DL\,(mrem)\times t_r\,(years)\times\lambda\left(\frac{1}{years}\right)}{SF_{ext\text{-}15cm}\left[\left(\frac{mrem}{year}\right)\Big/\left(\frac{pCi}{g}\right)\right]\times F_{CD}\times F_{AM}\times F_{OFF\text{-}SET}\times EF_r\left(\frac{350\ days}{year}\right)\times ED_r\,(1\ year)\times\left(\frac{1day}{24hours}\right)\times ACF\times\left(1-e^{-\lambda t_r}\right)\times\left[ET_{o,r}\left(\frac{1.752\ hours}{day}\right)\times GSF_o\,(1.0)+ET_{i,r}\left(\frac{16.4\ hours}{day}\right)\times GSF_i\,(0.4)\right]\times\left(\frac{1year}{365days}\right)}$$

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.

- 2-D Exposure to Direct External Exposure (Materials with fixed contamination in a finite slab using ground plane toxicity values)

$$SDCC_{2\text{-}Dr\text{-}gp}\left(\frac{pCi}{cm^2}\right)=\frac{DL\,(mrem)\times t_r\,(years)\times\lambda\left(\frac{1}{years}\right)}{SF_{ext}\left[\left(\frac{mrem}{year}\right)\Big/\left(\frac{pCi}{cm^2}\right)\right]\times F_{CD}\times F_{AM}\times F_{OFF\text{-}SET}\times EF_r\left(\frac{350\ days}{year}\right)\times ED_r\,(1\ year)\times\left(\frac{1day}{24hours}\right)\times ACF\times\left(1-e^{-\lambda t_r}\right)\times\left[ET_{o,r}\left(\frac{1.752\ hours}{day}\right)\times GSF_o\,(1.0)+ET_{i,r}\left(\frac{16.4\ hours}{day}\right)\times GSF_i\,(0.4)\right]\times\left(\frac{1year}{365days}\right)}$$

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 Worker

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

$$SDCC_{dow\text{-}total}\left(\frac{pCi}{cm^2}\right)=\frac{DL\,(mrem)\times t_w\,(1\ year)\times\lambda\left(\frac{1}{year}\right)}{\left(\frac{1-e^{-kt_w}}{kt_w}\right)\times\left(1-e^{-\lambda t_w}\right)\times EF_w\left(\frac{225\ days}{year}\right)\times ED_w\,(1\ year)\times\left[\begin{array}{l}\left(SF_{d\text{-}oral}\left(\frac{mrem}{pCi}\right)\times IF_w\left(\frac{90\ cm^2}{day}\right)\right)+\\ \left(SF_{inh}\left(\frac{mrem}{pCi}\right)\times HR_w\left(\frac{2.5\ m^3}{hour}\right)\times\frac{1}{PEF\left(\frac{m^3}{Kg}\right)}\times SLF\left(\frac{6.6E+08\ cm^2}{Kg}\right)\times ET_w\left(\frac{8\ hours}{day}\right)\right)+\\ \left(SF_{d\text{-}ext}\left[\left(\frac{mrem}{year}\right)\Big/\left(\frac{pCi}{cm^2}\right)\right]\times F_{AM}\times F_{OFF\text{-}SET}\times GSF_o\,(1.0)\times ACF\,(1.0)\left(\frac{1day}{24hours}\right)\times ET_w\left(\frac{8\ hours}{day}\right)\times\left(\right.\right.\end{array}\right.}$$

where

$$IF_w\left(\frac{90\ cm^2}{day}\right)=FTSS_h\,(0.5)\times ET_w\left(\frac{8\ hours}{day}\right)\times SE\,(0.5)\times SA_w\left(\frac{45\ cm^2}{event}\right)\times FQ_w\left(\frac{1\ event}{hour}\right)$$

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

$$SDCC_{3\text{-}Dow\text{-}sv}\left(\frac{pCi}{g}\right)=\frac{DL\,(mrem)\times t_w\,(1\ year)\times\lambda\left(\frac{1}{years}\right)}{SF_{ext}\left[\left(\frac{mrem}{year}\right)\Big/\left(\frac{pCi}{g}\right)\right]\times F_{CD}\times F_{AM}\times F_{OFF\text{-}SET}\times EF_w\left(\frac{225\ days}{year}\right)\times ED_w\,(1\ year)\times\left(\frac{1\ day}{24\ hours}\right)\times GSF_o\,(1.0)\times\left(1-e^{-\lambda t_w}\right)\times ET_w\left(\frac{8\ hours}{day}\right)\times\left(\frac{1\ year}{365\ days}\right)\times F_{SURF}}$$

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.

- 3-D Exposure to Direct External Exposure (Materials with fixed contamination at 1cm in outside walls, streets and sidewalks using 1cm soil volume toxicity values)

$$SDCC_{3\text{-}Dow\text{-}1cm}\left(\frac{pCi}{g}\right)=\frac{DL\,(mrem)\times t_w\,(1\ year)\times\lambda\left(\frac{1}{years}\right)}{SF_{ext\text{-}1cm}\left[\left(\frac{mrem}{year}\right)\Big/\left(\frac{pCi}{g}\right)\right]\times F_{CD}\times F_{AM}\times F_{OFF\text{-}SET}\times EF_w\left(\frac{225\ days}{year}\right)\times ED_w\,(1\ year)\times\left(\frac{1\ day}{24\ hours}\right)\times GSF_o\,(1.0)\times\left(1-e^{-\lambda t_w}\right)\times ET_w\left(\frac{8\ hours}{day}\right)\times\left(\frac{1\ year}{365\ days}\right)\times F_{SURF}}$$

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.

- 3-D Exposure to Direct External Exposure (Materials with fixed contamination at 5cm in outside walls, streets and sidewalks using 5cm soil volume toxicity values)

$$SDCC_{3\text{-}Dow\text{-}5cm}\left(\frac{pCi}{g}\right)=\frac{DL\,(mrem)\times t_w\,(1\ year)\times\lambda\left(\frac{1}{years}\right)}{SF_{ext\text{-}5cm}\left[\left(\frac{mrem}{year}\right)/\left(\frac{pCi}{g}\right)\right]\times F_{CD}\times F_{AM}\times F_{OFF\text{-}SET}\times EF_w\left(\frac{225\ days}{year}\right)\times ED_w\,(1\ year)\times\left(\frac{1\ day}{24\ hours}\right)\times GSF_o\,(1.0)\times\left(1-e^{-\lambda t_w}\right)\times ET_w\left(\frac{8\ hours}{day}\right)\times\left(\frac{1\ year}{365\ days}\right)\times F_{SURF}}$$

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.

- 3-D Exposure to Direct External Exposure (Materials with fixed contamination at 15cm in outside walls, streets and sidewalks using 15cm soil volume toxicity values)

$$SDCC_{3\text{-}Dow\text{-}15cm}\left(\frac{pCi}{g}\right)=\frac{DL\,(mrem)\times t_w\,(1\ year)\times\lambda\left(\frac{1}{years}\right)}{SF_{ext\text{-}15cm}\left[\left(\frac{mrem}{year}\right)/\left(\frac{pCi}{g}\right)\right]\times F_{CD}\times F_{AM}\times F_{OFF\text{-}SET}\times EF_w\left(\frac{225\ days}{year}\right)\times ED_w\,(1\ year)\times\left(\frac{1\ day}{24\ hours}\right)\times GSF_o\,(1.0)\times\left(1-e^{-\lambda t_w}\right)\times ET_w\left(\frac{8\ hours}{day}\right)\times\left(\frac{1\ year}{365\ days}\right)\times F_{SURF}}$$

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.

