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Soil Screening Guidance for Radionuclides: User's Guide

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DISCLAIMER

Notice: The Soil Screening Guidance is based on policies set out in the Preamble to the Final Rule of the National Oil and Hazardous Substances Pollution Contingency Plan (NCP), which was published on March 8, 1990 (55 *Federal Register* 8666).

This guidance document sets forth recommended approaches based on EPA's best thinking to date with respect to soil screening for radionuclides. This document does not establish binding rules. Alternative approaches for screening radionuclides in soil may be found to be more appropriate at specific sites (e.g., where site circumstances do not match the underlying assumptions, conditions and models of the guidance). The decision whether to use an alternative approach and a description of any such approach should be placed in the Administrative Record for the site. Accordingly, if comments are received at individual sites questioning the use of the approaches recommended in this guidance, the comments should be considered and an explanation provided for the selected approach. The Soil Screening Guidance for Radionuclides: Technical Background Document (TBD) may be helpful in responding to such comments.

The policies set out in both the Soil Screening Guidance for Radionuclides: User's Guide and the supporting TBD are intended solely as guidance to the U.S. Environmental Protection Agency (EPA) personnel; they are not final EPA actions and do not constitute rulemaking. These policies are not intended, nor can they be relied upon, to create any rights enforceable by any party in litigation with the United States government. EPA officials may decide to follow the guidance provided in this document, or to act at variance with the guidance, based on an analysis of specific site circumstances. EPA also reserves the right to change the guidance at any time without public notice.

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ATTACHMENTS

LIST OF EXHIBITS

LIST OF ACRONYMS

ARAR	Applicable or Relevant and Appropriate Requirement
ASTM	American Society for Testing and Materials
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act
CLP	Contract Laboratory Program
CSM	Conceptual Site Model
CV	Coefficient of Variation
DAF	Dilution Attenuation Factor
DQA	Data Quality Assessment
DQO	Data Quality Objective
EA	Exposure Area
EPA	Environmental Protection Agency
HEAST	Health Effects Assessment Summary Table
HELP	Hydrological Evaluation of Landfill Performance
HHEM	Human Health Evaluation Manual
IRIS	Integrated Risk Information System
ISC2	Industrial Source Complex Model
MARSSIM	Multi-Agency Radiation Survey and Site Investigation Manual
MCL	Maximum Contaminant Level
MDC	Minimum Detectable Concentration
NPL	National Priorities List
NTIS	National Technical Information Service
OERR	Office of Emergency and Remedial Response
ORIA	Office of Radiation and Indoor Air
PA/SI	Preliminary Assessment/Site Inspection
PEF	Particulate Emission Factor
PRG	Preliminary Remediation Goal
QAPP	Quality Assurance Project
Q/C	Site-Specific Dispersion Model
QA/QC	Quality Assurance/Quality Control
RAGS	Risk Assessment Guidance for Superfund
RCRA	Resource Conservation and Recovery Act
RfD	Reference Dose
RI	Remedial Investigation
RI/FS	Remedial Investigation/Feasibility Study
RME	Reasonable Maximum Exposure
ROD	Record of Decision
SAB	Science Advisory Board
SAP	Sampling and Analysis Plan
SSL	Soil Screening Level
TBD	Technical Background Document
USDA	U.S. Department of Agriculture
WRS	Wilcoxon Rank Sum

1.0 INTRODUCTION

1.1 Purpose

The Soil Screening Guidance for Radionuclides is a tool that the U.S. Environmental Protection Agency (EPA) developed to help standardize and accelerate the evaluation and cleanup of soils contaminated with radioactive materials at sites on the National Priorities List (NPL) with future residential land use.[1] This guidance provides a methodology for environmental science/engineering professionals with a background in radiological risk assessment to calculate risk-based, site-specific, soil screening levels (SSLs) for radionuclides in soil that may be used to identify areas needing further investigation at NPL sites. [1]

SSLs are not national cleanup standards. SSLs alone do not trigger the need for response actions or define "unacceptable" levels of radionuclides in soil. In this guidance, "screening" refers to the process of identifying and defining areas, radionuclides, and conditions, at a particular site that do not require further Federal attention. Generally, at sites where radionuclide concentrations fall below SSLs, no further action or study is warranted under the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA). Generally, where radionuclide concentrations equal or exceed SSLs, further study or investigation, but not necessarily cleanup, is warranted.

This radionuclide SSL guidance is a continuation of other EPA documents related to SSL for chemicals. These include EPA's *Soil Screening Guidance: User's Guide* (U.S. EPA, 1996a) and the *Soil Screening Guidance: Technical Background Document* (U.S. EPA, 1996b) that apply the SSL framework to NPL sites with hazardous organic and inorganic soil contaminants. They do not address sites with radioactive contaminants. These documents provide standardized exposure equations for deriving generic and site-specific SSLs for chemicals under a residential land use setting, assuming three soil exposure pathways—soil ingestion, inhalation of volatiles and fugitive dusts, and ingestion of contaminated ground water. Chemical- specific SSLs are based on a target risk of one-in-a-million (10^{-6}) for carcinogens, a hazard quotient of 1 for noncarcinogens, or, for the ground water migration pathway, a nonzero maximum contaminant level goal (MCLG), maximum contaminant level (MCL), or a risk-based level. For each contaminant, the lowest pathway-specific SSL is selected as the appropriate screening level.

An overview of a comparison between the key features of the soil screening frameworks for chemicals and radionuclides is provided in Table 1 below. Much of the guidance for radionuclides is based on or cites information presented in the chemical Soil Screening Guidance documents. Users are therefore strongly encouraged to become familiar with these documents.

This guidance elaborates a framework developed for soil screening levels for radionuclides that is consistent and compatible with the SSL framework for chemicals. Radionuclide SSLs are risk-based concentrations, in activity units of picocuries per gram of soil (pCi/g), derived from equations combining exposure information assumptions with EPA radiotoxicity data. This User's Guide focuses on the application of a simple site-specific approach by providing a step-by-step methodology to calculate site-specific SSLs and is part of a larger framework that includes both generic and more detailed approaches to calculating screening levels. The Soil Screening Guidance for Radionuclides: Technical Background Document (TBD) (U.S. EPA, 2000), provides detailed information about these other approaches. Generic SSLs for the most common radionuclides found at NPL sites are included in the TBD. Generic SSLs are calculated from the same equations presented in this guidance, but are based on a number of default assumptions chosen to be protective of human health for most site conditions. Generic SSLs can be used in place of site-specific screening 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 SSLs with the potential for deriving a higher SSL that provides an appropriate level of protection.

The framework presented in the TBD also includes more detailed modeling approaches for developing screening levels that take into account more complex site conditions than the simple site-specific methodology

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[1] Note that the Superfund program defines "soil" as having a particle size under 2 mm, while the RCRA program allows for particles under 9 mm in size.

emphasized in this guidance. More detailed approaches may be appropriate when site conditions (e.g., very deep water table, very thick uncontaminated unsaturated zone, soils underlain by karst or fractured rock aquifers) are different from those assumed in the simple site-specific methodology presented here. The technical details supporting the methodology used in this guidance are provided in the TBD.

SSLs developed in accordance with this guidance are based on future residential land use assumptions and related exposure pathways. Using this guidance for sites where residential land use assumptions do not apply could result in overly conservative screening levels; however, EPA recognizes that some parties responsible for sites with non-residential land use might still find benefit in using the SSLs as a tool to conduct a conservative initial screening.

SSLs developed in accordance with this guidance could also be used for Resource Conservation and Recovery Act (RCRA) corrective action sites as "action levels," since the RCRA corrective action program currently views the role of action levels as generally fulfilling the same purpose as soil screening levels.[2] In addition, States may use this guidance in their voluntary cleanup programs, to the extent they deem appropriate. When applying SSLs to RCRA corrective action sites or for sites under State voluntary cleanup programs, users of this guidance should recognize, as stated above, that SSLs are based on residential land use assumptions. Where these assumptions do not apply, other approaches for determining the need for further study might be more appropriate.

1.2 Role of Soil Screening Levels

In identifying and managing risks at sites, EPA considers a spectrum of radionuclide concentrations. The level of concern associated with those concentrations depends on the likelihood of exposure to radioactive soil contamination at levels of potential concern to human health.

Exhibit 1 illustrates the spectrum of soil contamination encountered at Superfund sites and the conceptual range of risk management responses. At one end are levels of contamination that clearly warrant a response action; at the other end are levels that warrant no further study under CERCLA. Screening levels identify the lower bound of the spectrum—levels below which EPA believes no further study is warranted under CERCLA, provided conditions associated with the SSLs are met. Appropriate cleanup goals for a particular site may fall anywhere within this range depending on site-specific conditions.

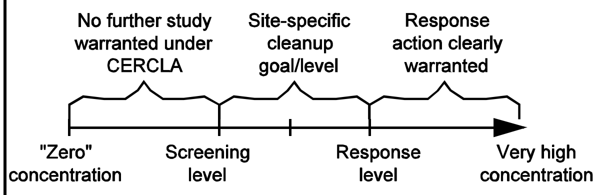

Exhibit 1. Conceptual Risk Management Spectrum for Contaminated Soil

EPA anticipates the use of SSLs as a tool to facilitate prompt identification of radionuclides and exposure areas of concern during both remedial actions and some removal actions under CERCLA. However, the application of this or any screening methodology is not mandatory at sites being addressed under CERCLA or RCRA. The framework leaves discretion to the site manager and technical experts (e.g., risk assessors, hydrogeologists) to determine whether a screening approach is appropriate for the site and, if screening is to be used, the proper method of implementation. 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 as part of the site's Record of Decision (ROD). The decision to use a screening approach should be made early in the process of investigation at the site.

EPA developed the Soil Screening Guidance for Radionuclides to be consistent with and to enhance the current Superfund investigation process and anticipates its primary use during the early stages of a remedial investigation (RI) at NPL sites. It does not replace the Remedial Investigation/Feasibility Study (RI/FS) or risk assessment, but use of screening levels can focus the RI and risk assessment on aspects of the site that are more likely to be a concern under CERCLA. By screening out

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[2] Further information on the role of action levels in the RCRA corrective action program is available in an Advance Notice of Proposed Rulemaking (signed April 1996).

areas of sites, potential radionuclides of concern, or exposure pathways from further investigation, site managers and technical experts can limit the scope of the remedial investigation or risk assessment. SSLs can save resources by helping to determine which areas do not require additional Federal attention early in the process. Furthermore, data gathered during the soil screening process can be used in later Superfund phases, such as the baseline risk assessment, feasibility study, treatability study, and remedial design. This guidance may also be appropriate for use by the removal program when demarcation of soils above residential risk-based numbers coincides with the purpose and scope of the removal action.

The process presented in this guidance to develop and apply simple, site-specific soil screening levels is likely to be most useful where it is difficult to determine whether areas of soil are contaminated to an extent that warrants further investigation or response (e.g., whether areas of soil at an NPL site require further investigation under CERCLA through an RI/FS). As noted above, the screening levels have been developed assuming residential land use. Although some of the models and methods presented in this guidance could be modified to address exposures under other land uses, EPA has not yet standardized assumptions for those other uses.

Applying site-specific screening levels involves developing a conceptual site model (CSM), collecting a few easily obtained site-specific soil parameters (such as the dry bulk density and percent moisture), and sampling to measure radionuclide levels in surface and subsurface soils. Often, much of the information needed to develop the CSM can be derived from previous site investigations [e.g., the Preliminary Assessment/Site Inspection (PA/SI)] and, if properly planned, SSL sampling can be accomplished in one mobilization.

An important part of this guidance is a recommended sampling approach that balances the need for more data to reduce uncertainty with the need to limit data collection costs.

Knowledge of background radionuclide concentrations at the site is critical when screening site soils, since facility operations may have contaminated site soils with some of the same radionuclides that are found naturally-occurring in background soil. In many cases, the concentration of the radionuclide of concern in background soil, and the variability of the background soil concentration, may be much greater than the screening level. In these situations, the site manager should not exclude the radionuclide of potential concern from being evaluated in the risk assessment, as the contamination from the facility may pose a threat to human health and the environment. Risk management options for the radionuclides of concern will be evaluated in the CERCLA remedy selection process.

This guidance provides the information needed to calculate SSLs for 60 radionuclides (See Attachment C for list of radionuclides). Sufficient information may not be available to develop soil screening levels for additional radionuclides. These radionuclides should not be screened out, but should be addressed in the baseline risk assessment for the site. The *Risk Assessment Guidance for Superfund* (RAGS), *Volume 1: Human Health Evaluation Manual* (HHEM), *Part A, Interim Final.* (U.S. EPA, 1989a) provides guidance on conducting baseline risk assessments for NPL sites. In addition, the baseline risk assessment should address the radionuclides, exposure pathways, and areas at the site that are not screened out.

Although SSLs are “risk-based,” they do not eliminate the need to conduct a site-specific risk assessment. SSLs are concentrations of radionuclides in soil that are designed to be protective of exposures in a residential setting. A site-specific risk assessment is an evaluation of the risk posed by exposure to site contaminants in various media. To calculate SSLs, the exposure equations and pathway models are run in reverse to backcalculate an “acceptable level” of radionuclides in soil. For each pathway, radiotoxicity criteria are used to define an acceptable level of contamination in soil, based on a one-in-a-million (10^{-6}) individual excess lifetime cancer risk. SSLs are backcalculated for the migration to ground water pathway using ground water concentration limits [maximum contaminant levels (MCLs)].

Table 1. Comparison of Soil Screening Frameworks for Chemicals and Radionuclides

Guidance	Chemicals	Radionuclides	Comments
Applicable land use exposure scenarios	Residential only	Same as chemicals	EPA may include additional guidance for other land uses (e.g., commercial/ industrial, suburban, playground, and hunter/fisher) in future updates.
Target receptor	RME individual	Same as chemicals	Ecological receptors are not addressed
Standardized equations for deriving SSLs for soil exposure pathways	• Soil ingestion • Inhalation of volatiles and fugitive dusts • Ingestion of potable ground water containing chemicals leached from soil Identifies dermal absorption, plant uptake, and migration of volatiles into basement pathways but does not calculate SSLs for these pathways	• Soil ingestion • Inhalation fugitive dusts • Ingestion of potable ground water containing radionuclides leached from soil • Direct external radiation exposure • Ingestion of home grown fruits and vegetables	Chemical-specific SSLs are expressed in mass concentration units of milligrams of contaminant per kilogram of soil (mg/kg). Radionu-clide-specific SSLs are expressed in activity concentration units of picocuries per gram of soil (pCi/g). Additional equations are required for radionuclides to account for other significant soil exposure pathways while some chemical pathways are not applicable to radionuclides.
Basis for SSLs	• Target risk limit of 10^{-6} for carcinogens • Hazard quotient of 1 for noncarcinogens • Nonzero MCLGs or MCLs (whichever is most protective), or if neither were available risk-based limits, for the ground water migration pathway	• Uses same target risk limit as chemicals • Uses MCLs, proposed MCLs (for uranium), or risk-based limits for the ground water migration pathway for radionuclides	EPA classifies all radionuclides as known human (Group A) carcinogens. For noncarcinogenic chemicals, nonzero MCLGs are considered (if available). MCLs exist for almost every radionuclide.
Default values for the age-adjusted soil ingestion factor	• $IF_{soil/adj}$ = 114 mg-yr/kg-day	• $IF_{soil/adj}$ = 120 mg-yr/day	The radionuclide slope factors for soil ingestion use a biokinetic model that accounts for the age and sex weighted mass of the affected organs. Therefore, it is not necessary to include the mass of the receptor in the default $IF_{soil/adj}$ for radionuclides.

Table 1. Comparison of Soil Screening Frameworks for Chemicals and Radionuclides

Guidance	Chemicals	Radionuclides	Comments
Default values for the dilution/attenuation factor (DAF) and the particulate emission factor (PEF)	• DAF = 20 • PEF = 1.32E+9 m^3/kg	Same as chemicals	The default PEF is the same as for chemicals. A key assumption in the derivation of the PEF is that the 1/2 acre lot has only 50% vegetative cover. Although the ingestion of homegrown produce is not quantitatively evaluated in the SSG for chemicals, the assumption of 50% vegetative cover allows for the presence of a family garden.
Soil measurement/ verification of guidelines	• Measured average soil contaminant concentrations in exposure areas of concern • Exposure area (EA) for averaging concentrations: 0.5 acres (residential lot) • Averaging depth for surface soils: 0-2 cm • Evaluation depth for subsurface soil contamination: surface to the limit of detectable contamination or to the top of the saturated zone • Number of surface soil samples required: Based on site-specific conditions or a default value of 6 randomly-selected specimens composited into 4 samples for analyses. • Number of subsurface soil samples required: For each source area, takes 2 or 3 soil borings in areas suspected of having the highest contaminant concentrations.	• Measures same parameter as for chemicals • Uses same exposure area (EA) as chemicals • Averaging depth for surface soils: 0-15 cm • Uses same evaluation depth for subsurface soil contamination as for chemicals • Uses same number of surface soil samples as for chemicals. • Uses same number of subsurface soil samples as for chemicals • Conducts surface scans for small areas of elevated activity	See Step 3, Defining Data Collection Needs for Soils for more detailed guidance.

One exception to the above approach is uranium, which presents both chemical and radiological hazards. SSLs for uranium must consider both of these types of hazards. As a general rule, the radiological hazard dominates inhalation of insoluble forms of uranium, while the chemical toxicity is the major hazard from intake of soluble forms of uranium. Chemical toxicity of uranium in the kidney has been a concern in establishing health protection standards for workers and the general public for many years. EPA developed for its rulemaking addressing radionuclide MCLs an updated oral RfD for uranium of 0.6 μg/kg/day (U.S. EPA, 1998c). SSLs for uranium should be calculated using both the radiological guidelines presented in this document and the approach provided in the Soil Screening Guidance for non-carcinogenic chemicals. Since the SSL is a numerical concentration, it should be based on the most protective health quantity whether it be kidney toxicity or radiological risk.

SSLs can be used as Preliminary Remediation Goals (PRGs) provided appropriate conditions are met (i.e., conditions found at a specific site are similar to conditions assumed in developing the SSLs). The concept of calculating risk-based contaminant levels in soils for use as PRGs (or "draft" cleanup levels) was introduced in the RAGS HHEM, *Part B, Development of Risk-Based Preliminary Remediation Goals*. (U.S. EPA, 1991c). **The models, equations, and assumptions presented in the Soil Screening Guidance for Radionuclides supersede those described in RAGS HHEM, Part B, for residential soils. In addition, this guidance presents methodologies to address the leaching of contaminants through soil to an underlying potable aquifer. This pathway should be addressed in the development of PRGs.**

PRGs may then be used as the basis for developing final cleanup levels based on the nine-criteria analysis described in the National Contingency Plan [Section 300.430 (3)(2)(I)(A)]. The directive entitled *Role of the Baseline Risk Assessment in Superfund Remedy Selection Decisions* (U.S. EPA, 1991d) discusses the modification of PRGs to generate cleanup levels. The SSLs should only be used as cleanup levels when a site-specific nine-criteria evaluation of the SSLs as PRGs for soils indicates that a selected remedy achieving the SSLs is protective, complies with Applicable or Relevant and Appropriate Requirements (ARARs), and appropriately balances the other criteria, including cost. Note that potential soil ARARs exist for several of the more common naturally-occurring radionuclides (^{226}Ra, ^{228}Ra, ^{230}Th, ^{232}Th, ^{235}U, and ^{238}U) under 40 CFR Part 192.12(a), Part 192.32(b)(2), and Part 192.41, and 10 CFR Part 40 Appendix A, I, Criterion 6(6). For further guidance on using these ARARs, see OSWER Directive 9200.4-25 (U.S. EPA, 1998b), dated February 12, 1998 and OSWER Directive 9200.4-35P (U.S. EPA, 2000a), dated April 11, 2000. The equations presented in this document supersede those described in RAGS HHEM, Part B, and should be used to determine PRGs and RGs.

1.3 Scope of Soil Screening Guidance for Radionuclides

In a residential setting, potential pathways of exposure to radionuclides in soil included in this guidance are as follows (see Exhibit 2):

- Direct ingestion of soil
- Inhalation of fugitive dusts
- Ingestion of contaminated ground water caused by migration of radionuclides through soil to an underlying potable aquifer
- External radiation exposure from photon-emitting radionuclides in soil
- Ingestion of homegrown produce that has been contaminated via plant uptake

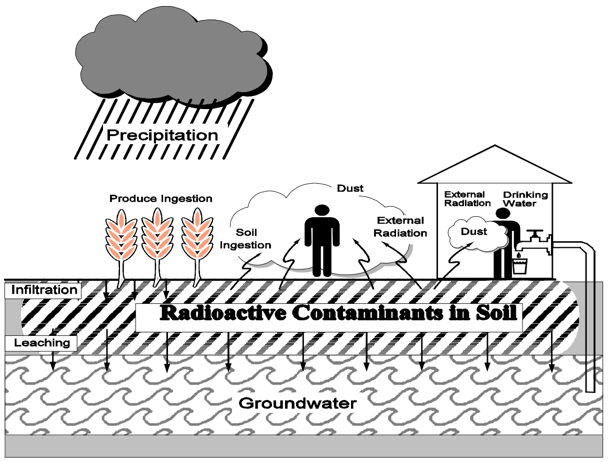


Exhibit 2: Exposure Pathways Addressed by SSLs for Radionuclides

The Soil Screening Guidance for Radionuclides addresses each of these pathways to the greatest extent practical. The mode of exposure to radionuclides is different than that of chemicals. This renders some chemical pathways inapplicable to radionuclides (e.g., inhalation of volatiles, dermal absorption) while adding other pathways unique to radiation (e.g., external exposure to photons emitted by radionuclides). The radiological pathways listed above represent the most likely exposure mechanisms for individuals in a residential setting. The external exposure pathway is, for most radionuclides, the dominant exposure and typically represents the most significant risk. For some radionuclides, the ingestion of contaminated produce and drinking water constitute the most likely exposure pathways provided that these items are obtained from onsite sources. The inhalation of fugitive dust pathway is included in the analysis; however, it is of significance for only a very few radionuclides. All of these pathways have generally accepted radiological risk methods, models, and assumptions that lend themselves to a standardized approach.

The Soil Screening Guidance for Radionuclides addresses the human exposure pathways listed previously and will be appropriate for most residential settings. The presence of additional pathways or unusual site conditions does not preclude the use of SSLs in areas of the site that are currently residential or likely to be residential in the future. However, the risks associated with additional pathways or conditions (e.g., fish consumption, raising of livestock for meat or milk consumption, fugitive dusts caused by heavy truck traffic on unpaved roads) should be considered in the RI/FS to determine whether SSLs are adequately protective.

The Soil Screening Guidance for Radionuclides should not be used for screening out areas with chemical contaminants.

Exhibit 3 provides key attributes of the Soil Screening Guidance for Radionuclides: User's Guide.

Exhibit 3: Key Attributes of the User's Guide

- Standardized equations are presented to address human exposure pathways in a residential setting consistent with Superfund's concept of "Reasonable Maximum Exposure" (RME).
- Source size (area and depth) can be considered on a site-specific basis using mass-limit models.
- Parameters are identified for which site-specific information is needed to develop SSLs.
- Default parameter values are provided to calculate generic SSLs when site-specific information is not available.
- SSLs for the migration to ground water pathway are based on maximum contaminant levels (MCLs), while SSLs for all other pathways are based on a 10^{-6} lifetime cancer risk to an individual.
- Radiation risk coefficients used to calculate SSLs represent the average risk per unit exposure to members of a population exposed throughout life to a constant concentration of a radionuclide in a specific environmental medium. They assume no radioactive decay.

2.0 SOIL SCREENING PROCESS

The soil screening process (Exhibit 4) is a step-by-step approach that involves:

- Developing a conceptual site model (CSM)
- Comparing the CSM to the SSL scenario
- Defining data collection needs
- Sampling and analyzing soils at site
- Calculating site-specific SSLs
- Comparing site soil radionuclide concentrations to calculated SSLs
- Determining which areas of the site require further study.

It is important to follow this process to implement the Soil Screening Guidance for Radionuclides properly. The remainder of this guidance discusses each activity in detail.

2.1 Step 1: Developing a Conceptual Site Model

The CSM is a three-dimensional "picture" of site conditions that illustrates radionuclide distributions, release mechanisms, exposure pathways and migration routes, and potential receptors. The CSM documents current site conditions and is supported by maps, cross sections, and site diagrams that illustrate human and environmental exposure through radionuclide release and migration to potential receptors. Developing an accurate CSM is critical to proper implementation of the Soil Screening Guidance for Radionuclides.

As a key component of the RI/FS and EPA's Data Quality Objectives (DQO) process, the CSM should be updated and revised as investigations produce new information about a site. *Data Quality Objectives for Superfund: Interim Final Guidance* (U.S. EPA, 1993a) and *Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA* (U.S. EPA, 1989c) provide a general discussion about the development and use of the CSM during RIs. Developing the CSM involves several steps, discussed in the following subsections.

2.1.1 Collect Existing Site Data. The initial design of the CSM is based on existing site data compiled during previous studies. These data may include site sampling data, historical records, aerial photographs, maps, and State soil surveys, as well as information on local and regional conditions relevant to radionuclide migration and potential receptors. Data sources include Superfund site assessment documents (i.e., the PA/SI), documentation of removal actions, and records of other site characterizations or actions. Published information on local and regional climate, soils, hydrogeology, and ecology may be useful. In addition, information on the population and land use at and surrounding the site will be important to identify potential exposure pathways and receptors. The RI/FS guidance (U.S. EPA, 1989c) discusses collection of existing data during RI scoping, including an extensive list of potential data sources. The Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM) (U.S. EPA, 1997b) [Section 3.4] discusses the collection of existing data specific to sites contaminated with radioactive materials.

2.1.2 Organize and Analyze Existing Site Data. One of the most important aspects of the CSM development process is to identify and characterize all potential exposure pathways and receptors at the site by considering site conditions, relevant exposure scenarios, and the properties of radionuclides present in site soils.

Attachment A, the Conceptual Site Model Summary, provides four forms for organizing site data for soil screening purposes. The CSM summary organizes site data according to general site information, soil radionuclide source characteristics, exposure pathways and receptors.

Note: If a CSM has already been developed for the site in question, use the summary forms in Attachment A to ensure that it is adequate.

Exhibit 4

Soil Screening Process for Radionuclides

Step One: **Develop Conceptual Site Model**

- Collect existing site data (historical records such as previous surveys and sampling data, site operating records, aerial photographs, maps, PA/SI data, available background information, State soil surveys, etc.)
- Organize and analyze existing site data
  - Identify known sources of contamination and potential contaminants
  - Identify potentially contaminated areas and affected media
  - Identify potential migration routes, exposure pathways, and receptors
- Construct a preliminary diagram of the CSM
- Perform site reconnaissance
  - Confirm and/or modify CSM
  - Identify remaining data gaps

Step Two: **Compare Soil Component of CSM to Soil Screening Scenario**

- Confirm that future residential land use is a reasonable assumption for the site
- Identify pathways present at the site that are addressed by the guidance
- Identify additional pathways present at the site not addressed by the guidance
- Compare pathway-specific generic SSLs with available concentration data
- Estimate whether background levels exceed generic SSLs

Step Three: **Define Data Collection Needs for Soils to Determine Which Site Areas Exceed SSLs**

- Stratify the site based on existing data
- Identify exposure areas
- Develop sampling and analysis plan for determining mean soil radionuclide concentrations
  - Determine appropriate survey instruments and techniques and establish QA/QC protocols
  - Sampling strategy for surface soils (includes defining study boundaries, developing a decision rule, specifying limits on decision errors, and optimizing the design)
  - Sampling strategy for subsurface soils (includes defining study boundaries, developing a decision rule, specifying limits on decision errors, and optimizing the design)
  - Sampling to measure soil characteristics (bulk density, moisture content, porosity, soil texture, pH)
- Determine appropriate field methods and establish QA/QC protocols

Step Four: **Sample and Analyze Soils at Site**

- Identify radionuclides
- Delineate area and depth of sources and identify non-impacted areas as appropriate
- Determine soil characteristics
- Conduct preliminary data review
- Revise CSM, as appropriate

Step Five: **Derive Site-specific SSLs, if needed**

- Identify SSL equations for relevant pathways
- Obtain site-specific input parameters from CSM summary
- Replace variables in SSL equations with site-specific data gathered in Step 4
- Calculate SSLs
  - Account for exposure to multiple contaminants

Step Six: **Compare Site Soil Contaminant Concentrations to Calculated SSLs**

- Select appropriate statistical tests and verify test assumptions
- For surface soils, screen out exposure areas where all composite samples do not exceed SSLs by a factor of two
- For subsurface soils, screen out source areas where the highest average soil core concentration does not exceed the SSLs

Step Seven: **Decide How to Address Areas Identified for Further Study**

- Review and confirm the data that led to the decision
- Consider likelihood that additional areas can be screened out by collecting additional data
- Integrate soil data with other media in the baseline risk assessment to estimate cumulative risk at the site
- Determine the need for action
- Use SSLs as PRGs

2.1.3 Construct a Preliminary Diagram of the CSM. Once the existing site data have been organized and a basic understanding of the site has been attained, draw a preliminary "sketch" of the site conditions, highlighting source areas, potential exposure pathways, and receptors. Ultimately, when site investigations are complete, this sketch will be refined into a three-dimensional diagram that summarizes the data. Also, a brief summary of the contamination problem should accompany the CSM. Attachment A provides an example of a complete CSM summary.

2.1.4 Perform Site Reconnaissance. At this point, a site visit would be useful because conditions at the site may have changed since the PA/SI was performed (e.g., removal actions may have been taken). During site reconnaissance, update site sketches/topographic maps with the locations of buildings, source areas, wells, and sensitive environments. Anecdotal information from nearby residents or site workers may reveal undocumented disposal practices and thus previously unknown areas of contamination that may affect the current CSM interpretation.

Based on the new information gained from site reconnaissance, update the CSM as appropriate. Identify any remaining data gaps in the CSM so that these data needs can be incorporated into the Sampling and Analysis Plan (SAP).

2.2 Step 2: Comparing CSM to SSL Scenario

The Soil Screening Guidance for Radionuclides is likely to be appropriate for sites where residential land use is reasonably anticipated. However, the CSM may include other sources and exposure pathways that are not covered by this guidance. Compare the CSM with the assumptions and limitations inherent in the SSLs to determine whether additional or more detailed assessments are needed for any exposure pathways or radionuclides. Early identification of areas or conditions where SSLs are not applicable is important so that other characterization and response efforts can be considered when planning the sampling strategy.

2.2.1 Identify Pathways Present at the Site Addressed by Guidance. The following are potential pathways of exposure to radioactive soil contaminants in a residential setting and are addressed by this guidance document:

- Direct ingestion of soil
- Inhalation of fugitive dusts
- Ingestion of contaminated ground water caused by migration of radionuclides through soil to an underlying potable aquifer
- External radiation exposure from radionuclides in soil
- Ingestion of homegrown produce that has been contaminated via plant uptake

This guidance quantitatively addresses each of these pathways. Whether some or all of the pathways are relevant at the site depends upon the radionuclides and conditions at the site.

For **surface** soils under the residential land use assumption, the external exposure pathway will typically be the dominant exposure pathway for most radionuclides (e.g., ^{54}Mn, ^{60}Co, ^{137}Cs, etc.). For some radionuclides (e.g., ^{3}H, ^{99}Tc, ^{129}I, etc.), the ground water pathway often dominates, although not to the extent that the external exposure pathway does. The plant ingestion pathway and soil ingestion pathway also play a dominant role for a few radionuclides of interest (for plant ingestion - ^{14}C, ^{63}Ni, ^{90}Sr, etc.; for soil ingestion - ^{241}Am, ^{244}Cm, ^{230}Th, ^{232}Th, etc.). In the majority of cases, the inhalation of fugitive dust pathway plays an insignificant role.

For **subsurface** soils, risks from migration of radionuclides to an underlying aquifer is the only potential concern for this scenario. Volatilization is not included as a pathway since it is a concern for only a very limited number of radionuclides (such as ^{3}H and ^{14}C). The majority of all radionuclides are present in soil as nonvolatile ionic species or inorganic compounds (i.e., Henry's law constant is zero). Thus, volatilization and subsequent inhalation has not been included. If ^{3}H or ^{14}C volatilization is a concern, an approach similar to that in the Soil Screening Guidance for chemicals can be used to model the exposure. Consideration of the ground water pathway may be eliminated if ground water beneath or adjacent to the site is not a potential source of drinking water. Coordinate this decision on a site-specific basis with State or local authorities responsible for ground water use and classification. The rationale for excluding this exposure pathway should be consistent with EPA ground water policy (U.S. EPA, 1988a, 1990a, 1992a, 1992c, and 1993b).

In addition to the more common pathways of exposure in a residential setting, concerns have been raised regarding the potential for migration of radon from subsurface soils into basements. The dominant factor in indoor radon levels is home construction practices and the extent to which these practices employ radon-resistant techniques. Homes built atop soil with identical levels of radium can have orders of magnitude differences in indoor radon levels depending on the extent to which radon-resistant techniques are used. As NORM, radium is present in all soils. Reducing the radium content in the soil may not result in any reduction in indoor radon levels. However, taking simple and inexpensive steps in home construction will ensure that radon levels in homes are kept below ARAR levels. For existing homes with elevated levels of radon, a variety of methods can be used to reduce radon concentrations to ARAR levels. Discussion of radon mitigation standards may be found in several EPA publications, including *Radon Mitigation Standards*, EPA 402-R-93-078. Also note that potential soil Applicable or Relevant and Appropriate Requirements (ARARs) exist for radon under 192.12(b)(1) and 192.41(b). For further guidance on using these ARARs, see the August 1997 memorandum from Stephen Luftig (OERR) and Larry Weinstock (ORIA) titled "Establishment of cleanup levels for CERCLA sites with radioactive contamination," OSWER Directive 9200.4-18, (U.S. EPA, 1997c).

2.2.2 Identify Additional Pathways Present at the Site Not Addressed by Guidance.

The presence of additional pathways does not preclude the use of SSLs in site areas that are currently residential or likely to be residential in the future. However, the risks associated with these additional pathways should also be considered in the RI/FS to determine whether SSLs are adequately protective. Where the following conditions exist, a more detailed site-specific study should be performed:

- The site is **adjacent to bodies of surface water** where the potential for contamination of surface water by overland flow or release of contaminated ground water into surface water through seeps should be considered.
- There are potential terrestrial or aquatic **ecological concerns**.
- There are **other likely human exposure pathways** that were not considered in development of the SSLs (e.g., local fish consumption; raising of beef, dairy, or other livestock; recreational activities such as playground activities, hunting and fishing, construction activities).
- There are **unusual site conditions** such as large areas of contamination, unusually high fugitive dust levels due to soil being tilled for agricultural use, or heavy traffic on unpaved roads.
- There are **certain subsurface site conditions** such as karst, fractured rock aquifers, or contamination extending below the water table, that result in the screening models not being sufficiently conservative.
- There is the probability of prolonged skin contact with high levels of high energy beta-emitting contaminants for periods of time (several years), and all other pathways show a very low risk. The skin contact exposure pathway is normally several orders of magnitude lower than either the inhalation, ingestion, or external exposure pathway (depending on the radionuclide, see Section 2.2.1) due to very low risk coefficients and normal hygiene practices (washing skin routinely).

2.2.3 Compare Available Data to Background.

EPA may be concerned with two types of radioactivity background at sites: naturally-occurring and anthropogenic. Naturally-occurring background radiation is much more ubiquitous in the environment than naturally-occurring background chemicals.

Natural background radiation includes terrestrial radionuclides, cosmic radiation and cosmogenic radionuclides. Anthropogenic background consists of manmade isotopes which are distributed in the environment due primarily to releases from nuclear weapons testing and to the very small, but measurable releases from nuclear facilities.

A comparison of available data (e.g., State soil surveys or other sources of soil radioactivity analyses) on local background concentrations with generic SSLs may indicate whether background concentrations at the site are elevated. Generally, EPA does not cleanup below natural background levels; however, where anthropogenic background levels exceed SSLs and EPA has determined that a response action is necessary and feasible, EPA's goal will be to develop a comprehensive response to address area soils. This will often require coordination with different authorities that have jurisdiction over other sources of contamination in the area. This will help avoid response actions that create “clean islands” amid widespread contamination.

Knowledge of background radionuclide concentrations at the site is critical when screening site soils, since facility operations may have contaminated site soils with some of the same radionuclides that are found naturally-occurring in background soil. In many cases, the concentration of the radionuclide of concern in background soil, and the variability of the background soil concentration, may be much greater than the screening level. In these situations, the site manager should not exclude the radionuclide of potential concern from being evaluated in the risk assessment, as the contamination from the facility may pose a threat to human health and the environment. Risk management options for the radionuclides of concern will be evaluated in the CERCLA remedy selection process.