- 3-D Exposure to Direct External Exposure (Fixed contaminated dust on surfaces of outside walls, streets and sidewalks using ground plane toxicity values)

$$SDCC_{3\text{-}Dow\text{-}gp}\left(\frac{pCi}{cm^2}\right)=\frac{DL\,(mrem)\times t_w\,(1\ year)\times\lambda\left(\frac{1}{years}\right)}{SF_{ext}\left[\left(\frac{mrem}{year}\right)/\left(\frac{pCi}{cm^2}\right)\right]\times F_{CD}\times F_{AM}\times F_{OFF\text{-}SET}\times EF_w\left(\frac{225\ days}{year}\right)\times ED_w\,(1\ year)\times\left(\frac{1\ day}{24\ hours}\right)\times GSF_o\,(1.0)\times\left(1-e^{-\lambda t_w}\right)\times ET_w\left(\frac{8\ hours}{day}\right)\times\left(\frac{1\ year}{365\ days}\right)\times F_{SURF}}$$

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

$$SDCC_{2\text{-}Dow\text{-}sv}\left(\frac{pCi}{g}\right)=\frac{DL\,(mrem)\times t_w\,(1\ year)\times\lambda\left(\frac{1}{years}\right)}{SF_{ext}\left[\left(\frac{mrem}{year}\right)/\left(\frac{pCi}{g}\right)\right]\times F_{CD}\times F_{AM}\times F_{OFF\text{-}SET}\times EF_w\left(\frac{225\ days}{year}\right)\times ED_w\,(1\ year)\times\left(\frac{1\ day}{24\ hours}\right)\times GSF_o\,(1.0)\times ACF\times\left(1-e^{-\lambda t_w}\right)\times ET_w\left(\frac{8\ hours}{day}\right)\times\left(\frac{1\ year}{365\ days}\right)}$$

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.

- 2-D Exposure to Direct External Exposure (Materials with fixed contamination in a finite slab at 1cm depth using 1cm soil volume toxicity values)

$$SDCC_{2\text{-}Dow\text{-}1cm}\left(\frac{pCi}{g}\right)=\frac{DL\,(mrem)\times t_w\,(1\ year)\times\lambda\left(\frac{1}{years}\right)}{SF_{ext\text{-}1cm}\left[\left(\frac{mrem}{year}\right)/\left(\frac{pCi}{g}\right)\right]\times F_{CD}\times F_{AM}\times F_{OFF\text{-}SET}\times EF_w\left(\frac{225\ days}{year}\right)\times ED_w\,(1\ year)\times\left(\frac{1\ day}{24\ hours}\right)\times GSF_o\,(1.0)\times ACF\times\left(1-e^{-\lambda t_w}\right)\times ET_w\left(\frac{8\ hours}{day}\right)\times\left(\frac{1\ year}{365\ days}\right)}$$

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.

- 2-D Exposure to Direct External Exposure (Materials with fixed contamination in a finite slab at 5cm depth using 5cm soil volume toxicity values)

$$SDCC_{2\text{-}Dow\text{-}5cm}\left(\frac{pCi}{g}\right)=\frac{DL\,(mrem)\times t_w\,(1\ year)\times\lambda\left(\frac{1}{years}\right)}{SF_{ext\text{-}5cm}\left[\left(\frac{mrem}{year}\right)/\left(\frac{pCi}{g}\right)\right]\times F_{CD}\times F_{AM}\times F_{OFF\text{-}SET}\times EF_w\left(\frac{225\ days}{year}\right)\times ED_w\,(1\ year)\times\left(\frac{1\ day}{24\ hours}\right)\times GSF_o\,(1.0)\times ACF\times\left(1-e^{-\lambda t_w}\right)\times ET_w\left(\frac{8\ hours}{day}\right)\times\left(\frac{1\ year}{365\ days}\right)}$$

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.

- 2-D Exposure to Direct External Exposure (Materials with fixed contamination in a finite slab at15cm depth using 15cm soil volume toxicity values)

$$SDCC_{2\text{-}Dow\text{-}15cm}\left(\frac{pCi}{g}\right)=\frac{DL\,(mrem)\times t_w\,(1\ year)\times\lambda\left(\frac{1}{years}\right)}{SF_{ext\text{-}15cm}\left[\left(\frac{mrem}{year}\right)/\left(\frac{pCi}{g}\right)\right]\times F_{CD}\times F_{AM}\times F_{OFF\text{-}SET}\times EF_w\left(\frac{225\ days}{year}\right)\times ED_w\,(1\ year)\times\left(\frac{1\ day}{24\ hours}\right)\times GSF_o\,(1.0)\times ACF\times\left(1-e^{-\lambda t_w}\right)\times ET_w\left(\frac{8\ hours}{day}\right)\times\left(\frac{1\ year}{365\ days}\right)}$$

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.

- 2-D Exposure to Direct External Exposure (Materials with fixed contamination in a finite slab using ground plane toxicity values)

$$SDCC_{2\text{-}Dow\text{-}gp}\left(\frac{pCi}{cm^2}\right)=\frac{DL\,(mrem)\times t_w\,(1\ year)\times\lambda\left(\frac{1}{years}\right)}{SF_{ext}\left[\left(\frac{mrem}{year}\right)/\left(\frac{pCi}{cm^2}\right)\right]\times F_{CD}\times F_{AM}\times F_{OFF\text{-}SET}\times EF_w\left(\frac{225\ days}{year}\right)\times ED_w\,(1\ year)\times\left(\frac{1\ day}{24\ hours}\right)\times GSF_o\,(1.0)\times ACF\times\left(1-e^{-\lambda t_w}\right)\times ET_w\left(\frac{8\ hours}{day}\right)\times\left(\frac{1\ year}{365\ days}\right)}$$

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.

#### 4.2.2 Indoor Worker

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

- exposure to contamination deposited on streets and sidewalks (incidental ingestion, inhalation of particulates and external exposure to ionizing radiation from settled dust using ground plane toxicity values)

$$SDCC_{diw\text{-}total}\left(\frac{pCi}{cm^2}\right)=\frac{DL\,(mrem)\times t_w\,(1\,year)\times\lambda\left(\frac{1}{year}\right)}{\left(\frac{1-e^{-kt_w}}{kt_w}\right)\times\left(1-e^{-\lambda t_w}\right)\times EF_w\left(\frac{250\,days}{year}\right)\times ED_w\,(1\,years)\times\left[\begin{array}{l}\left(SF_{d\text{-}oral}\left(\frac{mrem}{pCi}\right)\times IF_w\left(\frac{90\,cm^2}{day}\right)\right)+\\ \left(SF_{inh}\left(\frac{mrem}{pCi}\right)\times HR_w\left(\frac{2.5\,m^3}{hour}\right)\times\frac{1}{PEF\left(\frac{m^3}{Kg}\right)}\times SLF\left(\frac{6.\bar{6}E+08\,cm^2}{Kg}\right)\times ET_w\left(\frac{8\,hours}{day}\right)\times DF_i\,(0.4)\right)+\\ \left(SF_{d\text{-}ext}\left[\left(\frac{mrem}{year}\right)\middle/\left(\frac{pCi}{cm^2}\right)\right]\times F_{AM}\times F_{OFF\text{-}SET}\times GSF_i\,(0.4)\times ACF\,(1.0)\times\left(\frac{1\,day}{24\,hours}\right)\times ET_w\left(\frac{8\,hours}{day}\right)\times\right.\end{array}\right.}$$

where

$$IF_w\left(\frac{90\,cm^2}{day}\right)=FTSS_h\,(0.5)\times ET_w\left(\frac{8\,hours}{day}\right)\times SE\,(0.5)\times SA_w\left(\frac{45\,cm^2}{event}\right)\times FQ_w\left(\frac{1\,event}{hour}\right)$$

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

$$SDCC_{3\text{-}Diw\text{-}sv}\left(\frac{pCi}{g}\right)=\frac{DL\,(mrem)\times t_w\,(1\,year)\times\lambda\left(\frac{1}{years}\right)}{SF_{ext}\left[\left(\frac{mrem}{year}\right)\middle/\left(\frac{pCi}{g}\right)\right]\times F_{CD}\times F_{AM}\times F_{OFF\text{-}SET}\times EF_w\left(\frac{250\,days}{year}\right)\times ED_w\,(1\,year)\times\left(\frac{1\,day}{24\,hours}\right)\times GSF_i\,(0.4)\times\left(1-e^{-\lambda t_w}\right)\times ET_w\left(\frac{8\,hours}{day}\right)\times\left(\frac{1\,year}{365\,days}\right)\times F_{SURF}}$$

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.