Note that potential soil ARARs exist for several of the more common naturally-occurring radionuclides (^{226}Ra, ^{228}Ra, ^{230}Th, ^{232}Th, ^{235}U, and ^{238}U) under 40 CFR Part 192.12(a), Part 192.32(b)(2), and Part 192.41, and 10 CFR Part 40 Appendix A, I, Criterion 6(6). For further guidance on using these ARARs, see OSWER Directive 9200.4-25 (U.S. EPA, 1998b), dated February 12, 1998 and OSWER Directive 9200.4-35P (U.S. EPA, 2000a), dated April 11, 2000.

2.3 Step 3: Defining Data Collection Needs for Soils

Once the CSM has been developed and the site manager has determined that the Soil Screening Guidance for Radionuclides is appropriate to use at a site, an Sampling and Analysis Plan (SAP) should be developed. Attachment A, the Conceptual Site Model Summary, lists the data needed to apply the Soil Screening Guidance for Radionuclides. The summary will help identify data gaps in the CSM that require collection of site-specific data. The soil SAP is likely to contain different sampling strategies that address:

- Surface soil
- Subsurface soil
- Soil characteristics

To develop sampling strategies that will properly assess site contamination, EPA recommends that site managers consult with the technical experts in their Region, including risk assessors, toxicologists, health physicists, chemists and hydrogeologists. These experts can assist the site manager to use the Data Quality Objectives (DQO) process to satisfy Superfund program objectives.

The DQO process is a systematic planning process developed by EPA to ensure that sufficient data are collected to support EPA decision making. Using the DQO Process ensures that the type, quantity, and quality of environmental data used in decision making will be appropriate for the intended medium. A full discussion of the DQO process is provided in *Data Quality Objectives for Superfund: Interim Final Guidance* (U.S. EPA, 1993a) and the *Guidance for the Data Quality Objectives Process* (U.S. EPA, 1994b). In addition, MARSSIM provides extensive discussions of the DQO Process as it is applied to conducting radiation site surveys.

Most key elements of the DQO process have already been incorporated as part of this Soil Screening Guidance for Radionuclides. Exhibit 5 shows the general components of the DQO process as it is applied to environmental data analysis. Detailed DQOs for the soil screening process are provided in Attachment B. Exhibit 6 expands upon step 4 of the DQO process, and provides additional guidance to define site study boundaries The remaining elements involve identifying the site-specific information needed to calculate SSLs. The following sections present an overview of the sampling strategies needed to use the Soil Screening Guidance for Radionuclides. For a more detailed discussion, see the supporting Soil Screening Guidance for Radionuclides: Technical Background Document (TBD).

2.3.1 Stratify the Site Based on Existing Data. At this point in the soil screening process, existing data can be used to stratify the site into three types of areas requiring different levels of investigation:

- Areas unlikely to be contaminated

- Areas known to be highly contaminated
- Areas that may be contaminated and cannot be ruled out.

Areas that are unlikely to be contaminated generally will not require further investigation if historical site use information or other site data, which are reasonably complete and accurate, confirm this assumption. These may be areas of the site that were completely undisturbed by activities at the facility.

A crude estimate of the degree of soil contamination can be made for other areas of the site by comparing site concentrations to the generic SSLs in Appendix A of the TBD. Generic SSLs have been calculated for 60 radionuclides using default values in the SSL equations, resulting in conservative values that will be protective for the majority of site conditions.

The pathway-specific generic SSLs can be compared with available concentration data from previous site investigations or removal actions to help divide the site into areas with similar levels of soil contamination and develop appropriate sampling strategies.

The surface soil sampling strategy discussed in this document is most appropriate for those areas that may be contaminated and can not be designated as uncontaminated. Areas which are known to be contaminated (based on existing data) will be investigated and characterized in the RI/FS.

2.3.2 Identify Exposure Areas. An **exposure area** (EA) is a physical area of a specified size and shape for which a separate decision will be made as to whether or not the area exceeds the screening criteria. To facilitate survey design and ensure that the number of survey data points for a specific site are relatively uniformly distributed among areas of similar contamination potential, the site is divided into EAs that share a common history or other characteristics, or are naturally distinguishable from other portions of the site (see Exhibit 6).

An EA should not include areas that have potentially different levels of contamination. The EA's characteristics should be generally consistent with the SSL exposure pathway modeling. EAs should be limited in size based on classification, exposure pathway modeling assumptions, and site-specific conditions. This guidance suggests an upper bound for the size of an EA is 2,000 m^2 (0.5-acre).

This limitation on EA size is intended to ensure that each area is assigned an adequate number of data points. Because the number of samples is independent of the EA size, limiting the size of an EA ensures that the default sample density does not exceed 333 m^2 per sample. This also serves to limit the sample spacing. The statistical basis for the default sample number is provided in Section 3.3.3.

2.3.3 Develop Sampling and Analysis Plan for Surface Soil. The surface soil sampling strategy is designed to collect the data needed to evaluate exposures via direct ingestion of soil, inhalation of fugitive dusts, external radiation exposure, ingestion of homegrown produce pathways, as well as migration of contaminants to groundwater.

The SAP developed for surface soils should specify sampling and analytical procedures as well as the development of QA/QC procedures. To identify the appropriate analytical procedures, the screening levels must be known. If data are not available to calculate site-specific SSLs (Section 2.5.1), then the generic SSLs in Appendix A of the TBD should be used.

The depth over which surface soils are sampled should reflect the CSM and the pathway assumptions that form the basis for the SSL determination. The residential setting used to develop the SSLs for each pathway assumes that: 1) there is no clean cover of soil; 2) the top few centimeters of soil are available for resuspension in air; 3) the top 15 cm of contaminated soil are homogenized by agricultural activities (e.g., plowing); 4) there is a sufficiently large area and depth of contamination to approximate an infinite slab source for external exposure purposes; 5) there is enough land for the residential garden to supply one-half of the residents' annual produce consumption; and, 6) while the plant root system grows to a depth of 1 meter, most plant nutrients are obtained from within the upper 20 cm of soil. Further discussion of the basis for these assumptions is provided in the appropriate pathway discussions in Section 2.5.1.

Note that the size, shape, and orientation of sampling volume (i.e., "support") for heterogenous media have a significant effect on reported measurement values.

Sample characteristics such as sample depth, volume, area, moisture level, and composition, as well as sample preparation techniques which may alter the sample, are important planning considerations for Data Quality Objectives. Comparison of data from methods that are based on different supports can be difficult. Defining the sampling support is important in the early stages of site characterization. This may be accomplished through the DQO process with existing knowledge of the site, contamination, and identification of the exposure pathways that need to be characterized. Refer to *Preparation of Soil Sampling Protocols: Sampling Techniques and Strategies* (U.S. EPA, 1992e) for more information about soil sampling support.

As explained in the *Supplemental Guidance to* RAGS: *Calculating the Concentration Term* (U.S. EPA, 1992d), an individual is assumed to move randomly across an **exposure area (EA)** over time, spending equivalent amounts of time in each location. Thus, the concentration contacted over time is best represented by the spatially averaged concentration over the EA. Ideally, the surface soil sampling strategy would determine the true population mean of radionuclide soil concentrations in an EA. Because determination of the "true" mean would require extensive sampling at high costs, the maximum radionuclide concentration from composite samples is used as a conservative estimate of the mean.

The number of samples required to satisfy the DQOs for the survey is then based on the selection of a statistical test, which in turn is based on whether or not the radionuclide of concern is present in background. For guidance when the radionuclide of concern is present in background, refer to the TBD.

Radionuclide Not Present in Background. For those radionuclides that are not generally present in background, measurement of background soil concentration is not necessary and radionuclide concentrations are compared directly with the screening level. With only a single set of EA samples, the statistical test used here is called a one-sample test. The one-sample test may also be used for those radionuclides that are present in background but are found only at a small fraction of the SSL. In this case, the background contribution is included in the radioactivity in the samples for the EA. Thus, the total concentration is compared to the screening level. This option should only be used if one expects that ignoring the background concentration will not affect the outcome of the statistical test. The advantage of ignoring a small background contribution is that a background reference area is not required and no background sampling is needed. This may simplify the soil screening process considerably.

Exhibit 5: Data Quality Objectives Process

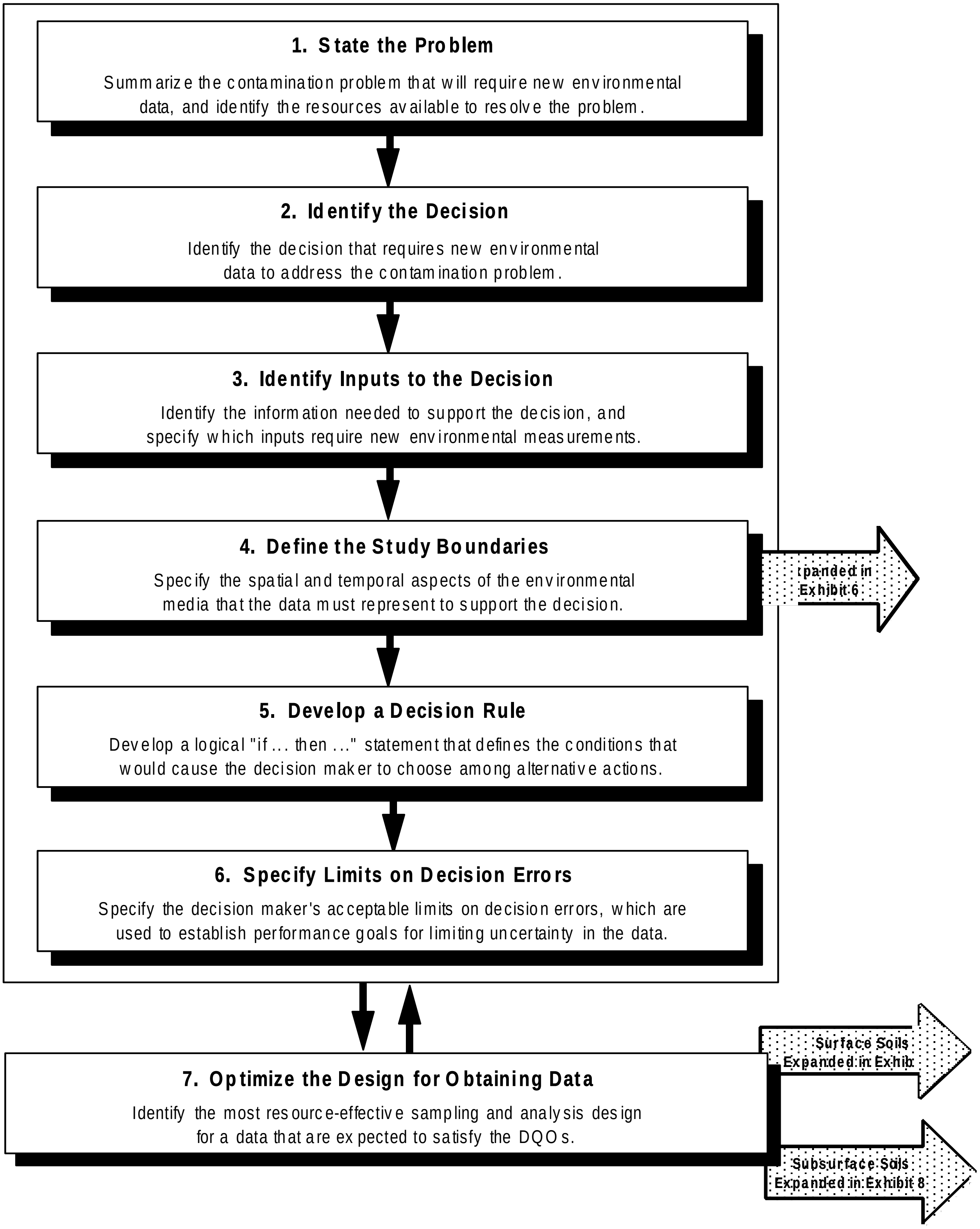
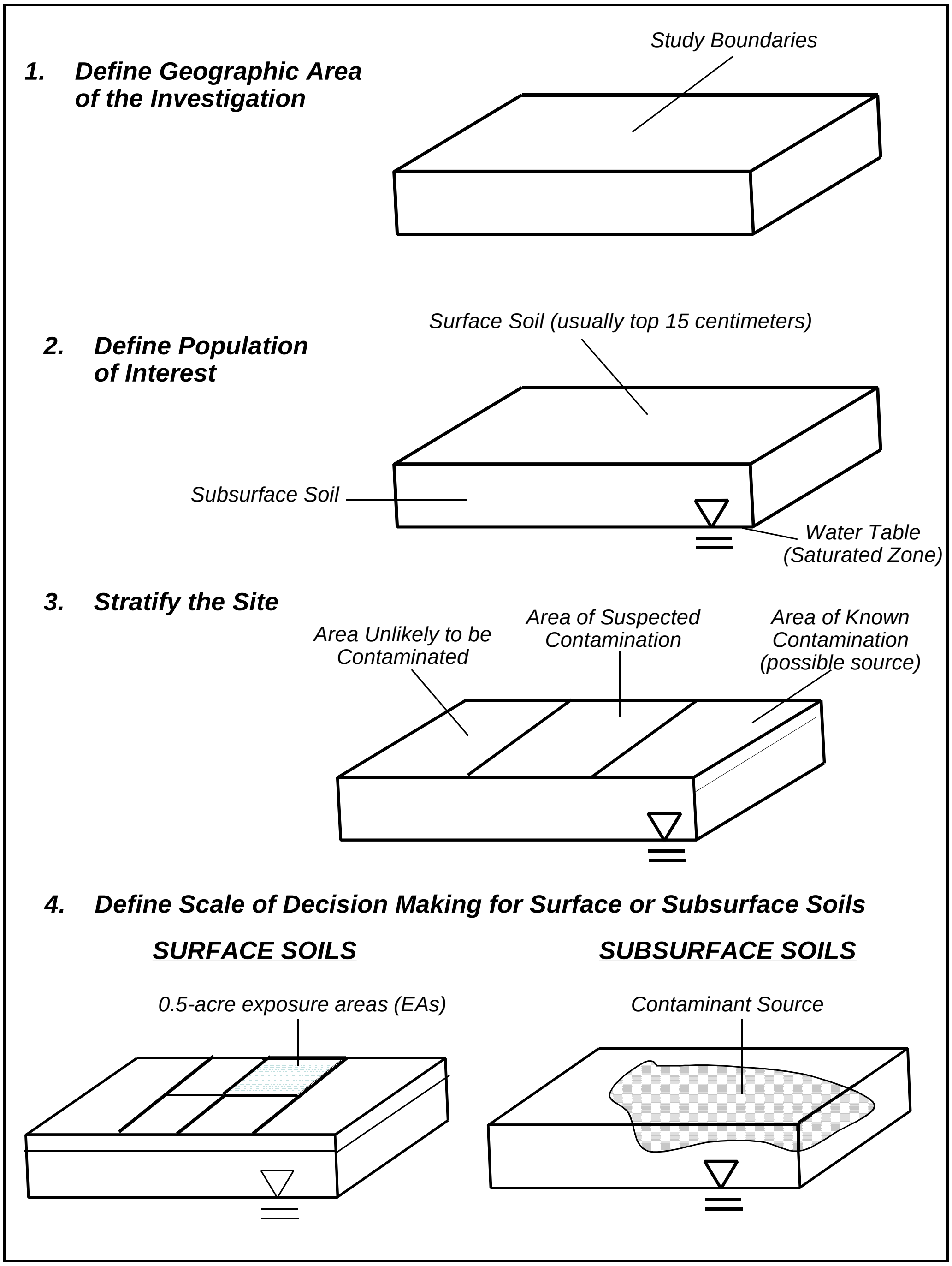


Exhibit 6: Defining the Study Boundaries



Back to Exhibit 5 Step 5, "Develop a Decision Rule"

The Max test, which is used when the radionuclide of concern is not generally present in background, is a simple decision rule comparing the maximum radionuclide concentrations of composite samples with soil screening levels. Another, more complex strategy called the Sign test is presented in Part 6 of the TBD. The User's Guide for Radionuclides uses the Max test rather than the Sign test to maintain consistency with the approach taken in the SSG for chemicals. While the Sign test is a more complex statistical method than the Max test, it is based on the same statistical null hypothesis (i.e., the EA requires further investigation). Some EAs that cannot be screened out with the Max test could be screened out with the Sign test since it uses a less conservative estimate of the mean concentration than does the Max test.

In addition to determining the mean concentration of a radionuclide in an EA, it is important to identify the presence of small areas of elevated activity. This is done by the performance of scanning surveys. The sensitivity of scanning surveys will be insufficient to detect small areas of elevated activity for most radionuclides with levels of contamination as low as those of the SSLs calculated for large areas of uniform contamination. However, standard scanning survey techniques may be able to detect SSLs calculated for smaller areas of contamination. Scan surveys are intended to provide a degree of confidence that any significant areas of elevated activity are identified. Therefore, scanning surveys should be performed for all EAs prior to sampling. The extent of the survey coverage should be dictated by the potential for small areas of elevated activity in the EA. EAs with a high potential for small areas of elevated activity should receive 100% coverage. In EAs with a very low potential for small areas of elevated activity, scanning surveys should be performed in at least 10% of the area. In such cases, the areas selected for scan should be those with highest potential based on professional judgement. Due to the limited sensitivity of scan surveys, any small areas of elevated activity found during the survey should be identified for further investigation (i.e., not screened out).

Exhibit 7 provides a summary of SAP design considerations for EAs when the radionuclides of concern for surface soils are not present in background. The following strategy can be used for **surface soils** to estimate the mean concentration of radionuclides in an EA when the radionuclide of concern is not present in background.

- Divide areas to be sampled in the screening process into 0.5-acre exposure areas, the size of a suburban residential lot. If the site is currently residential, the exposure area should be the actual residential lot size. The exposure areas should not be laid out in such a way that they unnecessarily combine areas of high and low levels of contamination. The orientation and exact location of the EA, relative to the distribution of the contaminant in the soil, can lead to instances where sampling the EA may have contaminant concentration results above the mean, and in other instances, results below the mean.

- Composite surface soil samples. Because the objective of surface soil screening is to estimate the mean contaminant concentration, the physical "averaging" that occurs during compositing is consistent with the intended use of the data. Compositing allows sampling of a larger number of locations while controlling analytical costs, since several individual samples are physically mixed (homogenized) and one or more subsamples are drawn from the mixture and submitted for analysis.

- Strive to achieve a Type I (false negative) error rate of 5 percent (i.e., in only 5 percent of the cases, soil contamination is assumed to be below the screening level when it is really above the screening level). EPA also strives to achieve a 20 percent Type II (false positive) error rate (i.e., in only 20 percent of the cases, soil contamination is assumed to be above the screening level when it is really below the screening level). These error rate goals influence the number of samples to be collected in each exposure area. For this guidance, EPA has defined the "gray region" as one-half to 2 times the SSL. Thus, the width of the gray region, also known as the shift, Δ, is equal to 1.5 times the SSL. Refer to Section 2.6 for further discussion.

- The default sample size chosen for this guidance (see Exhibit 7) provides adequate coverage for a coefficient of variation (CV) based upon 250 percent variability in contaminant values (CV=2.5). (If a CV larger than 2.5 is expected, use an appropriate sample size from the table in Exhibit 7 of the User's Guide, or tables in the TBD.)

- Take six composite samples for each exposure area with each composite sample made up of four individual samples. Exhibit 7 shows other sample sizes needed to achieve the decision error rates for other CVs. Collect the composites randomly across the EA and through the top 15 centimeters of soil, which are of greatest concern for the external exposure and consumption of homegrown produce pathways.

- Analyze the six samples per exposure area to determine the radionuclides present and their concentrations.

For further information on compositing across or within EA sectors, developing a random sampling strategy, and determining sample sizes that control decision error rates, refer to the TBD.

Note that the Max test requires a Data Quality Assessment (DQA) test following sampling and analysis (Section 2.4.2) to ensure that the DQOs (i.e., decision error rate goals) are achieved. If DQOs are not met, additional sampling may be required.

2.3.4 Develop Sampling and Analysis Plan for Subsurface Soils. The subsurface and surface soil sampling strategies differ because the exposure mechanisms differ. Exposure to surface contaminants occurs as individuals move around a residential lot. The surface soil sampling strategy reflects this type of exposure.

In general, exposure to subsurface contamination occurs when radionuclides migrate down to an underlying aquifer. Thus, subsurface sampling focuses on collecting the data required for modeling the migration to ground water pathway. Measurements of soil characteristics and estimates of the area and depth of contamination and the average contaminant concentration in each source area are needed to supply the data necessary to calculate the migration to ground water SSLs.

Source areas are the decision units for subsurface soils. A source area is defined by the horizontal extent, and vertical extent or depth of contamination. **Sites with multiple sources should develop separate SSLs for each source.**

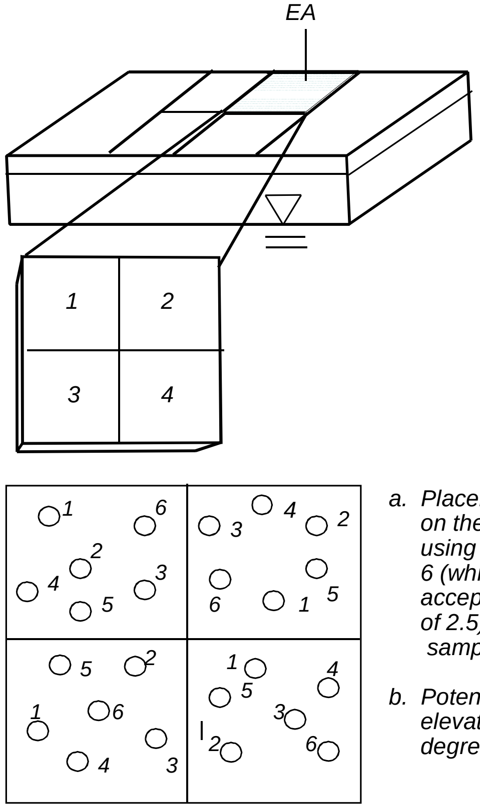
The SAP developed for subsurface soils should specify sampling and analytical procedures as well as the development of QA/QC procedures. To identify the appropriate procedures, the SSLs must be known. If data are not available to calculate site-specific SSLs (Section 2.5.2), the generic SSLs in Appendix A of the TBD should be used.

The primary goal of the subsurface sampling strategy is to estimate the mean radionuclide concentration and average soil characteristics within the source area. As with the surface soil sampling strategy, the subsurface soil sampling strategy follows the DQO process (see Exhibits 5, 6, and 8). Exhibit 8 provides a summary of SAP design considerations for subsurface soils. If the radionuclide of concern is not present in background, the decision rule is based on comparing the mean radionuclide concentration within each contaminant source with source-specific SSLs.

Current investigative techniques and statistical methods cannot accurately determine the mean concentration of subsurface soils within a contaminated source without a costly and intensive sampling program that is well beyond the level of effort generally appropriate for screening. Thus, conservative assumptions should be used to develop hypotheses on likely contaminant distributions.

Exhibit 7: Designing a Sampling and Analysis Plan for Surface Soils

Radionuclide Not Present in Background



1. Subdivide Site Into EAs

For surface soils, the individual unit for decision making is an "EA," or exposure area. It measures 0.5 acre in area or less.

2. Divide EA Into a Grid

This step defines the number of specimens (N) that will make up one composite sample.

3. Organize Surface Sampling Program for EA

a. Placement of sample locations on the grid was developed using a default sample size of 6 (which is based on acceptable error rates for a CV of 2.5) and a stratified random sampling pattern.

b. Potential for small areas of elevated activity determines degree of scan coverage.

If the EA CV is suspected to be greater than 2.5, use the table below to select an adequate sample size or refer to the TBD for other sample design options.

Probability of Decision Error at 0.5 SSL and 2 SSL Using Max Test

Sample Size[b]	**CV=2.5[a]**		CV=3.0		CV=3.5		CV=4.0	
	$E_{0.5}$[c]	$E_{2.0}$[d]	$E_{0.5}$	$E_{2.0}$	$E_{0.5}$	$E_{2.0}$	$E_{0.5}$	$E_{2.0}$
	C = 4 specimens per composite[e]							
6	**0.21**	**0.08**	0.28	0.11	0.31	0.11	0.35	0.16
7	0.25	0.05	0.31	0.08	0.36	0.09	0.41	0.15
8	0.25	0.04	0.36	0.05	0.42	0.07	0.41	0.09
9	0.28	0.03	0.36	0.04	0.44	0.07	0.48	0.08

a The CV is the coefficient of variation for individual, uncomposited measurements across the entire EA, including measurement error.
b Sample size (N) = number of composite samples
c $E_{0.5}$ = Probability of requiring further investigation when the EA mean is 0.5 SSL
d $E_{2.0}$ = Probability of not requiring further investigation when the EA mean is 2.0 SSL
e C = number of specimens per composite sample, when each composite consists of points from a stratified random or systemic grid sample from across the entire EA.

NOTE: All decision error rates are based on 1,000 simulations that assume that each composite is representative of the entire EA, half the EA has concentrations below the limit of detection, and half the EA has concentrations that follow a gamma distribution (a conservative distributional assumption).

This guidance bases the decision to investigate a source area further on the highest mean soil boring contaminant concentration within the source, reflecting the conservative assumption that the highest mean subsurface soil boring concentration among a set of borings taken from the source area represents the mean of the entire source area. Similarly, estimates of contaminant depths should be conservative. The investigation should include the maximum depth of contamination encountered within the source without going below the water table.

For each source, the guidance recommends taking 2 or 3 soil borings located in the areas suspected of having the highest contaminant concentrations within the source. These subsurface soil sampling locations are based primarily on knowledge of likely surface soil contamination patterns (see Exhibit 6) and subsurface conditions. However, buried sources may not be discernible at the surface. Information on past practices at the site included in the CSM can help identify subsurface source areas.

Take soil cores from the soil boring using either split spoon sampling or other appropriate sampling methods. *Description and Sampling of Contaminated Soils: A Field Pocket Guide* (U.S. EPA, 1991f), and *Subsurface Characterization and Monitoring Techniques: A Desk Reference Guide, Vol. I & II* (U.S. EPA, 1993e), can be consulted for information on appropriate subsurface sampling methods. For radioactive contaminants, core samples may also be obtained and monitored intact in the field to determine if layers of radioactivity are present. In addition, the use of a subsurface sampling technique, which results in a borehole or soil face, may be "logged" using a gamma scintillation detector. This enables scanning of the exposed soil surface to identify radioactive contamination within small fractions of hole depth, thus facilitating the identification of the presence and depth distribution of subsurface radioactivity. This information may be used to direct further core sampling and laboratory analysis as warranted.

Sampling should begin at the ground surface and continue until either no contamination is encountered or the water table is reached. **Subsurface sampling intervals can be adjusted at a site to accommodate site-specific information on subsurface contaminant distributions and geological conditions** (e.g., very deep water table, very thick uncontaminated unsaturated zone, user well far beyond edge of site, soils underlain by karst or fractured rock aquifers). Sample splits and subsampling should be performed according to *Preparation of Soil Sampling Protocols: Sampling Techniques and Strategies* (U.S. EPA, 1992e).

If each subsurface soil core segment represents the same subsurface soil interval (e.g., 2 feet), the average concentration from the surface to the depth of contamination is the simple arithmetic average of contaminant concentrations measured for core samples representative of each of the 2-foot segments from the surface to the depth of contamination. However, if the sample intervals are not all of the same length (e.g., some are 2 feet while others are 1 foot or 6 inches), the calculation of the average concentration in the total core must account for the different lengths of the segments.

If c_i is the concentration measure in a core sample, representative of a core interval or segment of length l_i, and the n-th segment is considered to be the last segment sampled in the core (i.e., the n-th segment is at the depth of contamination), the average concentration in the core from the surface to the depth of contamination should be calculated as the following depth-weighted average ($\bar{c}$).

Alternatively, the average boring concentration can be determined by adding the total contaminant activities together (from the sample results) for all sample segments to get the total contaminant activity for the boring. The total contaminant activity is then divided by the total dry weight of the core (as determined by the dry bulk density measurements) to estimate average soil boring concentration.

Finally, the soil investigation for the migration to ground water pathway should not be conducted independently of ground water investigations. Contaminated ground water may indicate the presence of a nearby source area that would leach contaminants from soil into aquifer systems.

2.3.5 Develop Sampling and Analysis Plan to Determine Soil Characteristics. The soil parameters necessary for SSL calculations are soil texture, dry bulk density, and pH. Although laboratory measurements of these parameters cannot be obtained under Superfund's Contract Laboratory Program (CLP), independent soil testing laboratories across the country can perform these tests at a relatively low cost.

To appropriately apply the migration-to-ground water models, average or typical soil properties should be used for a source in the SSL equations (see Step 5). Take samples for measuring soil parameters with samples for measuring contaminant concentrations. If possible, consider splitting single samples for contaminant and soil parameter measurements. A number of soil testing laboratories can handle and test radioactive samples. However, if testing contaminated samples for soil parameters is a problem, samples may be obtained from clean areas of the site as long as they represent the same soil texture and are taken from approximately the same depth as the contaminant concentration samples.

Soil Texture. Soil texture class (e.g., loam, sand, silt loam) is necessary to estimate average soil moisture conditions and to apply the Hydrological Evaluation of Landfill Performance (HELP) model to estimate infiltration rates (see Attachment A). The appropriate texture classification is determined by a particle size analysis and the U.S. Department of Agriculture (USDA) soil textural triangle shown in Exhibit 9. This classification system is based on the USDA soil particle size classification.

The particle size analysis method in Gee and Bauder (1986) can provide this particle size distribution. Other methods are appropriate as long as they provide the same particle size breakpoints for sand/silt (0.05 mm) and silt/clay (0.002 mm). Field methods are an alternative for determining soil textural class. Exhibit 9 presents an example from Brady (1990).

Dry Bulk Density. Dry soil bulk density (ρ_b) is used to calculate total soil porosity and can be determined for any soil horizon by weighing a thin-walled tube soil sample (e.g., Shelby tube) of known volume and subtracting the tube weight [American Society for Testing and Materials (ASTM) D 2937]. Determine moisture content (ASTM 2216) on a subsample of the tube sample to adjust field bulk density to dry bulk density. The other methods (e.g., ASTM D 1556, D 2167, D 2922) are generally applicable only to surface soil horizons and are not appropriate for subsurface characterization. ASTM soil testing methods are readily available in the *Annual Book of ASTM Standards, Volume 4.08, Soil and Rock; Building Stones*, available from ASTM, 100 Barr Harbor Drive, West Conshohocken, PA, 19428.

pH. Soil pH is used to select site-specific partition coefficients. This simple measurement is made with a pH meter in a soil/water slurry (McLean, 1982) and may be measured in the field using a portable pH meter.

2.3.6 Determine Analytical Methods and Establish QA/QC Protocols. Assemble a list of feasible sampling and analytical survey methods during this step.

Routinely, radiological soil surveys are conducted using a mix of three types of radiation measurement methods: 1) scans, 2) direct measurements, and 3) sampling and laboratory analysis. Based on the potential radionuclide contaminants and their associated radiations, the detection sensitivities of various instruments and techniques are determined and documented. Methods must not only be chosen based on their reliability and suitability to the physical and environmental conditions at the site, but they must be capable of detecting the radionuclides of concern to the appropriate minimum detectable concentration (MDC). During survey design, it is generally considered good practice to select a measurement system with an MDC between 10-50% of the SSL.

For soil screening purposes, most SSLs for radionuclides are too low to be detected using scans and direct measurements. Therefore, sampling and laboratory analysis must be the primary means of soil screening for the majority of radionuclides. Once the survey design and sampling methods are selected, appropriate standard operating procedures (SOPs) should be developed and documented. Both sample depth and area are considerations in determining appropriate sample volume, and sample volume is a key consideration for determining the laboratory MDC. The depth should also correlate with the CSM developed for the site.

Field methods will be useful in defining the study boundaries (i.e., area and depth of contamination) during both site reconnaissance and sampling. The design and capabilities of field portable instrumentation are rapidly evolving. Documents describing the standard operating procedures for field instruments are available though the National Technical Information Service (NTIS).

Additionally, MARSSIM provides further information on field (Chapter 6) and laboratory (Chapter 7) measurement methods and instrumentation for radionuclides. Appendix H of MARSSIM describes typical field and laboratory equipment plus associated cost and instrument sensitivities. MARSSIM also discusses the concept of detection sensitivity and provides guidance on determining sensitivities and selecting appropriate measurement methods.

SAP quality control may be thought of in three parts: 1) determining the type of QC samples needed to detect precision or bias; 2) determining the number of samples as part of the survey design; and 3) scheduling sample collections throughout the survey process to identify and control sources of error and uncertainties.

Because a great amount of variability and bias can exist in the collection, subsampling, and analysis of soil samples, some effort should be made to characterize this variability and bias. *A Rationale for the Assessment of Errors in the Sampling of Soils* (U.S. EPA, 1990c) outlines an approach that advocates the use of a suite of QA/QC samples to assess variability and bias. Field duplicates and splits are some of the best indicators of overall variability in the sampling and analytical processes. At least 10 percent of both the discrete samples and the composites should be split and sent to a laboratory for confirmatory analysis. (*Quality Assurance for Superfund Environmental Data Collection Activities,* U.S. EPA, 1993c).

Regardless of whether surface or subsurface soils are sampled, the Superfund quality assurance program guidance (U.S. EPA, 1993c) should be consulted. In addition, *Specifications and Guidelines for Quality Systems for Environmental Data Collection and Environmental Technology Program* (ANSI/ASCQ, 1994) describes a basic set of specifications and guidelines by which a quality system for programs involving environmental data collection and environmental technology can be planned, implemented, and assessed. Standard limits on the precision and bias of sampling and analytical operations conducted during sampling do apply and should be followed to give consistent and defensible results.

2.4 Step 4: Sampling and Analyzing Site Soils & DQA

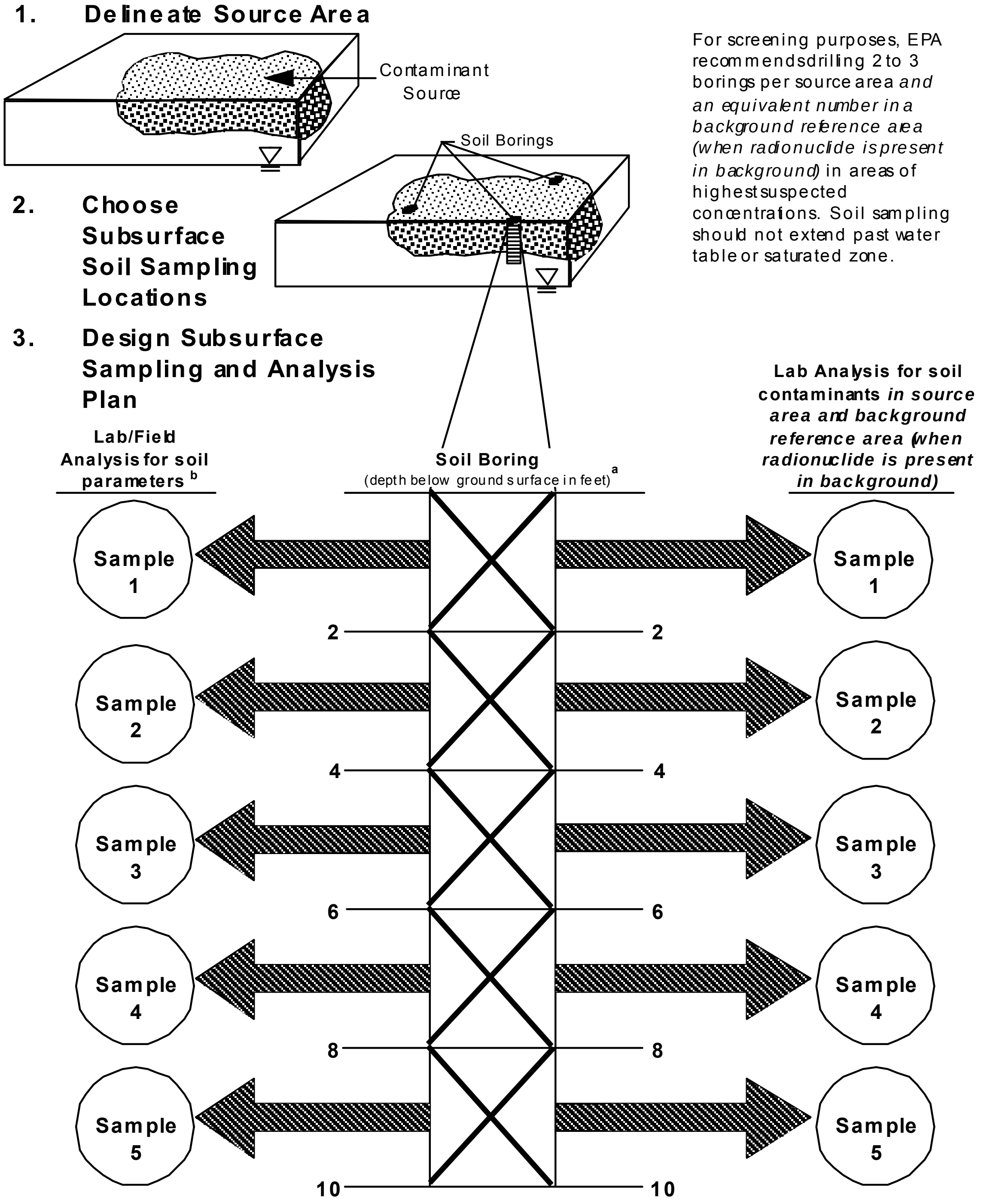
Once the sampling strategies have been developed and implemented, the samples should be analyzed according to the analytical laboratory and field methods specified in the SAP. Results of the analyses should identify the concentrations of potential radionuclides of concern for which site-specific SSLs will be calculated.