- 3-D Exposure to Direct External Exposure (Materials with fixed contamination at 1cm in outside walls, streets and sidewalks using 1cm soil volume toxicity values)

$$SDCC_{3\text{-}Diw\text{-}1cm}\left(\frac{pCi}{g}\right)=\frac{DL\,(mrem)\times t_w\,(1\,year)\times\lambda\left(\frac{1}{years}\right)}{SF_{ext\text{-}1cm}\left[\left(\frac{mrem}{year}\right)\middle/\left(\frac{pCi}{g}\right)\right]\times F_{CD}\times F_{AM}\times F_{OFF\text{-}SET}\times EF_w\left(\frac{250\,days}{year}\right)\times ED_w\,(1\,year)\times\left(\frac{1\,day}{24\,hours}\right)\times GSF_i\,(0.4)\times\left(1-e^{-\lambda t_w}\right)\times ET_w\left(\frac{8\,hours}{day}\right)\times\left(\frac{1\,year}{365\,days}\right)\times F_{SURF}}$$

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.

- 3-D Exposure to Direct External Exposure (Materials with fixed contamination at 5cm in outside walls, streets and sidewalks using 5cm soil volume toxicity values)

$$SDCC_{3\text{-}Diw\text{-}5cm}\left(\frac{pCi}{g}\right)=\frac{DL\,(mrem)\times t_w\,(1\,year)\times\lambda\left(\frac{1}{years}\right)}{SF_{ext\text{-}5cm}\left[\left(\frac{mrem}{year}\right)\middle/\left(\frac{pCi}{g}\right)\right]\times F_{CD}\times F_{AM}\times F_{OFF\text{-}SET}\times EF_w\left(\frac{250\,days}{year}\right)\times ED_w\,(1\,year)\times\left(\frac{1\,day}{24\,hours}\right)\times GSF_i\,(0.4)\times\left(1-e^{-\lambda t_w}\right)\times ET_w\left(\frac{8\,hours}{day}\right)\times\left(\frac{1\,year}{365\,days}\right)\times F_{SURF}}$$

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.

- 3-D Exposure to Direct External Exposure (Materials with fixed contamination at 15cm in outside walls, streets and sidewalks using 15cm soil volume toxicity values)

$$SDCC_{3\text{-}Diw\text{-}15cm}\left(\frac{pCi}{g}\right)=\frac{DL\,(mrem)\times t_w\,(1\,year)\times\lambda\left(\frac{1}{years}\right)}{SF_{ext\text{-}15cm}\left[\left(\frac{mrem}{year}\right)\middle/\left(\frac{pCi}{g}\right)\right]\times F_{CD}\times F_{AM}\times F_{OFF\text{-}SET}\times EF_w\left(\frac{250\,days}{year}\right)\times ED_w\,(1\,year)\times\left(\frac{1\,day}{24\,hours}\right)\times GSF_i\,(0.4)\times\left(1-e^{-\lambda t_w}\right)\times ET_w\left(\frac{8\,hours}{day}\right)\times\left(\frac{1\,year}{365\,days}\right)\times F_{SURF}}$$

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.

- 3-D Exposure to Direct External Exposure (Fixed contaminated dust on outside walls, streets and sidewalks using ground plane toxicity values)

$$SDCC_{3\text{-}Diw\text{-}gp}\left(\frac{pCi}{cm^2}\right)=\frac{DL\,(mrem)\times t_w\,(1\,year)\times\lambda\left(\frac{1}{years}\right)}{SF_{ext}\left[\left(\frac{mrem}{year}\right)\middle/\left(\frac{pCi}{cm^2}\right)\right]\times F_{CD}\times F_{AM}\times F_{OFF\text{-}SET}\times EF_w\left(\frac{250\,days}{year}\right)\times ED_w\,(1\,year)\times\left(\frac{1\,day}{24\,hours}\right)\times GSF_i\,(0.4)\times\left(1-e^{-\lambda t_w}\right)\times ET_w\left(\frac{8\,hours}{day}\right)\times\left(\frac{1\,year}{365\,days}\right)\times F_{SURF}}$$

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

$$SDCC_{2\text{-}Diw\text{-}sv}\left(\frac{pCi}{g}\right)=\frac{DL\,(mrem)\times t_w\,(1\,year)\times\lambda\left(\frac{1}{years}\right)}{SF_{ext}\left[\left(\frac{mrem}{year}\right)\middle/\left(\frac{pCi}{g}\right)\right]\times F_{CD}\times F_{AM}\times F_{OFF\text{-}SET}\times EF_w\left(\frac{250\,days}{year}\right)\times ED_w\,(1\,year)\times\left(\frac{1\,day}{24\,hours}\right)\times GSF_i\,(0.4)\times ACF\times\left(1-e^{-\lambda t_w}\right)\times ET_w\left(\frac{8\,hours}{day}\right)\times\left(\frac{1\,year}{365\,days}\right)}$$

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.

- 2-D Exposure to Direct External Exposure (Materials with fixed contamination in a finite slab at 1cm depth using 1cm soil volume toxicity values)

$$SDCC_{2\text{-}Diw\text{-}1cm}\left(\frac{pCi}{g}\right)=\frac{DL\,(mrem)\times t_w\,(1\,year)\times\lambda\left(\frac{1}{years}\right)}{SF_{ext\text{-}1cm}\left[\left(\frac{mrem}{year}\right)\middle/\left(\frac{pCi}{g}\right)\right]\times F_{CD}\times F_{AM}\times F_{OFF\text{-}SET}\times EF_w\left(\frac{250\,days}{year}\right)\times ED_w\,(1\,year)\times\left(\frac{1\,day}{24\,hours}\right)\times GSF_i\,(0.4)\times ACF\times\left(1-e^{-\lambda t_w}\right)\times ET_w\left(\frac{8\,hours}{day}\right)\times\left(\frac{1\,year}{365\,days}\right)}$$

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.

- 2-D Exposure to Direct External Exposure (Materials with fixed contamination in a finite slab at 5cm depth using 5cm soil volume toxicity values)

$$SDCC_{2\text{-}Diw\text{-}5cm}\left(\frac{pCi}{g}\right)=\frac{DL\,(mrem)\times t_w\,(1\ year)\times\lambda\left(\frac{1}{years}\right)}{SF_{ext\text{-}5cm}\left[\left(\frac{mrem}{year}\right)/\left(\frac{pCi}{g}\right)\right]\times F_{CD}\times F_{AM}\times F_{OFF\text{-}SET}\times EF_w\left(\frac{250\ days}{year}\right)\times ED_w\,(1\ year)\times\left(\frac{1\ day}{24\ hours}\right)\times GSF_i\,(0.4)\times ACF\times\left(1-e^{-\lambda t_w}\right)\times ET_w\left(\frac{8\ hours}{day}\right)\times\left(\frac{1\ year}{365\ days}\right)}$$

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.

- 2-D Exposure to Direct External Exposure (Materials with fixed contamination in a finite slab at 15cm depth using 15cm soil volume toxicity values)

$$SDCC_{2\text{-}Diw\text{-}15cm}\left(\frac{pCi}{g}\right)=\frac{DL\,(mrem)\times t_w\,(1\ year)\times\lambda\left(\frac{1}{years}\right)}{SF_{ext\text{-}15cm}\left[\left(\frac{mrem}{year}\right)/\left(\frac{pCi}{g}\right)\right]\times F_{CD}\times F_{AM}\times F_{OFF\text{-}SET}\times EF_w\left(\frac{250\ days}{year}\right)\times ED_w\,(1\ year)\times\left(\frac{1\ day}{24\ hours}\right)\times GSF_i\,(0.4)\times ACF\times\left(1-e^{-\lambda t_w}\right)\times ET_w\left(\frac{8\ hours}{day}\right)\times\left(\frac{1\ year}{365\ days}\right)}$$

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.

- 2-D Exposure to Direct External Exposure (Materials with fixed contamination in a finite slab using ground plane toxicity values)

$$SDCC_{2\text{-}Diw\text{-}gp}\left(\frac{pCi}{cm^2}\right)=\frac{DL\,(mrem)\times t_w\,(1\ year)\times\lambda\left(\frac{1}{years}\right)}{SF_{ext}\left[\left(\frac{mrem}{year}\right)/\left(\frac{pCi}{cm^2}\right)\right]\times F_{CD}\times F_{AM}\times F_{OFF\text{-}SET}\times EF_w\left(\frac{250\ days}{year}\right)\times ED_w\,(1\ year)\times\left(\frac{1\ day}{24\ hours}\right)\times GSF_i\,(0.4)\times ACF\times\left(1-e^{-\lambda t_w}\right)\times ET_w\left(\frac{8\ hours}{day}\right)\times\left(\frac{1\ year}{365\ days}\right)}$$

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 Exposure Parameter Justification

The following sections describe the exposure parameter default variables and the values selected.

### 4.3.1 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 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 hr/d. The exposure time for direct external exposure is the entire work day or 8 hr/d.

### 4.3.2 Fraction Transferred from Surface to Skin (FTSS)

In general, this is the fraction of residue on a surface that can be transferred to skin. US 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.

### 4.3.3 Surface Area (SA)

In general, this is the skin area contacted during the mouthing event. The OPP default is 20 cm$^2$ based on the surface area of the 3 fingers that a child will most likely use for hand to mouth transfer. Total skin surface area increases by about 3 fold from age 2 to an adult. Average area of both hands for an adult is about 900 cm$^2$, so it would be about 300 cm$^2$ for a 2 year old. Assuming 3 fingers of one hand represents about 5% of the total area of both hands, it would increase from 15 cm$^2$ to 45 cm$^2$ from age 2 to adult. On this basis, the SA values used here are assumed to start at 15 cm$^2$ and increase linearly to 45 cm$^2$ at age 17 and remain constant after that.

### 4.3.4 Frequency of Hand to Mouth (FQ)

The OPP defaults suggest 9.5 events/hr for toddlers, based on observations at day care centers. This will decline with age, but very little data are available for other ages. Michaud et al (1994) assumed a mouthing frequency of twice per day for adults. It was decided to group the age cohort-specific hand-to-mouth frequency as follows: 1 to 6 yr - 9.5 times/hr, 7 to 12yr - 5 times/hr, 8 to 18 yr - 2 times/hr and 19 to 31 yr - 1 time/hr.

### 4.3.5 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.

### 4.3.6 Resident Age-Adjusted Dust Ingestion Rate ($IF_r$)

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.

### 4.3.7 Worker Dust Ingestion Rate ($IF_w$)

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

### 4.3.8 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. However, the variable 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 the indoor surfaces 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 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 $yr^{-1}$) 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 ($yr^{-1}$)
t = Time (yr)

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. The following exhibit 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(- | PRG |
|---|---|---|---|---|---|---|

| | | | | | kt)) / (kt) | |
|---|---|---|---|---|---|---|
| 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 |

#### 4.3.9 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. However, the radiation doses caused by these two pathways 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.

#### 4.3.10 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 *DOCUMENTATION FOR THE DRAFT 2002 NONPOINT SOURCE NATIONAL EMISSION INVENTORY FOR CRITERIA AND HAZARDOUS AIR POLLUTANTS (MARCH 2005 VERSION)*, Table 2, Page A-67, concerning paved roads. This value, combined with the California daily vehicle miles traveled by the length of the California interstates resulted in the most conservative 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.

**Table 2. 2002 Silt Loadings by State and Roadway Class Modeled in Paved Road Emission Factor Calculations (g/m²)**

| | Rural Roadway Classes | | | | | | Urban Roadway Classes | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| State | Inter-state | Other Principal Arterial | Minor Arterial | Major Collector | Minor Collector | Local | Inter-state | Freeways & Express-ways | Other Principal Arterial | Minor Arterial | Collector | 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 | 0.2 |
| 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 | 0.06 | 0.2 | 0.2 | 0.6 | 0.6 | 0.015 | 0.015 | 0.03 | 0.06 | 0.2 | 0.2 |
| Connecticut | 0.015 | 0.03 | 0.2 | 0.2 | 0.2 | 0.6 | 0.015 | 0.015 | 0.03 | 0.06 | 0.2 | 0.2 |
| Delaware | 0.015 | 0.03 | 0.03 | 0.2 | 0.2 | 0.2 | 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 | 0.03 | 0.06 | 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 | 0.03 | 0.06 | 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 | 0.06 | 0.2 | 0.2 | 0.6 | 0.6 | 0.015 | 0.015 | 0.03 | 0.03 | 0.06 | 0.2 |
| Indiana | 0.015 | 0.06 | 0.06 | 0.2 | 0.2 | 0.6 | 0.015 | 0.015 | 0.03 | 0.06 | 0.2 | 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 | 0.03 | 0.2 | 0.2 |
| Louisiana | 0.015 | 0.06 | 0.06 | 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 | 0.06 | 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 | 0.03 | 0.06 | 0.2 | 0.2 | 0.6 | 0.015 | 0.015 | 0.03 | 0.06 | 0.2 | 0.2 |
| Michigan | 0.015 | 0.06 | 0.2 | 0.2 | 0.2 | 0.6 | 0.015 | 0.015 | 0.03 | 0.03 | 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 | 0.06 | 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 | 0.03 | 0.06 | 0.2 | 0.2 | 0.6 | 0.015 | 0.015 | 0.03 | 0.06 | 0.2 | 0.2 |
| New Jersey | 0.015 | 0.03 | 0.06 | 0.2 | 0.2 | 0.2 | 0.015 | 0.015 | 0.03 | 0.06 | 0.2 | 0.2 |
| New Mexico | 0.015 | 0.2 | 0.2 | 0.2 | 0.2 | 0.6 | 0.015 | 0.015 | 0.03 | 0.06 | 0.2 | 0.2 |
| New York | 0.015 | 0.06 | 0.2 | 0.2 | 0.2 | 0.6 | 0.015 | 0.015 | 0.03 | 0.03 | 0.06 | 0.2 |
| North Carolina | 0.015 | 0.03 | 0.06 | 0.2 | 0.2 | 0.6 | 0.015 | 0.015 | 0.03 | 0.06 | 0.2 | 0.2 |
| North Dakota | 0.015 | 0.2 | 0.2 | 0.6 | 0.6 | 0.6 | 0.015 | 0.015 | 0.03 | 0.2 | 0.2 | 0.2 |
| Ohio | 0.015 | 0.03 | 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 | 0.03 | 0.2 | 0.2 | 0.2 | 0.6 | 0.015 | 0.015 | 0.03 | 0.06 | 0.2 | 0.2 |
| Rhode Island | 0.015 | 0.03 | 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 | 0.06 | 0.2 | 0.2 | 0.6 | 0.015 | 0.015 | 0.03 | 0.03 | 0.2 | 0.6 |
| 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 | 0.06 | 0.2 |
| Vermont | 0.015 | 0.06 | 0.2 | 0.2 | 0.2 | 0.2 | 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 | 0.06 | 0.2 | 0.2 | 0.6 | 0.6 | 0.015 | 0.015 | 0.03 | 0.06 | 0.2 | 0.2 |
| West Virginia | 0.015 | 0.06 | 0.2 | 0.2 | 0.2 | 0.6 | 0.015 | 0.015 | 0.03 | 0.06 | 0.2 | 0.2 |
| Wisconsin | 0.015 | 0.06 | 0.2 | 0.2 | 0.6 | 0.6 | 0.015 | 0.015 | 0.03 | 0.06 | 0.2 | 0.2 |
| Wyoming | 0.015 | 0.2 | 0.2 | 0.2 | 0.6 | 0.6 | 0.015 | 0.015 | 0.06 | 0.2 | 0.2 | 0.2 |

To obtain more accurate SDCC results, the SLF should be measured in the field. Table 13.2.1-4 from AP42 is reproduced below showing the high end typical industrial facility SLF ranges. The values range from 0.09 to 400 (g/m²). 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/m² 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/m² is recommended for short periods of time following application of snow/ice controls to limited access roads."(Cowherd and Englehart 1985; MRI 1997)

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Table 13.2.1-4 (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 (%) | | No. Of Travel Lanes | Total Loading x $10^{-3}$ | | | Silt Loading (g/m²) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Range | Mean | | Range | Mean | Units[b] | Range | Mean |
| Copper smelting | 1 | 3 | 15.4-21.7 | 19.0 | 2 | 12.9-19.5<br>45.8-69.2 | 15.9<br>55.4 | kg/km<br>lb/mi | 188-400 | 292 |
| Iron and steel production | 9 | 48 | 1.1-35.7 | 12.5 | 2 | 0.006-4.77<br>0.020-16.9 | 0.495<br>1.75 | kg/km<br>lb/mi | 0.09-79 | 9.7 |
| Asphalt batching | 1 | 3 | 2.6-4.6 | 3.3 | 1 | 12.1-18.0<br>43.0-64.0 | 14.9<br>52.8 | kg/km<br>lb/mi | 76-193 | 120 |
| Concrete batching | 1 | 3 | 5.2-6.0 | 5.5 | 2 | 1.4-1.8<br>5.0-6.4 | 1.7<br>5.9 | kg/km<br>lb/mi | 11-12 | 12 |
| Sand and gravel processing | 1 | 3 | 6.4-7.9 | 7.1 | 1 | 2.8-5.5<br>9.9-19.4 | 3.8<br>13.3 | kg/km<br>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 |

[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).