2.4.1 Delineate Area and Depth of Source. Both spatial area and depth data, as well as soil characteristic data, are needed to calculate site-specific SSLs for the external exposure and migration to ground water pathways. Site information from the CSM or prior surveys can be used to estimate the areal extent of the sources.

2.4.2 Perform DQA Using Sample Results. Data Quality Assessment (DQA) is a scientific and statistical evaluation that determines if the data are of the right type, quality, and quantity to support their intended use. The nature of the DQA is dependent upon whether the radionuclide of concern is present in background. For guidance for performing DQA when the radionuclide of concern is present in background, refer to the TBD. The following is a discussion of DQA for radionuclides not present in background.

Radionuclide Not Present in Background. After sampling has been completed, a DQA should be conducted if all composite samples are less than 2 times the SSL. This is necessary to determine if the original CV estimate (2.5), and hence the number of samples collected (6), was adequate for screening surface soils.

Exhibit 8: Designing a Sampling and Analysis Plan for <u>Subsurface</u> Soils Radionuclide Not Present in Background



1. Delineate Source Area

For screening purposes, EPA recommends drilling 2 to 3 borings per source area *and an equivalent number in a background reference area (when radionuclide is present in background)* in areas of highest suspected concentrations. Soil sampling should not extend past water table or saturated zone.

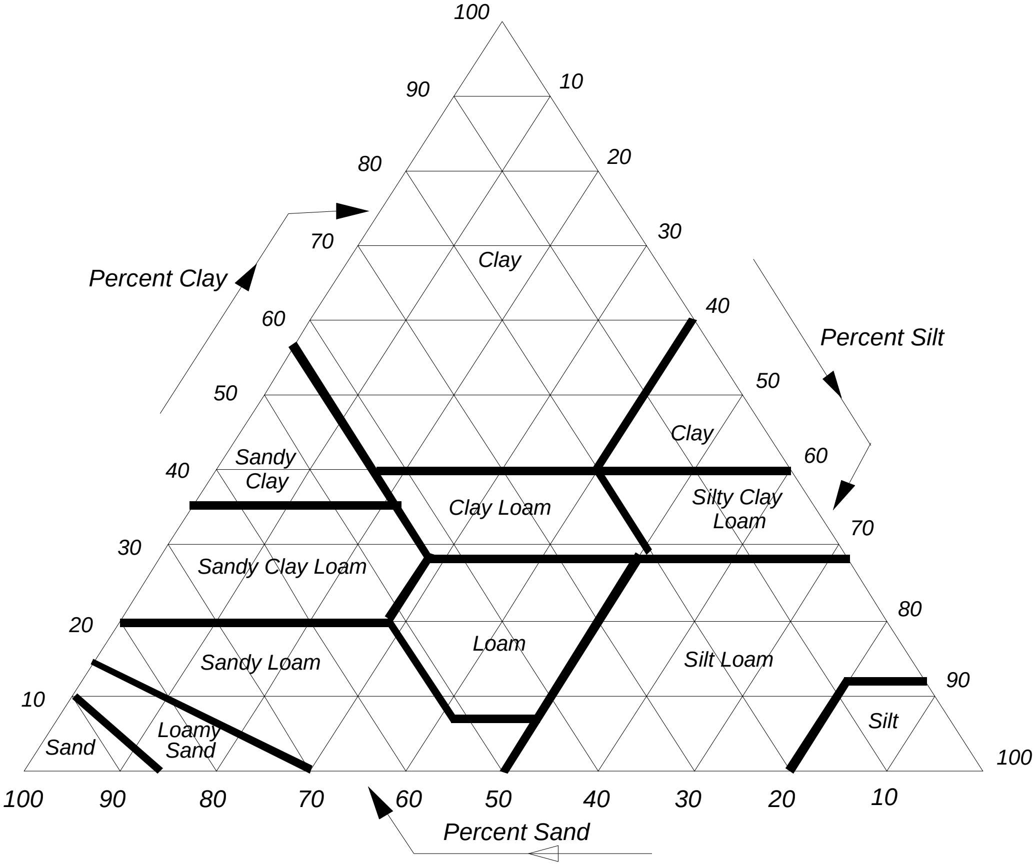
2. Choose Subsurface Soil Sampling Locations

3. Design Subsurface Sampling and Analysis Plan

[a] Picture depicts a continuous boring with 2 foot segments. For information on other methods such as interval sampling and depth weighted analysis, please refer to 2.3.3 of the User's Guide or 4.2 of the TBD.

[b] Soil Texture, Dry Bulk Density, Soil Organic Carbon *Moisture Content*, pH. Retain samples for possible discrete contaminant sampling.

Exhibit 9: U.S. Department of Agriculture soil texture classification



Criteria Used with the Field Method for Determining Soil Texture Classes *(Source: Brady, 1990)*

Criterion	***Sand***	***Sandy loam***	***Loam***	***Silt loam***	***Clay loam***	***Clay***
1. Individual grains visible to eye	*Yes*	*Yes*	*Some*	*Few*	*No*	*No*
2. Stability of dry clods	*Do not form*	*Do not form*	*Easily broken*	*Moderately easily broken*	*Hard and stable*	*Very hard and stable*
3. Stability of wet clods	*Unstable*	*Slightly stable*	*Moderately stable*	*Stable*	*Very stable*	*Very stable*
4. Stability of "ribbon" when wet soil rubbed between thumb and fingers	*Does not form*	*Does not form*	*Does not form*	*Broken appearance*	*Thin, will break*	*Very long, flexible*

Particle Size, mm

0.002 0.05 0.10 0.25 0.5 1.0 2.0

			Very Fine	*Fine*	*Med.*	*Coarse*	*Very Coarse*	
U.S. Department of Agriculture	*Clay*	*Silt*	*Sand*					*Gravel*

Source: USDA.

To conduct the DQA for a composite sample whose mean is below 2 SSL, first calculate the sample CV for the EA in question from the sample mean ($\bar{x}$), the number of specimens per composite sample (C), and sample standard deviation(s) as follows:

$$CV = \frac{\sqrt{C} * s}{\bar{x}} \ .$$

Use the sample size table in Exhibit 7 to check, for this CV, whether the sample size is adequate to meet the DQOs for the sampling effort. If sampling DQOs are not met, supplementary sampling may be needed to achieve DQOs.

However, for EAs with small sample means (e.g., all composites are less than the SSL), the sample CV calculated using the equation above may not be a reliable estimate of the population CV (i.e., as $\bar{x}$ approaches zero, the sample CV will approach infinity). To protect against unnecessary additional sampling in such cases, compare all composites against the formula SSL$\div\sqrt{C}$. If the maximum composite sample concentration is below the value given by the equation, then the sample size may be assumed to be adequate and no further DQA is necessary. In other words, EPA believes that the default sample size will adequately support walk-away decisions when all composites are well below the SSL. The TBD describes the development of this formula and provides additional information on implementing the DQA process.

2.4.3 Revise the CSM. Because these analyses reveal new information about the site, update the CSM accordingly. This revision could include identification of site areas that exceed the generic SSLs.

2.5 Step 5: Calculating Site-specific SSLs

With the soil properties data collected in Step 4 of the screening process, site-specific soil screening levels can now be calculated using the equations presented in this section. For a description of how these equations were developed, as well as background on their assumptions and limitations, consult the TBD.

In the SSG for chemicals, SSLs are expressed in mass units of mg/kg (i.e., mg of chemical per kg of soil). The concentrations of radioactive material in soil could also be expressed in units of mass. Instead, they are expressed in the traditional radiological units of pCi/g (i.e., picograms of activity per gram of soil). These units reflect the number of atoms of the isotope undergoing radioactive transformation (referred to as radioactive decay) per unit time. For more information concerning activity and mass, refer to appendix B of the TBD.

All SSL equations were developed to be consistent with RME in the residential setting. The Superfund program estimates the RME for chronic exposures on a site-specific basis by combining an average exposure-point concentration with reasonably conservative values for intake and duration (U.S. EPA, 1989a; RAGS HHEM, *Supplemental Guidance: Standard Default Exposure Factors*, U.S. EPA, 1991a, *Exposure Factors Handbook*, U.S. EPA, 1997a). Thus, all site-specific parameters (soil, aquifer, and meteorologic parameters) used to calculate SSLs should reflect average or typical site conditions in order to calculate average exposure concentrations at the site.

Equations for calculating SSLs are presented for surface and subsurface soils in the following sections. **For each equation, site-specific input parameters are highlighted in bold and default values are provided for use when site-specific data are not available.** Although these defaults are not worst case, they are conservative. At most sites, higher, but still protective SSLs can be calculated using site-specific data. The TBD describes development of these default values and presents generic SSLs calculated using the default values.

Attachment D provides toxicity criteria for 60 radionuclides commonly found at NPL sites. These criteria were obtained from the Health Effects Assessment Summary Tables (HEAST), which is regularly updated. **Prior to calculating SSLs at a site, check all relevant - radionuclide-specific values in Attachment D against values from HEAST at the following internet webpage** http://www.epa.gov/superfund/programs/risk/calctool.htm**. Only the most current values should be used to calculate SSLs.**

Where toxicity values have been updated, the generic SSLs should also be recalculated with current toxicity information.

2.5.1 SSL Equations--Surface Soils.

Exposure pathways addressed in the process for screening surface soils include direct ingestion of soil, inhalation of fugitive dusts, ingestion of contaminated ground water, external radiation exposure, and ingestion of homegrown produce.

Direct Ingestion of Soil. The Soil Screening Guidance for Radionuclides addresses chronic exposure to radionuclides through direct ingestion of contaminated soil in a residential setting.

A number of studies have shown that inadvertent ingestion of soil is common among children age 6 and younger (Calabrese et al., 1989; Davis et al., 1990: Van Wijnen et al., 1990). In some cases, children may ingest large amounts of soil (i.e., 3 to 5 grams) in a single event. This behavior, known as pica, may result in relatively high short-term exposures to radionuclides in soil.

Default values are used for all input parameters in the direct ingestion equations. The amount of data required to derive site-specific values for these parameters (e.g., soil ingestion rates, chemical-specific bioavailability) makes their collection and use impracticable for screening. Therefore, site-specific data are not generally available for this exposure route. The generic ingestion SSLs presented in Appendix A of the TBD are recommended for all NPL sites.

However, for radionuclides, both the magnitude and duration of exposure are important. Duration is critical because the toxicity criteria are based on "lifetime average daily dose." Therefore, the total intake, whether it be over 5 years or 50 years, is averaged over a lifetime of 70 years. To be protective of exposures to radionuclides in the residential setting, Superfund focuses on exposures to individuals who may live in the same residence for a high-end period of time (e.g., 30 years) because exposure to soil is higher during childhood and decreases with age. Equation 1 uses a time-weighted average soil ingestion rate for children and adults. The derivation of this time-weighted average is presented in U.S. EPA, 1991c.

Equation 1: Screening Level Equation for Ingestion of Radionuclides in Residential Soil

$$SSL_{soil\ ing} = \frac{TR}{SF \times IR \times 1x10^{-3} \times EF \times ED}$$

Parameter/Definition (units)	Default
TR/target cancer risk (unitless)	10^{-6}
SF_s/soil ingestion slope factor $(pCi)^{-1}$	See Attachment D
IR_s/soil ingestion rate (mg/d)	120 (age-averaged)
$1x10^{-3}$/conversion factor (g/mg)	--
EF/exposure frequency (d/yr)	350
ED/exposure duration (yr)	30

Inhalation of Fugitive Dusts. Inhalation of fugitive dusts is a consideration in surface soils.

Equation 2 is used to calculate fugitive dust SSLs for radionuclides. This equation requires calculation of a particulate emission factor (PEF, Equation 3) that relates the concentration of contaminant in soil to the concentration of dust particles in air. This PEF 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.

Both the emissions portion and the dispersion portion (Q/C) of the PEF equation have been updated since the first publication of RAGS HHEM, Part B, in 1991. As in Part B, the emissions part of the PEF equation is based on the "unlimited reservoir" model developed to estimate particulate emissions due to wind erosion (Cowherd et al., 1985). The box model in RAGS HHEM, Part B has been replaced with a Q/C term derived from the modeling exercise using the AREA-ST model incorporated into EPA's Industrial Source Complex Model (ISC2) platform. The AREA-ST model was run with a full year of meteorological data for 29 U.S. locations selected to be representative of a range of meteorologic conditions across the nation (EQ, 1993). The results of these modeling runs are presented in Exhibit 10 for square area sources of 0.5 to 30 acres in size.

When developing a site-specific PEF for the inhalation pathway, place the site into a climatic zone (see Attachment B). Then select a Q/C value from Exhibit 10 that best represents a site's size and meteorological conditions.

Additional information on the update of the PEF equation is provided in the TBD. Cowherd et al. (1985) present methods for site-specific measurement of the parameters necessary to calculate a PEF.

The default PEF for radionuclides presented in Equation 2 is the same as the one given in the SSG for chemicals. The default parameter values shown in Equation 3 have been chosen using the guidance of Cowherd et al. (1985), based upon the assumption of a family garden. The calculated PEF thus accounts for the increase in the fugitive dust concentration anticipated with an area of tilled soils.

Equation 2: Screening Level Equation for Inhalation of Radioactive Fugitive Dusts from Residential Soil

$$SSL_{dust} = \frac{TR}{SF_i \times IR_i \times (\frac{1}{PEF}) \times 1x10^{+3} \times EF \times ED \times [ET_o + (ET_i \times DF_i)]}$$

Parameter/Definition (units)	Default
TR/target cancer risk (unitless)	10^{-6}
SF_i /inhalation slope factor (pCi^{-1})	See Attachment D
IR_i /inhalation rate (m^3/d)	20
PEF/particulate emission factor (m^3/kg)	**$1.32x10^{+9}$ (Equation 3)**
$1x10^{+3}$/conversion factor (g/kg)	--
EF/exposure frequency (d/yr)	350
ED/exposure duration (yr)	30
ET_o/exposure time fraction, outdoor (unitless)	0.073
ET_i/exposure time fraction, indoor (unitless)	0.683
DF_i/dilution factor for indoor inhalation, (unitless)	0.4

Equation 3: Derivation of the Particulate Emission Factor

$$PEF = Q/C \times \frac{3600}{0.036 \times (1 - V) \times (U_m/U_t)^3 \times F(x)}$$

Parameter/Definition (units)	Default
PEF/particulate emission factor (m^3/kg)	$1.32x10^{+9}$
Q/C/inverse of mean conc. at center of a 0.5-acre-square source (g/m^2-s per kg/m^3)	**90.80**
V/fraction of vegetative cover (unitless)	**0.5 (50%)**
U_m /mean annual windspeed (m/s)	**4.69**
U_t /equivalent threshold value of windspeed at 7 m (m/s)	**11.32**
F(x)/function dependent on U_m/U_t derived using Cowherd et al. (1985) (unitless)	**0.194**

Exhibit 10 . Q/C Values by Source Area, City, and Climatic Zone

	Q/C (g/m^2-s per kg/m^3)					
	0.5 Acre	**1 Acre**	**2 Acre**	**5 Acre**	**10 Acre**	**30 Acre**
Zone I						
Seattle	82.72	72.62	64.38	55.66	50.09	42.86
Salem	73.44	64.42	57.09	49.33	44.37	37.94
Zone II						
Fresno	62.00	54.37	48.16	41.57	37.36	31.90
Los Angeles	68.81	60.24	53.30	45.93	41.24	35.15
San Francisco	89.51	78.51	69.55	60.03	53.95	46.03
Zone III						
Las Vegas	95.55	83.87	74.38	64.32	57.90	49.56
Phoenix	64.04	56.07	49.59	42.72	38.35	32.68
Albuquerque	84.18	73.82	65.40	56.47	50.77	43.37
Zone IV						
Boise	69.41	60.88	53.94	46.57	41.87	35.75
Winnemucca	69.23	60.67	53.72	46.35	41.65	35.55
Salt Lake City	78.09	68.47	60.66	52.37	47.08	40.20
Casper	100.13	87.87	77.91	67.34	60.59	51.80
Denver	75.59	66.27	58.68	50.64	45.52	38.87
Zone V						
Bismark	83.39	73.07	64.71	55.82	50.16	42.79
Minneapolis	90.80	79.68	70.64	61.03	54.90	46.92
Lincoln	81.64	71.47	63.22	54.47	48.89	41.65
Zone VI						
Little Rock	73.63	64.51	57.10	49.23	44.19	37.64
Houston	79.25	69.47	61.53	53.11	47.74	40.76
Atlanta	77.08	67.56	59.83	51.62	46.37	39.54
Charleston	74.89	65.65	58.13	50.17	45.08	38.48
Raleigh-Durham	77.26	67.75	60.01	51.78	46.51	39.64
Zone VII						
Chicago	97.78	85.81	76.08	65.75	59.16	50.60
Cleveland	83.22	73.06	64.78	55.99	50.38	43.08
Huntington	53.89	47.24	41.83	36.10	32.43	27.67
Harrisburg	81.90	71.87	63.72	55.07	49.56	42.40
Zone VIII						
Portland	74.23	65.01	57.52	49.57	44.49	37.88
Hartford	71.35	62.55	55.40	47.83	43.00	36.73
Philadelphia	90.24	79.14	70.14	60.59	54.50	46.59
Zone IX						
Miami	85.61	74.97	66.33	57.17	51.33	43.74

External Exposure to Radionuclides in Soil. An individual residing on a contaminated site will be exposed to radiation emitted by radionuclides present in the soil. In modeling external exposure to contaminated soil, the RAGS/HHEM Part B model (U.S. EPA, 1991c) does not account for the following processes:

- radioactive decay and progeny (i.e., radioactive daughters) ingrowth;
- correction factors for the geometry of the contaminated soil;
- depletion of the contaminated soil horizon by environmental processes, such as leaching, erosion, or plant uptake; and
- corrections for shielding by clean cover material.

The RAGS/HHEM Part B model does not provide any corrections for radioactive decay. When ingrowth of progeny is expected to be of importance, the progeny are included at the outset of the SSL calculations.