Miscellaneous Sources

The default of 0.015 (g/m²) was chosen, with California interstate ADTV, for this calculator as a conservative value suitable for producing default sdccs. However, selecting a site-specific state and roadway class will provide a more accurate SLF and ADTV. For example, the North Dakota rural road class combined with local road type yields a mechanical PEF of $6.04 \times 10^8$ while the default state, road class and road type yields a mechanical PEF of $1.34 \times 10^5$. 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. Simple website navigation instructions are available. To quickly get to the functional class information make sure the "Highway Information" tab is selected and then make sure the drop-down-menu under "General Maps" indicates "Functional Class". Now 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.

#### 4.3.11 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)

To accommodate the fact that in most residential settings the assumption of an infinite slab source will result in overly conservative SSLs, 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. Because of the likely variation in the dimensions/geometry of outdoor surface contamination, a default ACF of 1.0 is presented for all isotopes for the 3-D exposure models addressing outside walls, streets and sidewalks. For the 2-D exposure models addressing finite slabs, the ACF is made variable by isotope and area for site-specific analysis. This calculator allows the user to select from 8 different slab area sizes. If no size is selected for the finite slab analysis, the ACF from the most protective slab size is selected. For further information on the derivation of the isotope-specific/area-specific ACF values for 2-D slabs see Contaminated Slabs. For a description of other EPA default ACF values, follow the link here.

#### 4.3.12 Surfaces Factor

The 3-D direct external exposure equations (building materials and dust) without $F_{SURF}$ are single surface equations. The surfaces factor, in the default and site-specific equations, are based on exposure to 2 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 ($F_{SURF}$). 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 and 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 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 $F_{SURF}$ values used in this calculator for each radioisotope. $F_{SURF}$ values were calculated for each position-specific and building-height specific combination.

### 4.4 Supporting Equations

There are two parts in the above land use equations that require further explanation. First is the use of the radionuclide decay constant ($\lambda$). Second is the variable particulate emission factor feature of this calculator.

#### 4.4.1 Radionuclide Decay Constant

Each equation (where appropriate by media) has a decay constant term which is based on the half-life of the isotope ($\lambda$). $\lambda$= Decay constant (0.693/half-life in years). The intention of this term is to derive realistic sdccs for isotopes with relatively short half-lives, compared to the exposure duration (ED). The term $(1 - e^{-\lambda t})$ takes into account the number of half-lives that will occur within the ED to calculate an appropriate value. Definitions of the input variables are in Table 1.

#### 4.4.2 Particulate Emission Factor (PEF)

Two particulate emission factors can be selected for this calculator: mechanically driven and the traditional wind driven emission factor.

##### 4.4.2.1 Mechanically Driven PEF for Paved Public Roads

These equations allow the user to input mean vehicle weight, road dimensions, distance traveled and time. 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 (PM10). 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. However, 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 A1-6. DETAILED INFORMATION FOR PAVED ROAD TESTS FOR REFERENCE 3

| 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.

1-8

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, ΣVKT, is estimated based on the size of the area of the contamination, the configuration of the road and amount of traffic. The default ΣVKT is based on California urban interstate statistics. The value of 2,822,326 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 conservative 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 ΣVKT 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] | 0.66 | 1.1 | 0.0024 |
| PM-10 | 4.6 | 7.3 | 0.016 |
| PM-15 | 5.5 | 9.0 | 0.020 |
| PM-30[d] | 24 | 38 | 0.082 |

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

Table 13.2.1-2. 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] g/VMT | g/VKT | lb/VMT |
|---|---|---|---|
| $PM_{2.5}$ | 0.1617 | 0.1005 | 0.00036 |
| $PM_{10}$ | 0.2119 | 0.1317 | 0.00047 |
| $PM_{15}$ | 0.2119 | 0.1317 | 0.00047 |
| $PM_{30}$[c] | 0.2119 | 0.1317 | 0.00047 |

#### 4.4.2.1.1 Default Equation for Mechanically Driven PEF for Paved Public Roads

Below is the equation used to determine the default mechanical PEF for public paved roads. None of the inputs can be changed.

$$PEF_{m\text{-}p\ default}\left(\frac{m^3}{kg}\right)=\frac{Q}{C_m}\left(\left(\frac{g}{m^2\text{-}s}\right)\Big/\left(\frac{kg}{m^3}\right)\right)\times\frac{1}{F_D}\times\frac{T\ (seconds)\times A_R\ (m^2)}{\left[k\text{-}pp\left(\frac{4.6\ g}{VKT}\right)\times\left(\frac{sL\left(\frac{0.015\ g}{m^2}\right)}{2}\right)^{0.65}\times\left(\frac{W\ (3.2\ tons)}{3}\right)^{1.5}-C\left(\frac{0.1317\ g}{VKT}\right)\right]\times\left[1-\frac{P\left(\frac{rain\ rays}{year}\right)}{4\times\left(\frac{365\ days}{year}\right)}\right]\times\Sigma\ VKT}$$

where

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

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

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

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

$sL\left(\frac{g}{m^2}\right)$ (road surface silt loading) = 0.015

W (tons) (mean vehicle weight in tons) = 3.2

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

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

#### 4.4.2.1.2 State-Specific Equation for Mechanically Driven PEF for Paved Public Roads

Below is the equation used to determine the state-specific mechanical PEF for public paved roads. The size of the site, mean vehicle weight, road dimensions, particle size multiplier, emission factor for fleet exhaust, brake and tire wear and number of rain days can be changed. The state, geographic setting and roadway class must be selected for the equation to operate.

$$PEF_{m\text{-}p\ state\text{-}specific}\left(\frac{m^3}{kg}\right)=\frac{Q}{C_m}\left(\left(\frac{g}{m^2\text{-}s}\right)\Big/\left(\frac{kg}{m^3}\right)\right)\times\frac{1}{F_D}\times\frac{T\ (seconds)\times A_R\ (m^2)}{\left[k\text{-}pp\left(\frac{4.6\ g}{VKT}\right)\times\left(\frac{sL\left(\frac{g}{m^2}\right)}{2}\right)^{0.65}\times\left(\frac{W\ (3.2\ tons)}{3}\right)^{1.5}-C\left(\frac{0.1317\ g}{VKT}\right)\right]\times\left[1-\frac{P\left(\frac{rain\ rays}{year}\right)}{4\times\left(\frac{365\ days}{year}\right)}\right]\times\Sigma\ VK}$$

where

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

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

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

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

$sL\left(\frac{g}{m^2}\right)$ (road surface silt loading) = values from Section 4.3.10

W (mean vehicle weight in tons) = 3.2

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

$\Sigma$ VKT (sum of vehicle km traveled during ED) = $\left(\frac{L_S\ (Km)\times AKV\left(\frac{Km}{yr}\right)\ \text{of road class}}{\text{Km of road class}}\times ED\ (yr)\right)$

#### 4.4.2.1.3 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 size of the site, road dimensions, particle size multiplier, emission factor for fleet exhaust, brake and tire wear and number of rain days, silt loading factor, mean vehicle weight inputs and ΣVKT inputs can be changed.