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.

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 SSLs.

No soil depletion processes are assumed to take place. Accordingly, the SSL model assumes that the contaminated zone is a constant, non-depleting source of radioactivity. This assumption provides an upper bound estimate of exposure to radionuclides in soil.

For the purposes of this report, adjustments for clean cover are not needed since, in all cases, it is assumed that the contaminated soil extends to the surface. The SSL model provides adjustments for indoor occupancy and associated shielding effects by the simple application of a gamma shielding factor and indoor occupancy time adjustment.

Equation 4: Screening Level Equation for External Exposure to Radionuclides in Soil

$$SSL_{EXT} = \frac{TR}{SF_e \times (\frac{EF}{365}) \times ED \times ACF \times [ET_o + (ET_i \times GSF)]}$$

Parameter/Definition (units)	**Default**
TR/target cancer risk (unitless)	10^{-6}
SF_e /external exposure slope factor	See Attachment D
(g/pCi/yr)	350
EF/exposure frequency (d/yr)	30
ED/exposure duration (yr)	**0.9**
ACF/area correction factor	0.073
ET_o/exposure time fraction, outdoor (unitless)	0.683
ET_i/exposure time fraction, indoor (unitless)	0.4
GSF/gamma shielding factor	

With the exception of the area correction factor, default values are used for all input parameters in Equation 4 to calculate external exposure SSLs. The amount of data required to derive site-specific values for these parameters makes their collection and use impracticable for calculation of simple site-specific SSLs. Therefore, site-specific data are generally not available for this exposure pathway. Alternative area correction factors, for use when site-specific data are available, are discussed in the TBD. The generic SSLs presented in Appendix A of the TBD are recommended for all sites.

Ingestion of Homegrown Produce. Persons living on a contaminated site may ingest radioactive material by consumption of plants grown in a family garden. In this model, the fruits and vegetables primarily become contaminated by root uptake of radionuclides contained in the pore water of the soil in which the plants are growing.

The following factors have been added/changed for exposure through this pathway for radionuclides as compared to chemicals:

- soil-plant transfer factors used to estimate root uptake from soil assume that the roots are wholly exposed to contaminated soil;

- air deposition, rain splash, and irrigation are not included;
- environmental equilibria assumed to exist for estimating concentrations of ^{3}H and ^{14}C in plants; and
- no more than 50% of produce is assumed to be homegrown (i.e., contaminated plant fraction ≤ 0.5), with adjustment for small site areas (i.e., <2,000 m^2).

The model accounts for that uptake with a simple soil-to-plant transfer factor. These soil-to-plant transfer factors have been developed based upon the assumption that the entire plant root system is wholly exposed to contaminated soil.

If the plant roots extend to a depth of 100 cm but the radionuclide contaminants are confined to the upper 15 cm, an initial assumption may be that only 15% of the root system is active in accumulating contaminants and that the reported soil-to-plant transfer factors should be reduced by a correction factor of 0.15. However, the equation for calculation of SSLs for this pathway does not apply any reduction to the soil-to-plant transfer factors. The basis for this assumption is as follows.

Most plant root systems are in fact very active in the upper soil horizon, especially in the upper 15 cm of soil. This point is illustrated in a number of ways: 1) by illustrations of root morphology and growth habit, 2) positive physiological factors including the availability of water, oxygen and nutrients near the soil surface, 3) negative physiological or agronomic factors—including subsurface soil compaction, subsurface zones of acidity, perched water tables, hypoxia, etc., 4) interactions with soil microbes—with a special focus on mychorrizal fungi, and 5) split root studies. Thus, roots commonly proliferate in the upper layers of soil. If one assumes that a plant is actively growing, then ion uptake characteristics and lateral root growth strongly suggest that simply attributing 15% of root uptake activity to the upper 15 cm of the soil is not a sound approach. Environmental forces may influence root growth to one or more meters in depth, but more so for obtaining water than nutrients. In reality, the upper 15 cm of soil may include 50% or more of the root system—and thus 50% or more of the ion uptake (SC&A, 1994).

The decision to not include air deposition or rain-splash does not affect any radionuclides because the increase in concentration from this route is not significant or is markedly reduced when peeling, washing, cooking, and other food preparation processes are taken into consideration (U.S. EPA, 1994d). The decision to not include the irrigation pathway is only an issue when there is medium to heavy irrigation using contaminated water for a radionuclide with a long half-life, a low K_d value, and an insignificant contribution from external exposure. The model also makes a conservative assumption to ignore the decay between harvest and ingestion and any removal during food processing.

The model does not include any special calculations for estimating concentrations of ^{3}H and ^{14}C in plants. Such calculations assume that a state of equilibrium exists among the concentrations of ^{3}H and ^{14}C in all environmental media—air, water, food products, and body tissues. This assumption may be overly conservative for a radioactively contaminated site with a finite area, but may be appropriate for an individual pathway, such as soil-to-plant pathway. For these calculations, the ^{3}H concentration in the plant is assumed to be the same as that in the contaminated water to which the plant is exposed. Similarly, the specific activity of ^{14}C in the plant (i.e., pCi/g of ^{14}C per gram of carbon in the plant) is the same as that of the ambient CO_2.

The model provides a factor, the Contaminated Plant Fraction (CPF), to adjust for the fraction of fruits and vegetables obtained from the contaminated site (assuming that the family living on the site obtains a portion of their fruits and vegetables from uncontaminated sources). The ingestion rate used in the calculation thus represents a total ingestion rate, which, when multiplied by the CPF, gives the ingestion rate of contaminated fruits and vegetables.

The CPF is dependent upon the surface area of the contaminated zone in m^2, A_s, and is calculated using the following equation.

$$CPF = A_s / 4{,}000 \quad 0 \leq A_s \leq 2{,}000\ m^2$$

$$CPF = 0.5 \qquad A_s > 2{,}000\ m^2$$

For an area greater than 2,000 m^2 (i.e., the default contaminated site surface area), the CPF is set at an upper bound of 0.5 (i.e., site residents acquire no more than one-half of their fruits and vegetables from onsite).

The factor decreases linearly as the size of the contaminated area decreases below 2,000 m^2 (one-half acre).

Equation 5: Screening Level Equation for Ingestion of Radionuclides in Homegrown Produce

$$SSL = \frac{TR}{SF_p \times (IR_{vf} + IR_{lv}) \times 1x10^{+3} \times CPF \times TF_p \times ED}$$

Parameter/Definition (units)	Default
TR/target cancer risk (unitless)	10^{-6}
SF_p/produce ingestion slope factor $(pCi)^{-1}$	See Attachment D
IR_{vf}/vegetable and fruit ingestion rate (kg/yr)	42.7
IR_{lv}/leafy vegetables ingestion rate (kg/yr)	4.66
$1x10^{+3}$/conversion factor (g/kg)	--
CPF/contaminated plant fraction from the site (unitless)	**0.5**
TF_p/soil-to-plant transfer factor (pCi/g plant per pCi/g soil)	See Attachment C
ED/exposure duration (yr)	30

Default values are used for all input parameters in Equation 5 to calculate SSLs for this pathway. With the exception of the contaminated site surface area, A_s, the amount of data required to derive site-specific values for these parameters makes their collection and use impracticable for calculation of simple site-specific SSLs. Therefore, site-specific data are generally not available for this exposure pathway. The generic SSLs presented in the TBD are recommended for all sites, except for very small sites with $A_s < 2,000$ m^2 (i.e., < 0.5 acre).

2.5.2 SSL Equations--Subsurface Soils. The Soil Screening Guidance for Radionuclides addresses only one exposure pathway for subsurface soils: ingestion of ground water contaminated by the migration of contaminants through soil to an underlying potable aquifer. Because the equations developed to calculate SSLs for these pathways assume an infinite source, they can violate mass-balance considerations, especially for small sources.

To address this concern, the guidance also includes equations for calculating mass-limit SSLs for this pathway **when the size (i.e., area and depth) of the contaminated soil source is known or can be estimated with confidence.**

Attachment D provides the toxicity criteria and regulatory benchmarks for 60 radionuclides commonly found at NPL sites. These criteria were obtained from HEAST (U.S. EPA, 1995a), and *Drinking Water Regulations and Health Advisories* (U.S. EPA, 1995c), which are regularly updated. **Prior to calculating SSLs at a site, all relevant radionuclide-specific values in Attachment D should be checked against the most recent version of their sources to ensure that they are up to date.**

Site-specific parameters necessary to calculate SSLs for subsurface soils are listed on Exhibit 11, along with recommended sources and measurement methods. In addition to the soil parameters described in Step 3, other site-specific input parameters include soil moisture, infiltration rate, and aquifer parameters. Guidance for collecting or estimating these other parameters at a site is provided on Exhibit 11 and in Attachment A.

Exhibit 11. Site-specific Parameters for Calculating Subsurface SSLs

Parameter	SSL Pathway		Data source	Method
		Migration to ground water		
Source Characteristics				
Source area (A)	●		Sampling data	Measure total area of contaminated soil
Source length (L)		●	Sampling data	Measure length of source parallel to ground water flow
Source depth	●	●	Sampling data	Measure depth of contamination or use conservative assumption
Soil Characteristics				
Soil texture		❍	Lab measurement	Particle size analysis (Gee & Bauder, 1986) and USDA classification; used to estimate θ_w & I
Dry soil bulk density (ρ_b)		❍	Field measurement	All soils: ASTM D 2937; shallow soils: ASTM D 1556, ASTM D 2167, ASTM D 2922
Soil moisture content (w)		❍	Lab measurement	ASTM D 2216; used to estimate dry soil bulk density
Soil pH	❍	❍	Field measurement	McLean (1982); used to select pH-specific K_d (metals)
Moisture retention exponent (b)		❍	Look-up	Attachment A; used to calculate θ_w
Saturated hydraulic conductivity (K_s)		❍	Look-up	Attachment A; used to calculate θ_w
Avg. soil moisture content (θ_w)	●	❍	Calculated	Attachment A
Meteorological Data				
Air dispersion factor (Q/C)			Q/C table (Table 5)	Select value corresponding to source area, climatic zone, and city with conditions similar to site
Hydrogeologic Characteristics (DAF)				
Hydrogeologic setting		❍	Conceptual site model	Place site in hydrogeologic setting from Aller et al. (1987) for estimation of parameters below (see Attachment A)
Infiltration/recharge (I)		●	HELP model; Regional estimates	HELP (Schroeder et al., 1984) may be used for site-specific infiltration estimates; recharge estimates also may be taken from Aller et al. (1987) or may be estimated from knowledge of local meteorologic and hydrogeologic conditions
Hydraulic conductivity (K)		●	Field measurement; Regional estimates	Aquifer tests (i.e., pump tests, slug tests) preferred; estimates also may be taken from Aller et al. (1987) or Newell et al. (1990) or may be estimated from knowledge of local hydrogeologic conditions
Hydraulic gradient (i)		●	Field measurement; Regional estimates	Measured on map of site's water table (preferred); estimates also may be taken from Newell et al. (1990) or may be estimated from knowledge of local hydrogeologic conditions
Aquifer thickness (d)		●	Field measurement; Regional estimates	Site-specific measurement (i.e., from soil boring logs) preferred; estimates also may be taken from Newell et al. (1990) or may be estimated from knowledge of local hydrogeologic conditions

● Indicates parameters used in the SSL equations.
❍ Indicates parameters/assumptions needed to estimate SSL equation parameters.

Migration to Ground Water SSLs. The Soil Screening Guidance for Radionuclides uses a simple linear equilibrium soil/water partition equation or a leach test to estimate contaminant release in soil leachate. It also uses a simple water-balance equation to calculate a dilution factor to account for reduction of soil leachate concentration from mixing in an aquifer.

The methodology for developing SSLs for the migration to ground water pathway was designed for use during the early stages of a site evaluation when information about subsurface conditions may be limited. Hence, the methodology is based on rather conservative, simplified assumptions about the release and transport of contaminants in the subsurface (Exhibit 12). These assumptions are inherent in the SSL equations and should be reviewed for consistency with the conceptual site model (see Step 2) to determine the applicability of SSLs to the migration to ground water pathway.

To calculate SSLs for the migration to ground water pathway, multiply the acceptable ground water concentration by the dilution factor to obtain a target soil leachate concentration. For example, if the dilution factor is 10 and the acceptable ground water concentration is 10 pCi/L, the target soil/water leachate concentration would be 100 pCi/L. Next, the partition equation is used to calculate the total soil concentration (i.e., SSL) corresponding to this soil leachate concentration. Alternatively, if a leach test is used, compare the target soil leachate concentration to extract concentrations from the leach tests.

Soil/Water Partition Equation. The soil/water partition equation (Equation 6) relates concentrations of contaminants adsorbed to soil organic carbon to soil leachate concentrations in the zone of contamination. It calculates SSLs corresponding to target soil leachate contaminant concentrations (C_w). An adjustment has been added to the equation to relate sorbed concentration in soil to the measured total soil concentration. This adjustment assumes that soil-water and solids are conserved during sampling.

Exhibit 12: Simplifying Assumptions for the SSL Migration to Ground Water Pathway

- The source is infinite (i.e., steady-state concentrations will be maintained in ground water over the exposure period of interest)
- Contaminants are uniformly distributed throughout the zone of contamination
- Soil contamination extends from the surface to the water table (i.e., adsorption sites are filled in the unsaturated zone beneath the area of contamination
- There is no chemical or biological degradation in the unsaturated zone
- Equations in this document do not account for decay, however an electronic version of these equations will account for decay in the unsaturated zone
- Equilibrium soil/water partitioning is instantaneous and linear in the contaminated soil
- The receptor well is at the edge of the source (i.e., there is no dilution from recharge downgradient of the site) and is screened within the plume
- The aquifer is unconsolidated and unconfined (surficial)
- Aquifer properties are homogenous and isotropic
- Chelating or complexing agents not present
- No facilitated transport (e.g., colloidal transport of inorganic contaminants in aquifer

The use of the soil/water partition equation to calculate SSLs assumes an infinite source (steady-state) of contaminants that extend to the water table. More detailed models may be used to calculate higher SSLs that are still protective in some situations. For example, contaminants at sites with shallow sources, thick unsaturated zones, degradable contaminants, or unsaturated zone characteristics (e.g., clay layers) may attenuate before they reach ground water. Part 3 of the TBD provides information on the use of unsaturated zone models for soil screening. The decision to use such models should be based on balancing the additional investigative and modeling costs required to apply the more complex models against the cost savings that will result from higher SSLs.

Equation 6 : Soil Screening Level Partitioning Equation for Migration to Ground Water

$$SSL = C_w \times 1x10^{-3} \times (K_d + \frac{\theta_w}{\rho_b})$$

Parameter/Definition (units)	Default
SSL/ Screening Level in Soil (pCi/g)	
C_w/target soil leachate concentration (pCi/L)	MCL [a] x dilution factor
$1x10^{-3}$/conversion factor (kg/g)	--
K_d/soil-water partition coefficient (L/kg)	chemical specific
θ_w/water-filled soil porosity (L_{water}/L_{soil})	**0.3**
n/soil porosity (L_{pore}/L_{soil})	$1-(\rho_b/\rho_s)$
ρ_b/dry soil bulk density (kg/L)	**1.5**
ρ_s/soil particle density (kg/L)	2.65

[a] Radionuclide -specific (see Attachment D).

[b] See Attachment C.

Leach Test. A leach test may be used instead of the soil/water partition equation. If a leach test is used, compare the target soil leachate concentration (MCL x Dilution Factor) to extract concentrations from the leach tests. In some instances, a leach test may be more useful than the partitioning method, depending on the constituents of concern and the possible presence of RCRA wastes. If this option is chosen, soil parameters are not needed for this pathway. However, a dilution factor must still be calculated. This guidance suggests using the EPA Synthetic Precipitation Leaching Procedure (SPLP, EPA SW-846 Method 1312, U.S. EPA, 1994e). The SPLP was developed to model an acid rain leaching environment and is generally appropriate for a contaminated soil scenario. Like most leach tests, the SPLP may not be appropriate for all situations (e.g., soils contaminated with oily constituents may not yield suitable results). Therefore, apply the SPLP with discretion.

EPA is aware that many leach tests are available for application at hazardous waste sites, some of which may be appropriate in specific situations (e.g., the Toxicity Characteristic Leaching Procedure (TCLP) models leaching in a municipal landfill environment). It is beyond the scope of this document to discuss in detail leaching procedures and the appropriateness of their use. *Stabilization/Solidification of CERCLA and RCRA Wastes* (U.S. EPA, 1989b) and the EPA SAB's review of leaching tests (U.S. EPA, 1991c) discuss the application of various leach tests to various waste disposal scenarios. Consult these documents for further information.

See Step 3 for guidance on collecting subsurface soil samples that can be used for leach tests. To ensure adequate precision of leach test results, leach tests should be conducted in triplicate.

Dilution Factor Model. As soil leachate moves through soil and ground water, contaminant concentrations are attenuated by adsorption and degradation. In the aquifer, dilution by clean ground water further reduces concentrations before contaminants reach receptor points (i.e., drinking water wells). This reduction in concentration can be expressed by a dilution attenuation factor (DAF), defined as the ratio of soil leachate concentration to receptor point concentration. The lowest possible DAF is 1, corresponding to the situation where there is no dilution or attenuation of a contaminant (i.e., when the concentration in the receptor well is equal to the soil leachate concentration). On the other hand, high DAF values correspond to a large reduction in contaminant concentration from the contaminated soil to the receptor well.

The Soil Screening Guidance for Radionuclides addresses only one of these dilution-attenuation processes: contaminant dilution in ground water. A simple mixing zone equation derived from a water-balance relationship (Equation 7) is used to calculate a site-specific dilution factor. Mixing-zone depth is estimated from Equation 8, which relates it to aquifer thickness along with the other parameters from Equation 7. Mixing zone depth should not exceed aquifer thickness (i.e., use aquifer thickness as the upper limit for mixing zone depth).

Because of the uncertainty resulting from the wide variability in subsurface conditions that affect contaminant migration in ground water, defaults are not provided for the dilution model equations. Instead, a default DAF of 20 has been selected as protective for contaminated soil sources up to 0.5 acre in size. Analyses using the mass-limit models described in the SSG for chemicals suggest that a DAF of 20 may be protective of larger sources as well; however, this hypothesis should be evaluated on a site-specific basis. A discussion of the basis for the default DAF and a description of the mass-limit analysis is found in Part 2.6.4 of the TBD. However, since migration to ground water SSLs are most sensitive to the DAF, site-specific dilution factors should be calculated.