$$PEF_{m\text{-}p\ \text{site-specific}}\left(\frac{m^3}{kg}\right)=\frac{Q}{C_m}\left(\left(\frac{g}{m^2\text{-}s}\right)\Big/\left(\frac{kg}{m^3}\right)\right)\times\frac{1}{F_D}\times\frac{T\ (\text{seconds})\times A_R\ (m^2)}{\left[k\text{-}pp\left(\frac{4.6\ g}{VKT}\right)\times\left(\frac{sL\left(\frac{g}{m^2}\right)}{2}\right)^{0.65}\times\left(\frac{W\ (\text{tons})}{3}\right)^{1.5}-C\left(\frac{0.1317\ g}{VKT}\right)\right]\times\left[1-\frac{P\left(\frac{\text{rain rays}}{\text{year}}\right)}{4\times\left(\frac{365\ \text{days}}{\text{year}}\right)}\right]\times\Sigma\ VKT}$$

where

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

$A_R\ (m^2)=L_R\ (\text{length ft})\times W_R\ (\text{width ft})\times 0.092903\ m^2/ft^2$

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

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

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

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

#### 4.4.2.2 Mechanically Driven PEF for Unpaved public Roads

This equation allows the user to input silt percentage, silt moisture content, mean vehicle speed and site dimensions. 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 (PM10). Fugitive dust emissions are generated by vehicle traffic on unpaved public roads.

$$PEF_{m\text{-}up}\left(\frac{m^3}{kg}\right)=\frac{Q}{C_m}\left(\left(\frac{g}{m^2\text{-}s}\right)\Big/\left(\frac{kg}{m^3}\right)\right)\times\frac{1}{F_D}\times\frac{T\ (\text{seconds})\times A_R\ (m^2)}{\left(\frac{k\text{-}up\left(1.8\ \frac{\text{pounds}}{VMT}\right)\times\left(\frac{s\ (8.5\ \%)}{12}\right)^{a\text{-}p}\times\left(\frac{S\left(\frac{\text{miles}}{\text{hour}}\right)}{30}\right)^{d\text{-}p}}{\left(M\ \frac{(7.9\ \%)}{0.5}\right)^{c\text{-}p}}-C\left(\frac{0.00047\ \text{pounds}}{VMT}\right)\right)\times\left[\frac{\left(365-p\ (\text{rain days})\right)}{365}\right]\times\left(\frac{\left(\frac{281\ldots}{VK\ldots}\right.}{\left(\frac{1\ po\ldots}{VM\ldots}\right.}\right.}$$

where

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

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

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

$A_R\ (m^2)=L_R\ (\text{length ft})\times W_R\ (\text{width ft})\times 0.092903\ m^2/ft^2$

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

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

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

The following 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%, however moisture can range from 0.03 to 13% according to AP42 section on unpaved roads. However, 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 ΣVKT, 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 13.2.1-2. 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] | | |
|---|---|---|---|
| | g/VMT | g/VKT | lb/VMT |
| $PM_{2.5}$ | 0.1617 | 0.1005 | 0.00036 |
| $PM_{10}$ | 0.2119 | 0.1317 | 0.00047 |
| $PM_{15}$ | 0.2119 | 0.1317 | 0.00047 |
| $PM_{30}$[c] | 0.2119 | 0.1317 | 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 |

#### 4.4.2.3 Mechanically Driven PEF for Unpaved Industrial Roads

This equation allows the user to input mean vehicle weight, silt percentage and site dimensions. 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 (PM10). 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. However, 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.

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

where

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

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

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

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

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

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

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 |

#### 4.4.2.4 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 (PM10) 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.

- Wind-driven

$$PEF_w = Q/C_w\left(\left(\frac{g}{m^2\text{-}s}\right) \Big/ \frac{kg}{m^3}\right) \times \frac{3{,}600\left(\frac{seconds}{hour}\right)}{0.036 \times (1-V) \times \left(U_m\left(\frac{m}{s}\right)/U_t\left(\frac{m}{s}\right)\right)^3 \times F(\chi)}$$

where

$$\frac{Q}{C_w}\left(\left(\frac{g}{m^2\text{-}s}\right) \Big/ \frac{kg}{m^3}\right) = A \times \exp\left[\frac{\left(\ln A_s(acres) - B\right)^2}{C}\right]$$

**Table 1. Recommended Standard Default Factors**

| Symbol | Definition (units) | Default | Reference |
|---|---|---|---|
| | **SDCC Units** | | |
| $SDCC_{dr\text{-}total}$ | Residential SDCC for Exposure to Settled Dust on Surfaces ($pCi/cm^2$) | Isotope-specific | Determined in this calculator |
| $SDCC_{3\text{-}Dr\text{-}sv}$ | 3-D Residential SDCC for Direct External Exposure to Contaminated Building Materials using infinite soil volume (pCi/g) | Isotope-specific | Determined in this calculator |
| $SDCC_{3\text{-}Dr\text{-}1cm}$ | 3-D Residential SDCC for Direct External Exposure to Contaminated Building Materials using 1cm soil volume (pCi/g) | Isotope-specific | Determined in this calculator |
| $SDCC_{3\text{-}Dr\text{-}5cm}$ | 3-D Residential SDCC for Direct External Exposure to Contaminated Building Materials using 5 cm soil volume (pCi/g) | Isotope-specific | Determined in this calculator |
| $SDCC_{3\text{-}Dr\text{-}15cm}$ | 3-D Residential SDCC for Direct External Exposure to Contaminated Building Materials using 15 cm soil volume (pCi/g) | Isotope-specific | Determined in this calculator |
| $SDCC_{3\text{-}Dr\text{-}gp}$ | Residential SDCC for Direct External Exposure to Contaminated Dust ($pCi/cm^2$) | Isotope-specific | Determined in this calculator |
| $SDCC_{2\text{-}Dr\text{-}sv}$ | 2-D Residential SDCC for Direct External Exposure to Finite Slabs using infinite soil volume (pCi/g) | Isotope-specific | Determined in this calculator |
| $SDCC_{2\text{-}Dr\text{-}1cm}$ | 2-D Residential SDCC for Direct External Exposure to Finite Slabs using 1cm soil volume (pCi/g) | Isotope-specific | Determined in this calculator |
| $SDCC_{2\text{-}Dr\text{-}5cm}$ | 2-D Residential SDCC for Direct External Exposure to Finite Slabs using 5 cm soil volume (pCi/g) | Isotope-specific | Determined in this calculator |
| $SDCC_{2\text{-}Dr\text{-}15cm}$ | 2-D Residential SDCC for Direct External Exposure to Finite Slabs using 15 cm soil volume (pCi/g) | Isotope-specific | Determined in this calculator |
| $SDCC_{2\text{-}Dr\text{-}gp}$ | Residential SDCC for Direct External Exposure to Contaminated Dust on Finite Slabs ($pCi/cm^2$) | Isotope-specific | Determined in this calculator |
| $SDCC_{dow\text{-}total}$ | Outdoor Worker SDCC for Exposure to Settled Dust on Surfaces ($pCi/cm^2$) | Isotope-specific | Determined in this calculator |
| $SDCC_{3\text{-}Dow\text{-}sv}$ | 3-D Outdoor Worker SDCC for Direct External Exposure to Contaminated Building Materials using infinite soil volume (pCi/g) | Isotope-specific | Determined in this calculator |
| $SDCC_{3\text{-}Dow\text{-}1cm}$ | 3-D Outdoor Worker SDCC for Direct External Exposure to Contaminated Building Materials using 1 cm soil volume (pCi/g) | Isotope-specific | Determined in this calculator |
| $SDCC_{3\text{-}Dow\text{-}5cm}$ | 3-D Outdoor Worker SDCC for Direct External Exposure to Contaminated Building Materials using 5cm soil volume (pCi/g) | Isotope-specific | Determined in this calculator |
| $SDCC_{3\text{-}Dow\text{-}15cm}$ | 3-D Outdoor Worker SDCC for Direct External Exposure to Contaminated Building Materials using 15cm soil volume (pCi/g) | Isotope-specific | Determined in this calculator |
| $SDCC_{3\text{-}Dow\text{-}gp}$ | 3-D Outdoor Worker SDCC for Direct External Exposure to Contaminated Dust ($pCi/cm^2$) | Isotope-specific | Determined in this calculator |
| $SDCC_{2\text{-}Dow\text{-}sv}$ | 2-D Outdoor Worker SDCC for Direct External Exposure to Finite Slabs using infinite soil volume (pCi/g) | Isotope-specific | Determined in this calculator |
| $SDCC_{2\text{-}Dow\text{-}1cm}$ | 2-D Outdoor Worker SDCC for Direct External Exposure to Finite Slabs using 1 cm soil volume (pCi/g) | Isotope-specific | Determined in this calculator |
| $SDCC_{2\text{-}Dow\text{-}5cm}$ | 2-D Outdoor Worker SDCC for Direct External Exposure to Finite Slabs using 5cm soil volume (pCi/g) | Isotope-specific | Determined in this calculator |
| | 2-D Outdoor Worker SDCC for Direct | Isotope-specific | Determined in this calculator |