Equation 7: Derivation of Dilution Factor

$$DF_w = 1 + \frac{K \times i \times d}{I \times L}$$

Parameter/Definition (units)	Default
DF_w/dilution factor (unitless)	**20 (0.5-acre source)**
K/aquifer hydraulic conductivity (m/yr)	
i/hydraulic gradient (m/m)	
I/infiltration rate (m/yr)	
d/mixing zone depth (m)	
L/source length parallel to ground water flow (m)	

Equation 8: Estimation of Mixing Zone Depth

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

Parameter/Definition (units)
d/mixing zone depth (m)
L/source length parallel to ground water flow (m)
I/infiltration rate (m/yr)
K/aquifer hydraulic conductivity (m/yr)
i/hydraulic gradient (m/m)
d_a/aquifer thickness (m)

Mass-Limit SSLs. Use of infinite source models to estimate migration to ground water can violate mass balance considerations, especially for small sources. To address this concern, the Soil Screening Guidance includes models for calculating mass-limit SSLs for this pathways (Equation 9) that provide a lower limit to SSLs **when the area and depth (i.e., volume) of the source are known or can be estimated reliably.**

A mass-limit SSL represents the level of radionuclide in the subsurface that is still protective when the entire volume of contamination leaches over the 30 year exposure duration and the level of radionuclide at the receptor does not exceed the health-based limit.

To use mass-limit SSLs, determine the area and depth of the source, calculate both standard and mass-limit SSLs, compare them for each radionuclide of concern and select the higher of the two values.

Note that Equation 9 requires a site-specific determination of the average depth of contamination in the source. Step 3 provides guidance for conducting subsurface sampling to determine source depth. Where the actual average depth of contamination is uncertain, a conservative estimate should be used (e.g., the maximum possible depth in the unsaturated zone). At many sites, the average water table depth may be used unless there is reason to believe that contamination extends below the water table. In this case SSLs do not apply and further investigation of the source in question is needed.

Equation 9: Mass-Limit Soil Screening Level for Migration to Ground Water

$$SSL = \frac{C_w \times I \times ED \times 1x10^{-3}}{\rho_b \times d_s}$$

Parameter/Definition (units)	Default
SSL/ Soil Screening Level in Soil (pCi/g)	
C_w/target soil leachate concentration (pCi/L)	(MCL,)[a] * dilution factor
I/infiltration rate (m/yr)	**site-specific**
ED/exposure duration (yr)	70
$1x10^{-3}$/conversion factor (kg/g)	--
ρ_b/dry soil bulk density (kg/L)	**1.5**
d_s/depth of source (m)	**site-specific**

[a] Radionuclide -specific, see Attachment D.

2.5.3 Address Exposure to Multiple Radionuclides.

The SSLs generally correspond to a 10^{-6} lifetime cancer risk level. The potential for additive effects has not been "built in" to the SSLs through apportionment. While the pathways included in the analysis are considered to represent those a residential setting, SSLs are not calculated for a specific scenario (i.e., SSLs are not summed over a set of pathways). For radionuclides, EPA believes that setting a 10^{-6} risk level for individual radionuclides and pathways generally will lead to cumulative site risks within the 10^{-4} to 10^{-6} risk range for the combinations of radionuclides typically found at NPL sites.

SSLs and the Use of Surrogate Measurements. For sites with multiple radionuclides, it may be possible to measure just one of the radionuclides and still be able to demonstrate compliance (with the target risk level of 10^{-6}) for the radionuclides present through the use of surrogate measurements. Both time and resources can be saved if the analysis of one radionuclide is simpler than the analysis of the other. For example, using the measured ^{137}Cs concentration as a surrogate for ^{90}Sr reduces the analytical costs because the wet chemistry separations do not have to be performed for ^{90}Sr on every sample. In using one radionuclide to estimate the presence of others, a sufficient number of measurements, spatially separated throughout the EA, should be made to establish a consistent ratio. The number of measurements needed to determine the ratio is selected using the DQO process and based on the chemical, physical, and radiological characteristics of the nuclides and the site.

The potential for shifts or variations in the radionuclide ratios means that the surrogate method should be used with caution. Physical or chemical differences between the radionuclides may produce different migration rates, causing the radionuclides to separate and changing the radionuclide ratios. Remediation activities have a reasonable potential to alter the surrogate ratio established prior to remediation. When the ratio is established prior to remediation, additional post-remediation samples should be collected to ensure that the data used to establish the ratio are still appropriate and representative of the existing site condition. If these additional post-remediation samples are not consistent with the pre-remediation data, surrogate ratios should be re-established.

2.6 Step 6: Comparing Site Soil Radionuclide Concentrations to Calculated SSLs

Now that the site-specific SSLs have been calculated for the potential radionuclides of concern, compare them with the site radionuclide concentrations. At this point, it is reasonable to review the CSM with the actual site data to confirm its accuracy and the overall applicability of the Soil Screening Guidance for Radionuclides.

In theory, an exposure area would be screened from further investigation when the true mean of the population of radionuclide concentrations falls below the established screening level. However, EPA recognizes that data obtained from sampling and analysis are never perfectly representative and accurate, and that the cost of trying to achieve perfect results would be quite high. Consequently, EPA acknowledges that some uncertainty in data must be tolerated, and focuses on controlling the uncertainty which affects decisions based on those data. Thus, in the Soil Screening Guidance for Radionuclides, EPA has developed an approach for surface soils to minimize the chance of incorrectly deciding to:

- Screen out areas when the correct decision would be to investigate further (Type I error); or
- Decide to investigate further when the correct decision would be to screen out the area (Type II error).

The approach sets limits on the probabilities of making such decision errors, and acknowledges that there is a range (i.e., gray region) of radionuclide concentrations around the screening level where the variability in the data will make it difficult to determine whether the exposure area average concentration is actually above or below the screening level. The Type I and Type II decision error rates have been set at 5 percent and 20 percent, respectively, and the gray region has been set between one-half and two times the SSL. By specifying the upper edge of the gray region as twice the SSL, it is possible that exposure areas with mean radionuclide concentration values slightly above the SSL may be screened from further study.

2.6.1 Evaluation of Data for Surface Soils.

Thus, for surface soils, the radionuclide concentrations in each composite sample from an exposure area are compared to two times the SSL. Under the Soil Screening Guidance DQOs, areas are screened out from further study when radionuclide concentrations in all of the composite samples are less than two times the SSLs. Use of this decision rule (comparing radionuclide concentrations to twice the SSL) is appropriate only when the quantity and quality of data are comparable to the levels discussed in this guidance.

For existing data sets that may be more limited than those discussed in this guidance, the 95 percent upper-confidence limit on the arithmetic mean of the radionuclide concentrations in surface soils (i.e., the Land method as described in the *Supplemental Guidance to* RAGS*: Calculating the Concentration Term* (U.S. EPA, 1992c) should be compared to the SSL. If the 95 percentile on the arithmetic mean is less than the SSL, the exposure area may be screened out.

The TBD discusses the strengths and weaknesses of using the Land method for making screening decisions. As an alternative to the Max test, the TBD provides guidance on performing the Sign test when the contaminant is not present in background.

2.6.2 Evaluation of Data for Subsurface Soils. In this guidance, fewer samples are collected for subsurface soils than for surface soils; therefore, different decision rules apply.

Since subsurface soils are not characterized as well as surface soils, there is less confidence that the concentrations measured are representative of the entire source. Thus, a more conservative approach to screening is warranted. Because it may not be protective to allow for comparison to values above the SSL, mean radionuclide concentrations from each soil boring taken in a source area are compared with the calculated SSLs. Source areas with any mean soil boring radionuclide concentration greater than the SSLs generally warrant further consideration. On the other hand, where the mean soil boring radionuclide concentrations within a source are all less than the SSLs, that source area is generally screened out.

2.7 Step 7: Addressing Areas Identified for Further Study

The radionuclides, exposure pathways, and areas that have been identified for further study become a subject of the RI/FS. The results of the baseline risk assessment conducted as part of the RI/FS will establish the basis for taking remedial action. The threshold for taking action differs from the criteria used for screening. As outlined in *Role of the Baseline Risk Assessment in Superfund Remedy Selection Decisions* (U.S. EPA, 1991d), remedial action at NPL sites is generally warranted where cumulative risks for current or future land use exceed $1x10^{-4}$. The data collected for soil screening are useful in the RI and baseline risk assessment. However, additional data will probably need to be collected during future site investigations.

Once the decision has been made to initiate remedial action, the SSLs can then serve as preliminary remediation goals. This process is referenced in Section 1.2 of this document.

FOR FURTHER INFORMATION

More detailed discussions of the technical background and assumptions supporting the development of the Soil Screening Guidance are presented in the *Soil Screening Guidance for Radionuclides*: *Technical Background Document* (U.S. EPA, 1999). For additional copies of this guidance document, the Technical Background Document, or other EPA documents, call the National Technical Information Service (NTIS) at (703) 605-6000 or 1-800-553-NTIS (6847). Copies may also be downloaded from the internet at:
http://www.epa.gov/superfund/resources/radiation/radrisk.htm.

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Attachment A

Conceptual Site Model Summary

Attachment A

Conceptual Site Model Summary

Step 1 of the Soil Screening Guidance for Radionuclides: User’s Guide describes the development of a conceptual site model (CSM) to support the application of soil screening levels (SSLs) at a site. The CSM summary forms at the end of this attachment contain the information necessary to:

- Determine the applicability of SSLs to the site
- Calculate SSLs.

By identifying data gaps, these summary forms will help focus data collection and evaluation on the site-specific development and application of SSLs. The site investigator should use the summary forms during the SSL sampling effort to collect site-specific data and continually update the CSM with new information as appropriate.

The CSM summary forms indicate the information required for determining the applicability of the soil screening process to the site. Forms addressing source characteristics may be photocopied if more than one source is present at a site.

A site map showing contaminated soil sources and exposure areas (EAs) should be attached to the summary. If available, additional pages of other maps, summaries of analytical results, or more detailed descriptions of the site may be attached to the summary.

Form 1. General Site Information

The information included in this form is identical to the first page of the Site Inspection (SI) Data Summary form (page B-3 in *Guidance for Performing Site Inspections Under CERCLA*, U.S. EPA, 1992). However, the form should be updated to reflect any site activities conducted since the SI was completed.

Form 2. Site Characteristics

Form 2 indicates the information necessary to address the migration to ground water pathway and identify subsurface conditions that may limit the applicability of SSLs.

A hydrogeologic setting is defined as a unit with common hydrogeologic characteristics and therefore common vulnerability to contamination. Each setting provides a composite description of the hydrogeologic factors that control ground water movement and recharge. These factors can be used to make generalizations in the CSM about ground water conditions.

After placing the site into one of Heath's ground water regions (Heath, 1984), consider geologic and geomorphic features of the site and select a generic hydrogeologic setting from Aller et al. (1987) that is most similar to the site. If existing site information is not sufficient to definitively place the site in a setting, it should be possible to narrow the choice to two or three settings that will reduce the range of values necessary to develop SSLs. A copy of the setting diagram from Aller et al. (1987) should be attached to the CSM checklist to provide a general picture of subsurface site conditions.

Ground Water Flow Direction. The direction of ground water flow in the uppermost aquifer underlying each source is needed to determine source length parallel to that flow. If ground water flow direction is unknown or uncertain, assume it is parallel to the longest source dimension.

Aquifer Parameters. Aquifer parameters needed to estimate a site-specific dilution factor include hydraulic conductivity (K), hydraulic gradient (i), and aquifer thickness (d_a). Site-measured values for these parameters are the preferred alternative. Existing site documentation should be reviewed for in situ measurements of aquifer conductivity (i.e., from pump test data), water table maps that can be used to estimate hydraulic gradient, and boring logs that indicate the thickness of the uppermost aquifer. Detailed information on conducting and interpreting aquifer tests can be found in Nielsen (1991).

If site-measured values are not available, hydrogeologic knowledge of regional geologic conditions or measured values in the literature may be sources of reasonable estimates. Values from a similar site in the same region and hydrogeologic setting also may be used, but must be carefully reviewed to ensure that the subsurface conceptual models for the two sites show reasonable agreement. For all of these options, it is critical that the estimates and sources be reviewed by an experienced hydrogeologist knowledgeable of regional hydrogeologic conditions.

A third option is to obtain parameter estimates for the site’s hydrogeologic setting from Aller et al. (1987) or from the American Petroleum Institute’s (API's) hydrogeologic database (HGDB) (Newell et al., 1989, 1990). Aller et al. (1987) present ranges of values for K and i by hydrogeologic setting. The HGDB contains measured values for these parameters and aquifer depth for a number of sites in each hydrogeologic setting. If HGDB data are used, the median value presented for each setting should be used unless site-specific conditions indicate otherwise. Aquifer parameter values from these sources also can serve as a check of the validity of site-measured values or estimates obtained from other sources.

If outside sources such as Aller et al. (1987) are used to characterize site hydrogeologic conditions, the appropriate references and diagrams should be attached to the CSM checklist.

Infiltration Rate. Infiltration rate is used to calculate SSLs for subsurface soils (see Step 5). The simplest way to estimate infiltration rate (I) is to assume that infiltration is equal to recharge and obtain recharge estimates for the site's hydrogeologic setting from Aller et al. (1987). When using the Aller et al. (1987) estimates the user should recognize that these are estimates of average recharge conditions throughout the setting and site-specific values may differ to some extent. For example, areas within the setting with steeper than average slopes will tend to have lower infiltration rates and areas with flatter than average slopes will tend to have higher infiltration than average. An alternative is to use infiltration rates determined for a better-characterized site in the same hydrogeologic setting and with similar meteorological conditions as the site in question.

A third alternative is use the HELP model. Although HELP was originally written for hydrologic evaluation of landfills (Schroeder et al., 1984), inputs to the HELP program can be modified to estimate infiltration in undisturbed soils in natural settings. The most recent version of HELP and the most recent user's guide and documentation can be obtained by sending an address and two double-sided, high-density, DOS-formatted disks to:

attn. Eunice Burk
U.S. EPA
5995 Center Hill Ave.
Cincinnati, OH 45224
(513) 569-7871.

Meteorologic Parameters. Select a site-specific Q/C value from in the guidance for the particulate emission factor (PEF) equation to place the site in a climatic zone (Figure A-1).

Several site-specific parameters are required to calculate a PEF if fugitive dusts are of concern at the site (see Step 5 for surface soils). The threshold windspeed at 7 meters above ground surface ($U_{t,7}$) is calculated from source area roughness height and the mode soil aggregate size as described in Cowherd et al. (1985). Mode soil aggregate size refers to the mode diameter of aggregated soil particles measured under field conditions.

Other site-specific variables necessary for calculating the PEF include fraction vegetative cover (V) and the mean annual windspeed (U_m). Fraction vegetative cover is estimated by visual observations of the surface of known or suspected source areas at the site. Mean annual windspeed can be obtained from the National Weather Service surface station nearest to the site.

Form 3. Exposure Pathways and Receptors

Form 3 includes information necessary to determine the applicability of the Soil Screening Guidance for Radionuclides to a site (see Step 2 of the User's Guide). This form summarizes the site information necessary to identify and characterize potential exposure pathways and receptors at the site, such as site conditions, relevant exposure scenarios, and the properties of soil contaminants listed on Form 4. Table A-1 provides an example of exposure pathways that are not addressed by the guidance, but have relevance to CSM development.

Table A-1. Example Identification of Radiological Exposure Pathways Not Addressed by SSLs

Receptors/ Exposure Pathways	Contaminant Characteristics	Site Conditions
Human / Direct Pathways		
inhalation - radon	chronic health effects	elevated levels of radium in soils
inhalation - volatile radionuclides	chronic health effects	radionuclides bound chemically to volatile organic compounds or "special case" radionuclides (e.g., ^{3}H, ^{14}C, ^{222}Rn)
Human / Indirect Pathways		
consumption of meat or dairy products	bioaccumulation, biomagnification	nearby meat or dairy production
fish consumption	biomagnification	nearby surface waters with recreational or subsistence fishing
Ecological Pathways		
aquatic	aquatic toxicity	nearby surface waters or wetlands
terrestrial	toxicity to terrestrial organisms (e.g., DDT, Hg)	sensitive species on or near site

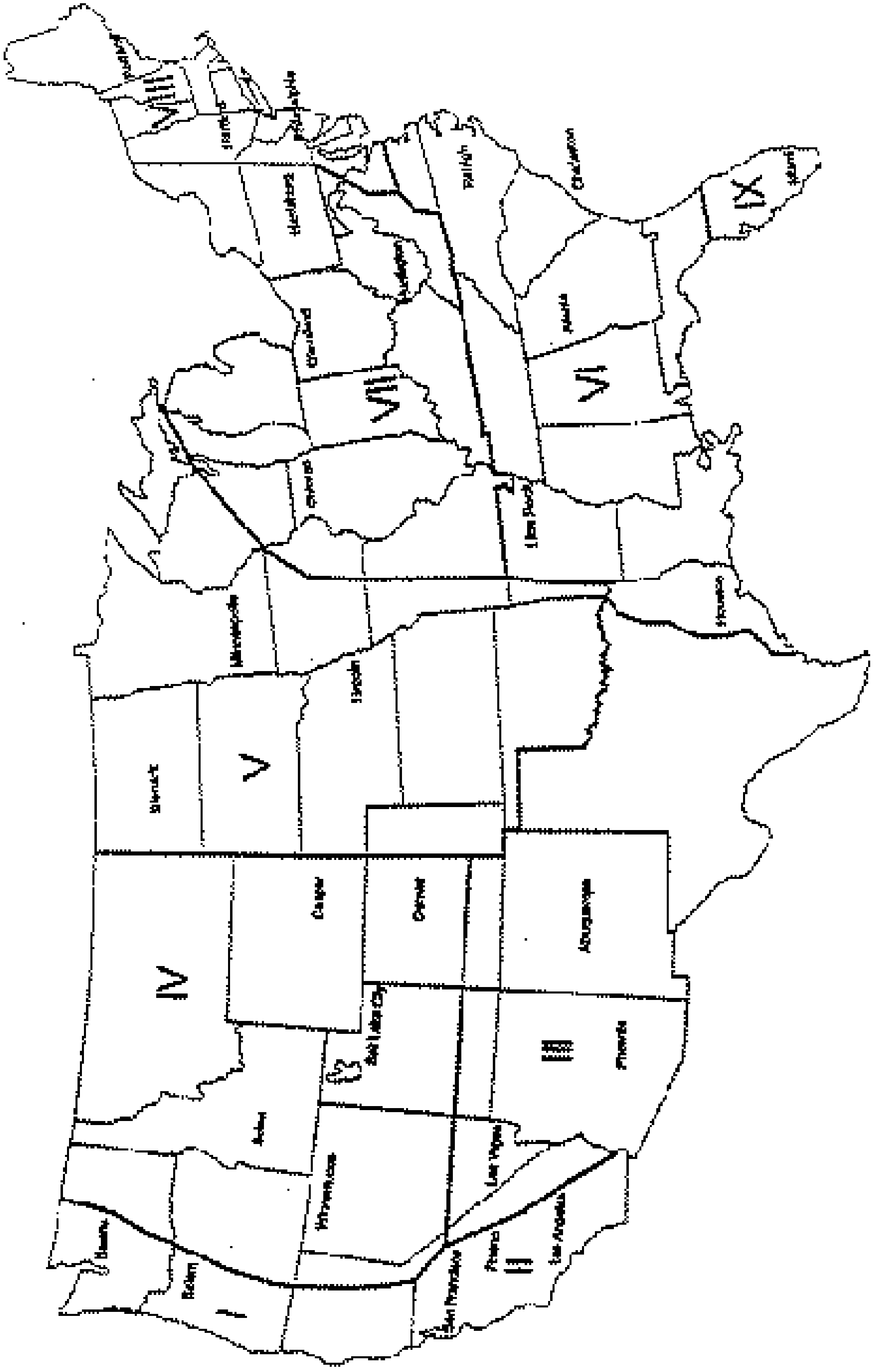

Figure A-1. U.S. climatic zones

Form 4. Soil Contaminant Source Characteristics

This form prompts the investigator to provide information on source characteristics, including soil contaminant levels and the physical and chemical parameters of site soils needed to calculate SSLs. One form should be completed for each contaminated soil source. Initially, the form should be filled out to the greatest extent possible with existing site information collected during CSM development (see Step 1 of the User's Guide). The forms should be updated after the SSL sampling effort is complete.