| | | | |
|---|---|---|---|
| $SDCC_{2\text{-Dow-15cm}}$ | External Exposure to Finite Slabs using 15cm soil volume (pCi/g) | | |
| $SDCC_{2\text{-Dow-gp}}$ | 2-D Outdoor Worker SDCC for Direct External Exposure to Contaminated Dust on Finite Slabs ($pCi/cm^2$) | Isotope-specific | Determined in this calculator |
| $SDCC_{diw\text{-total}}$ | Indoor Worker SDCC for Exposure to Settled Dust on Surfaces ($pCi/cm^2$) | Isotope-specific | Determined in this calculator |
| $SDCC_{3\text{-Diw-sv}}$ | 3-D Indoor Worker SDCC for Direct External Exposure to Contaminated Building Materials using infinite soil volume (pCi/g) | Isotope-specific | Determined in this calculator |
| $SDCC_{3\text{-Diw-1cm}}$ | 3-D Indoor Worker SDCC for Direct External Exposure to Contaminated Building Materials using 1 cm soil volume (pCi/g) | Isotope-specific | Determined in this calculator |
| $SDCC_{3\text{-Diw-5cm}}$ | 3-D Indoor Worker SDCC for Direct External Exposure to Contaminated Building Materials using 5 cm soil volume (pCi/g) | Isotope-specific | Determined in this calculator |
| $SDCC_{3\text{-Diw-15cm}}$ | 3-D Indoor Worker SDCC for Direct External Exposure to Contaminated Building Materials using 15 cm soil volume (pCi/g) | Isotope-specific | Determined in this calculator |
| $SDCC_{3\text{-Diw-gp}}$ | 3-D Indoor Worker SDCC for Direct External Exposure to Contaminated Dust ($pCi/cm^2$) | Isotope-specific | Determined in this calculator |
| $SDCC_{2\text{-Diw-sv}}$ | 2-D Indoor Worker SDCC for Direct External Exposure to Finite Slabs using infinite soil volume (pCi/g) | Isotope-specific | Determined in this calculator |
| $SDCC_{2\text{-Diw-1cm}}$ | 2-D Indoor Worker SDCC for Direct External Exposure to Finite Slabs using 1 cm soil volume (pCi/g) | Isotope-specific | Determined in this calculator |
| $SDCC_{3\text{-Diw-5cm}}$ | 2-D Indoor Worker SDCC for Direct External Exposure to Finite Slabs using 5 cm soil volume (pCi/g) | Isotope-specific | Determined in this calculator |
| $SDCC_{2\text{-Diw-15cm}}$ | 2-D Indoor Worker SDCC for Direct External Exposure to Finite Slabs using 15 cm soil volume (pCi/g) | Isotope-specific | Determined in this calculator |
| $SDCC_{2\text{-Diw-gp}}$ | 2-D Indoor Worker SDCC for Direct External Exposure to Contaminated Dust on Finite Slabs ($pCi/cm^2$) | Isotope-specific | Determined in this calculator |
| **Slope Factors** | | | |
| $SF_{d\text{-oral}}$ | Ingestion Slope Factor - dust (risk/pCi) | Isotope-specific | HEAST |
| $SF_{d\text{-ext}}$ | External Exposure Slope Factor - dust (risk/yr per $pCi/100cm^2$) | Isotope-specific | Developed for SDCC calculator (based on ground plane risk coefficients from FGR 13) |
| $SF_i$ | Inhalation Slope Factor - air (risk/pCi) | Isotope-specific | HEAST |
| $SF_{ext}$ | External Exposure Slope Factor - direct (risk/yr per pCi/g) | Isotope-specific | HEAST (based on soil volume risk coefficients from FGR 13) |
| $SF_{ext\text{-1cm}}$ | External Exposure Slope Factor - direct (risk/yr per pCi/g) | Isotope-specific | HEAST (based on soil volume risk coefficients from FGR 13) |
| $SF_{ext\text{-5cm}}$ | External Exposure Slope Factor - direct (risk/yr per pCi/g) | Isotope-specific | HEAST (based on soil volume risk coefficients from FGR 13) |
| $SF_{ext\text{-15cm}}$ | External Exposure Slope Factor - direct (risk/yr per pCi/g) | Isotope-specific | HEAST (based on soil volume risk coefficients from FGR 13) |
| **Dose and Decay Constant Variables** | | | |
| DR | Dose Limit (mrem) | 1 | User must specify dose rate |
| $t_w$ | Time - worker (years) | 1 | U.S. EPA 1991 (pg. 15) |
| $t_r$ | Time - resident (years) | 1 | U.S. EPA 1991 (pg. 15) |
| $\lambda$ | Decay Constant = 0.693/halflife | -- | Developed for Radionuclide Soil Screening Calculator (EPA 2000c) |
| k | Dissipation Rate Constant - ($years^{-1}$) | 0.0 | EPA 2003 (pg. D-8) |
| **Miscellaneous Variables** | | | |
| $AAF_a$ | Annual Age Fraction - adult (unitless) | 0.8 | This fraction is used to compose an age-adjusted intake. |
| $AAF_c$ | Annual Age Fraction - child (unitless) | 0.2 | This fraction is used to compose an age-adjusted intake. |
| ACF | Area Correction Factor (unitless) | 1.0 Resident | U.S. EPA 2000a. (pg. 2-22). |

| | | | |
|---|---|---|---|
| | | 1.0 Outdoor Worker<br>1.0 Indoor Worker | U.S. EPA 2000b. (pg. 5-1) |
| ACF | Area Correction Factor (unitless) | For 2-D analysis (isotope-specific) | Eckerman 2007 |
| 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 EPA 2005. |
| $DF_i$ | Indoor Air Dilution Factor - Outdoor (unitless) | 0.4 (assumes dilution) | EPA 2000a (pg 2-20) |
| $GSF_o$ | Gamma Shielding Factor - Outdoor (unitless) | 1 (assumes no shielding) | Other GSFs are presented in these reports.<br>U.S. EPA 2000a. (pg. 2-22).<br>U.S. EPA 2000b. (pg. 2-18) |
| $GSF_i$ | Gamma Shielding Factor - Indoor (unitless) | 0.4 (assumes shielding) | Other GSFs are presented in these reports.<br>U.S. EPA 2000a. (pg. 2-22).<br>U.S. EPA 2000b. (pg. 2-18) |
| $F_{AM}$ | Area and Material Factor (unitless) | 1.0 | ANL 2001 (Fig 8.6) |
| $F_{CD}$ | Depth and Cover Function (unitless) | 1.0 | ANL 2001 (Fig 8.6) |
| $F_{OFF-SET}$ | Off-set Factor (unitless) | 1.0 | ANL 2001 (Fig 8.6) |
| $F_{SURF}$ | Surfaces Factor (unitless) | isotope-specific | Eckerman 2007 |
| **Inhalation and Ingestion Rates** | | | |
| $IF_w$ | Worker Dust Ingestion Rate - Worker ($cm^2$/day) | 90 | Calculated Value based on EPA 2003 (pg. D-4) |
| $IF_r$ | Age-Adjusted Dust Ingestion Rate - Resident ($cm^2$/day) | 64.5 | Calculated Value based on EPA 2003 (pg. D-4) |
| $HF_r$ | Age adjusted Inhalation Rate ($m^3$/day) | 18 | Calculated Value based on U.S. EPA 1991 (pg. 15) |
| $HR_a$ | Adult Inhalation Rate ($m^3$/day; based on IRIS default) | 20 | U.S. EPA 1991 (pg. 15) |
| $HR_c$ | Child Inhalation Rate ($m^3$/day; based on IRIS default) | 10 | U.S. EPA 1991 (pg. 15) |
| $HR_w$ | Worker Inhalation Rate ($m^3$/hr) | 2.5 | U.S. EPA 1997 (pg. 5-25) |
| **Ingestion Rate Variables** | | | |
| $FTSS_h$ | Fraction Transferred Surface to Skin - Hard Surface (unitless) | 0.5 | EPA 2004 (Exhibit E-1 pg. E-6) |
| $SA_a$ | Surface Area of Fingers - Adult ($cm^2$) | 45 | EPA 2003 (pg. D-5) |
| $SA_c$ | Surface Area of Fingers - Child ($cm^2$) | 15 | EPA 2003 (pg. D-5) |
| $SA_w$ | Surface Area of Fingers - Worker ($cm^2$) | 45 | EPA 2003 (pg. D-5) |
| $FQ_a$ | Frequency of Hand to Mouth - Adult (events/hour) | 1 | EPA 2003 (pg. D-5) |
| $FQ_c$ | Frequency of Hand to Mouth - Child (events/hour) | 9.5 | EPA 2003 (pg. D-5) |
| $FQ_w$ | Frequency of Hand to Mouth - Worker (events/hour) | 1 | EPA 2003 (pg. D-5) |
| SE | Saliva Extraction Factor (unitless) | 0.5 | EPA 2003 (pg. D-5) |
| $ET_{h,a}$ | Exposure Time - Adult Hard Surface (hours/day) | 4 | EPA 2003 (pg. D-4) |
| $ET_{h,c}$ | Exposure Time - Child Hard Surface (hours/day) | 4 | EPA 2003 (pg. D-4) |
| $ET_{h,w}$ | Exposure Time - Worker Hard Surface (hours/day) | 8 | EPA 2003 (pg. D-4) |
| $ET_{o,r}$ | Exposure Time Outdoor - Resident (hours/day) | 1.752 | EPA 1997 (Table 15-132) |
| $ET_{i,r}$ | Exposure Time Indoor - Resident (hours/day) | 16.4 | EPA 1997 (Table 15-131) |
| $ET_w$ | Air Exposure Time - Worker (hours/day) | 8 | EPA 2003 (pg. D-4) |
| **Exposure Frequency, Exposure Duration, and Exposure Time Variables** | | | |
| $EF_{iw}$ | Exposure Frequency - indoor worker (days/year) | 250 | U.S. EPA 1991 (pg. 15) |
| $EF_{ow}$ | Exposure Frequency - outdoor worker (days/year) | 225 | U.S. EPA 1991 (pg. 15) |
| $EF_r$ | Exposure Frequency - resident (days/year) | 350 | U.S. EPA 1991 (pg. 15) |
| $ED_w$ | Exposure Duration - worker (years) | 1 | U.S. EPA 1991 (pg. 15) |
| $ED_r$ | Exposure Duration - resident (years) | 1 | U.S. EPA 1991 (pg. 15) |

| | | | |
|---|---|---|---|
| $ED_a$ | Exposure Duration - adult resident (years) | 1 | U.S. EPA 1991 (pg. 15) |
| $ED_c$ | Exposure Duration - child resident (years) | 1 | U.S. EPA 1991 (pg. 15) |
| **Particulate Emission Factor Variables** | | | |
| $PEF_w$ | Wind Particulate Emission Factor - Minneapolis ($m^3$/kg) | $1.36 \times 10^9$ Minneapolis-specific | U.S. EPA 1996a (pg. 23), U.S. EPA 1996b (pg. 31) |
| $Q/C_w$ | 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) |
| V | (fraction of vegetative cover) unitless | 0.5 | U.S. EPA 1999b, U.S. EPA 1996a (pg. 23), U.S. EPA 1996b (pg. 31) |
| $U_m$ | mean annual wind speed) m/s | 4.69 | U.S. EPA 1999b, U.S. EPA 1996a (pg. 23), U.S. EPA 1996b (pg. 31) |
| $U_t$ | equivalent threshold value of wind speed at 7m) m/s | 11.32 | U.S. EPA 1999b, U.S. EPA 1996a (pg. 23), U.S. EPA 1996b (pg. 31) |
| F(x) | function dependent on $U_m/U_t$) unitless | 0.194 | U.S. EPA 1999b, U.S. EPA 1996a (pg. 23), U.S. EPA 1996b (pg. 31) |
| A | Dispersion constant unitless | PEF and region-specific | U.S. EPA 2002 (pg. D-6 to D-8) |
| $A_s$ | Areal extent of the site or contamination (acres) | 0.5 (range 0.5 to 500 ) | U.S. EPA 2002 (pg. D-2) |
| B | Dispersion constant unitless | PEF and region-specific | U.S. EPA 2002 (pg. D-6 to D-8) |
| C | Dispersion constant unitless | PEF and region-specific | U.S. EPA 2002 (pg. D-6 to D-8) |
| $PEF_m$ | Mechanical Particulate Emission Factor - Phoenix ($m^3$/kg) | $3.05 \times 10^7$Phoenix-specific | 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/$m^3$) | 90.54 Phoenix-specific | EPA 2002 (Equation E-18) |
| $F_D$ | Dispersion correction factor (unitless) | 0.1858 (calculated) | EPA 2002 (Equation E-18) |
| $t_c$ | Total time over which exposure occurs (hr) $t_c$=T changing units to hrs. | 262,800 (30 yrs resident)<br>219,000 (25 yrs worker) | EPA 2002 (Equation E-18) |
| T | Total time over which exposure occurs. equal to ED (s) | 946,080,000 (30 yrs resident)<br>788,400,000 (25 yrs worker) | EPA 2002 (Equation E-18) |
| $A_R$ | Surface area of contaminated road segment ($m^2$),<br>AR = $L_R$ x $W_R$ x 0.092903 $m^2/ft^2$ | 274.2 | EPA 2002 (Equation E-18) |
| s | Road surface silt content (%) | 8.5 | EPA 2002 (Equation E-18) |
| W | Mean vehicle weight (tons) | 3.2 | EPA 2001 (Page 4-285) |
| $M_{dry}$ | Road surface material moisture content under dry, uncontrolled conditions (%) | 0.2 | EPA 2002 (Equation E-18) |
| p | Number of days per year with at least 0.01 inches of precipitation | Region-specific (150) | EPA 2002 (Exhibit E-4) |
| VKT | Sum of fleet vehicle kilometers traveled during the exposure duration (km/year) | 2,814,018 (based on annualized urban California road and traffic data) | DOT 2004 (hm20 and vm2) |
| $L_R$ | Length of road segment (ft)<br>$L_R$ = square root of site surface contamination used for $A_{s=}$=0.5 acres | 147.6 | EPA 2002 (Equation E-18) |
| $W_R$ | Width of road segment (ft) | 20 | EPA 2002 (Equation E-18) |

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## 4.5 Equation Details

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

**Exposure to settled dust on surfaces equations:**

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 EPA 2003 (pg. D-4). External exposure from deposited materials equation was modeled after the equation found in ANL 2001 (Fig 8.7).

**Direct external exposure equation:**

The direct external exposure from a volume and surface of a large area equation was modeled after ANL 2001 (Fig 8.6).

### 4.5.1 External Exposure Pathway 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, $F^n_G$, 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, $F_{OFF-SET}$.

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

Then, $F^n_G$ = $F_{CD}$ x $F_{AM}$ x $F_{OFF-SET}$.

#### *4.5.1.1 $F_{CD}$*

**Note:** The $F_{CD}$ is not included in the equations for this calculator. However, the discussion is still presented in following text. It would generally not be appropriate for the settled dust exposure pathway because the dust layer is so thin. It would not be necessary for the direct external exposure pathway because the soil volume risk coefficients are not concerned with depth.

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;

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

$t_s$ = source thickness (cm);

$\rho_s$ = 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.

#### 4.5.1.2 $F_{AM}$

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:

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

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.

#### 4.5.1.3 $F_{OFF\text{-}SET}$

The off-set factor, $F_{OFF\text{-}SET}$, 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:

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

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