Measurement of contaminant levels and the soil parameters listed on this form is described in Step 3 of this guidance.

Average soil moisture content (θ_w) defines the fraction of total soil porosity that is filled by water and air. These parameters are necessary to apply the soil/water partition equation. It is important that the moisture content used to calculate these parameters represent the annual average soil moisture conditions. Moisture content measurements on discrete soil samples should not be used because they are affected by preceding rainfall events and thus may not represent average conditions. Volumetric average soil water content may be estimated by the following relationship developed by Clapp and Hornberger (1978) and presented in the *Superfund Exposure Assessment Manual* (U.S. EPA, 1988):

$$\theta_w = n\ (I/K_s)^{\ 1/(2b+3)}$$

where

n = total soil porosity (L_{pore}/L_{soil})
I = infiltration rate (m/yr)
K_s = saturated hydraulic conductivity (m/yr)
b = soil-specific exponential parameter (unitless).

Total soil porosity (n) is estimated from dry soil bulk density (ρ_b) as follows:

$$n = 1 - (\rho_b/\rho_s)$$

where

ρ_s = soil particle density = 2.65 kg/L.

Site-specific values for infiltration rate (I) may be estimated using the HELP model or may be assumed to be equivalent to recharge (see Form 2).

Values for K_s and the exponential term 1/(2b+3) are shown in Table A-2 by soil texture class. Soil texture class can be determined using a particle size analysis and the U.S. Department of Agriculture (USDA) soil textural triangle shown as Exhibit 9 in the User's Guide. The particle size analysis method described in Gee and Bauder (Gee, G.W., and J.W. Bauder, Particle size analysis, A. Clute (ed.), *Methods of Soil Analysis. Part 1. Physical and Mineralogical Methods. 2nd Edition*, 9(1):383-411, American Society of Agronomy, Madison, WI, 1986) can provide the appropriate particle size distribution. Other methods are appropriate as long as they provide the same particle breakpoints for sand/silt (0.05 mm) and silt/clay (0.002 mm). Field methods are an alternative for determining soil textural class. Table A.3 Presents an example from Brady (Brady, N.C., *The Nature and Properties of Soils*, Macmillan Publishing Company, New York, NY, 1990).

Table A-2. Parameter Estimates for Calculating Average Soil Moisture Content (θ_w)

Soil texture	K_s (m/yr)	1/(2b+3)
Sand	1,830	0.090
Loamy sand	540	0.085
Sandy loam	230	0.080
Silt loam	120	0.074
Loam	60	0.073
Sandy clay loam	40	0.058
Silt clay loam	13	0.054
Clay loam	20	0.050
Sandy clay	10	0.042
Silt clay	8	0.042
Clay	5	0.039

Source: U.S. EPA, 1988.

Table A.3 Criteria Used with the Field Method for Determining Soil Texture Classes

Criterion	Sand	Sandy Loam	Loam	Silt Loam	Clay Loam	Clay
Individual grains visible to eye	Yes	Yes	Some	Few	No	No
Stability of dry clods	Do not form	Do not form	Easily broken	Moderately easily broken	Hard and stable	Very hard and stable
Stability of wet clods	Unstable	Slightly stable	Moderately stable	Stable	Very stable	Very stable
Stability of “ribbon” when wet soil rubbed between thumb and fingers	Does not form	Does not form	Does not form	Broken appearance	Thin, will break	Very long, flexible

Source: Brady, 1990.

Worksheets

The worksheets following Forms 1 through 4 provide a convenient means of assembling radionuclide-specific parameters necessary to calculate SSLs for the contaminants of concern (Worksheet 1), existing site data on contaminant concentrations collected during CSM development or the SSL sampling effort (Worksheet 2), and SSLs calculated for EAs (Worksheet 3) or contaminant sources (Worksheet 4) of concern at the site.

CSM Diagram

The CSM diagram is a product of CSM development that represents the linkages among contaminant sources, release mechanisms, exposure pathways and routes, and receptors to summarize the current understanding of the soil contamination problem (see Step 1 of the guidance). An example SSL CSM diagram, Figure A-2 (U.S. EPA, 1989), and a site sketch, Figure A-3 (U.S. EPA, 1987) are provided following the Worksheets.

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Soil Screening Guidance for Radionuclides
Conceptual Site Model Summary Forms

Form 1: General Site Information **Site Name** . . . .

EPA Region . . . . Date . . . .

Contractor Name and Address: . . . .

. . . .

. . . .

State Contact: . . . .

1. CERCLIS ID No. . . . .
   Address . . . . City . . . .
   County . . . . State . . . . Zip Code . . . . . . Congressional District . . . .

2. Owner Name . . . . Operator Name . . . .
   Owner Address . . . . Operator Address . . . .
   City . . . . State . . . . City . . . . State . . . .

3. Type of ownership (check all that apply):
   ☐ Private ☐ Federal Agency . . . . ☐ State ☐ County ☐ Municipal
   Other . . . . Ref. . . . .

4. Approximate size of property . . . . acres Ref. . . . .

5. Latitude . . . . . o . . | . . . . " Longitude . . . . o . . . | . . . . " Ref. . . . .

6. Site status ☐ Active ☐ Inactive ☐ Unknown Ref. . . . .

7. Years of operation From . . . . To . . . . ☐ Unknown Ref. . . . .

8. Previous investigations

Type	Agency/State/Contractor	Date	
. . . .	. . . .	. . . .	Ref. . . . .
. . . .	. . . .	. . . .	Ref. . . . .
. . . .	. . . .	. . . .	Ref. . . . .
. . . .	. . . .	. . . .	Ref. . . . .
. . . .	. . . .	. . . .	Ref. . . . .
. . . .	. . . .	. . . .	Ref. . . . .

Ref. = reference(s) on information source

Soil Screening Guidance for Radionuclides
Conceptual Site Model Summary Forms

Form 2: Site Characteristics **Site Name** . . . .

Hydrogeologic Characteristics (migration to ground water pathway)

Is ground water of concern at the site? ☐ yes ☐ no (if no, move to Infiltration Rate below).

Heath region . . . . **Hydrogeologic setting** . . . .

(attach setting diagram)

Check setting characteristics that apply: ☐ karst ☐ fractured rock ☐ solution limestone

Describe the stratigraphy and hydrogeologic characteristics of the site. (Attach available maps and cross-sections.)

. . . .

. . . .

. . . .

. . . .

Ref. . . . .

Identify and describe nearby sites in similar settings that have already been characterized.

. . . .

. . . .

. . . .

. . . .

Ref. . . . .

Aquifer Parameters	Unit	Typical	Min.	Max.	Reference or Source
hydraulic conductivity (K)	m/y				
hydraulic gradient (i)	m/m				
thickness (d_a)	m				

General direction of ground water flow across the site (e.g., NNE, SW): . . . .

(attach map.) Ref. . . . .

Infiltration rate (I) . . . . m/yr Method . . . .

Meteorological Characteristics (inhalation pathway)

climatological zone: . . . . (zone#, city) Q/C . . . . (g/m^2-s per kg/m^3)

fract. vegetative cover (V) . . . . (unitless) Reference . . . .

mean annual windspeed (U_m) . . . . m/s Reference . . . .

equivalent threshold value of windspeed at 7 m (U_t) . . . . m/s

fraction dependent on U_m/U_t . . . . (unitless)

Comments: . . . .

. . . .

. . . .

Soil Screening Guidance for Radionuclides
Conceptual Site Model Summary Forms

Form 3: Exposure Pathways and Receptors **Site Name** . . . .

Land Use Conditions

Current site use:

__ residential

__ industrial

__ commercial

__ agricultural

__ recreational

__ other

Surrounding land use:

__ residential

__ industrial

__ commercial

__ agricultural

__ recreational

__ other

Future land use:

__ residential

__ industrial

__ commercial

__ agricultural

__ recreational

__ other

Size of exposure areas (in acres) . . . .

Contaminant Release Mechanisms (check all that apply):

Source #___ ☐ leaching ☐ volatilization ☐ fugitive dusts ☐ erosion/runoff ☐ uptake by plants ☐ direct exposure
Source #___ ☐ leaching ☐ volatilization ☐ fugitive dusts ☐ erosion/runoff ☐ uptake by plants ☐ direct exposure
Source #___ ☐ leaching ☐ volatilization ☐ fugitive dusts ☐ erosion/runoff ☐ uptake by plants ☐ direct exposure

(describe rationale for not including any of the above release mechanisms)

. . . .

. . . .

. . . .

Media affected (or potentially affected) by soil contamination.

Source #___ ☐ air ☐ ground water ☐ surface water ☐ sediments ☐ wetlands ☐subsurface
Source #___ ☐ air ☐ ground water ☐ surface water ☐ sediments ☐ wetlands ☐subsurface
Source #___ ☐ air ☐ ground water ☐ surface water ☐ sediments ☐ wetlands ☐subsurface

Check if present on-site or on surrounding land (attach map showing locations)

☐ wetlands ☐ surface water ☐ subsistence fishing ☐ recreational fishing ☐ dairy/beef production ☐ elevated indoor radon

Check SSL exposure pathways applicable at site; describe basis for not including any pathway

☐ ingestion of soil ☐ inhalation ☐ migration to ground water ☐ produce ingestion

☐ external exposure

Check if there is a potential for:

☐ **Acute Effects (describe)**
☐ **Other Human Exposure Pathways (describe)**
☐ **Ecological concerns (describe)**
☐ **Small areas of elevated activity (describe)**

Soil Screening Guidance for Radionuclides
Conceptual Site Model Summary Forms

Form 4: Soil Contaminant Source Characteristics **Site Name** . . . .

Source No.: . . . .

Name: . . . . (e.g., drum storage area)

Type: . . . . (e.g., spill, dump, wood treater)

Location: . . . . (site map)

Waste type: . . . . (e.g., solvents, waste oil, tailings)

Description (describe history of contamination, other information)

. . . .

. . . .

. . . .

. . . .

Describe past/current remedial or removal actions

. . . .

. . . .

. . . .

. . . .

Source depth: . . . . m (☐ measures ☐ estimated) Ref. . . . .

Source area: . . . . . acres . . . . m^2 (☐ measures ☐ estimated) Ref. . . . .

Source length parallel to ground water flow: . . . . . . m (if uncertain, use longest source dimension)

Contaminant types (check all that apply): ☐ volatile organics ☐ other organics ☐ metals ☐ other inorganics ☐ radionuclides

Soil Contaminants Present (list): . . . .

. . . .

. . . .

(attach Worksheet #1)

Describe previous soil analyses. (attach available results and map showing sample locations)

. . . .

. . . .

. . . .

(attach Worksheet #2)

Are NAPLs suspected? ☐ **Yes** ☐ **No** Reason

. . . .

Average Soil Characteristics

average water content (θ_w) . . . . (L_{water}/L_{soil}) Ref. . . . .

dry bulk density (ρ_b) . . . . (kg/L) Ref. . . . .

pH . . . . Ref. . . . .

Worksheet 1. Contaminant-specific properties **Site Name** . . . .

Regulatory and Human Health Benchmarks[1]

Radionuclide	CASRN	MCL (pCi/L)	Slope factors				
			Ingestion - soil $(pCi)^{-1}$	Inhalation $(pCi)^{-1}$	Ingestion - water $(pCi)^{-1}$	External exposure (kg/pCi-s)	Ingestion - produce $(pCi)^{-1}$

Chemical Properties[2]

Contaminant	CAS #	Sources (no.)	K_{oc}[3] (L/kg)	K_d[4] (L/kg)	H[5]	D_{ia}[5] (cm^2/s)	D_{iw}[5] (cm^2/s)	S[5] (mg/L)

1. Attachment D
2. Attachment C
3. For organic compounds
4. For metals and inorganic compounds
5. Not applicable to metals except mercury

Worksheet 2. Contaminant concentrations by source **Site Name** . . . .

Source #: . . . .

Contaminant	CAS #	average	standard deviation	number of samples	minimum	maximum	variance

Source #: . . . .

Contaminant	CAS #	average	standard deviation	number of samples	minimum	maximum	variance

Worksheet 3. Surface SSLs by Exposure Area (EA) **Site Name** . . . .

EA #: . . . . **SSL type:** ☐ **site-specific** ☐ **generic (default)** ☐ **detailed approach**

Radionuclide	CASRN	Soil Screening Level (pCi/g)				
		Ingestion - soil	Inhalation	Ingestion - water	External exposure	Ingestion - produce

EA #: . . . . **SSL type:** ☐ **site-specific** ☐ **generic (default)** ☐**detailed approach**

Radionuclide	CASRN	Soil Screening Level (pCi/g)				
		Ingestion - soil	Inhalation	Ingestion - water	External exposure	Ingestion - produce

Worksheet 4. Subsurface SSLs by source **Site Name** . . . .

Source #: . . . . **SSL type:** ☐ **site-specific** ☐ **generic (default)** ☐**detailed approach**

Radionuclide	CASRN	Soil Screening Level (pCi/g)
		migration to ground water

Source #: . . . . **SSL type:** ☐ **site-specific** ☐ **generic (default)** ☐**detailed approach**

Radionuclide	CASRN	Soil Screening Level (pCi/g)
		migration to ground water

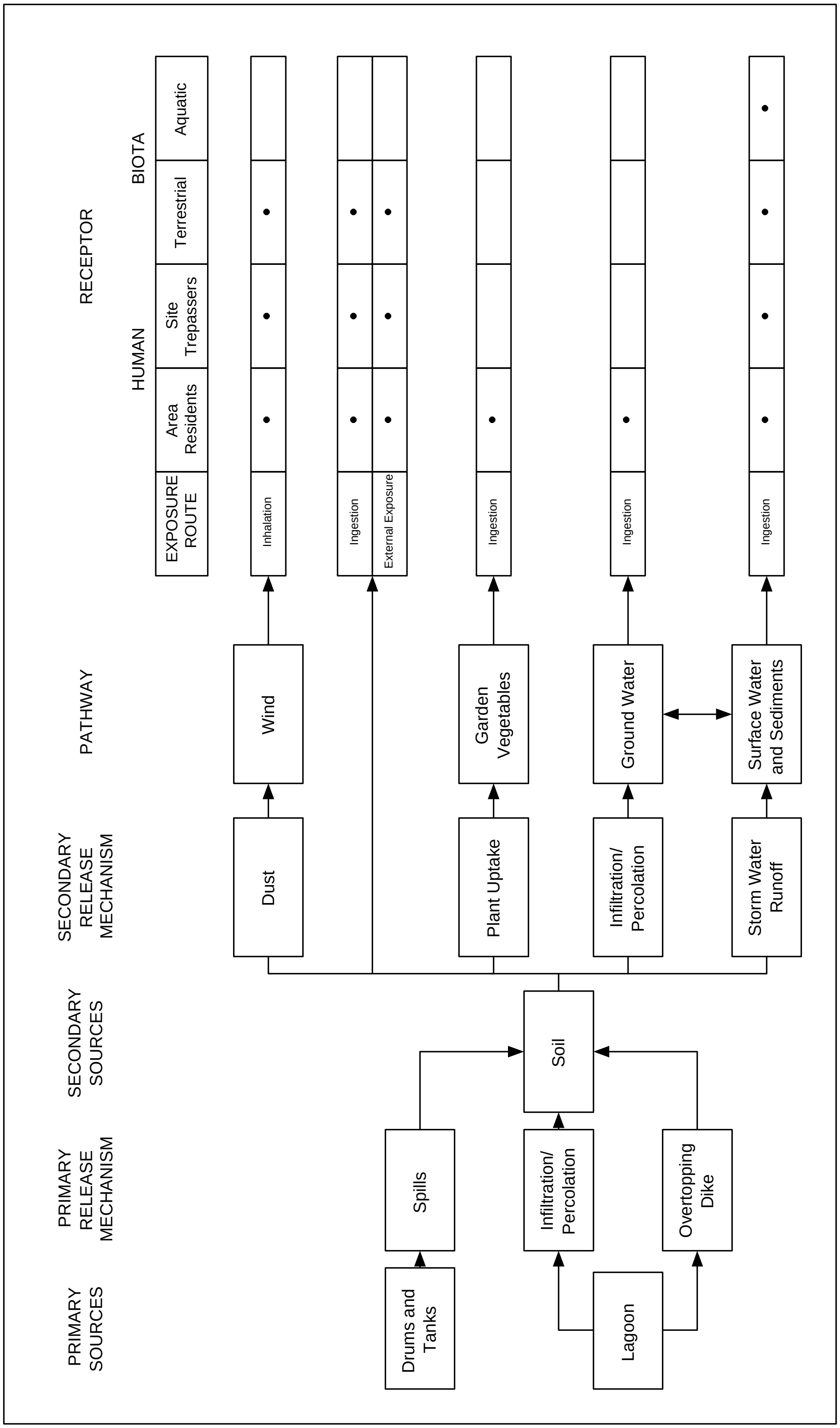

Figure A-2. Example conceptual site model diagram for contaminated soil (adapted from U.S. EPA, 1989)

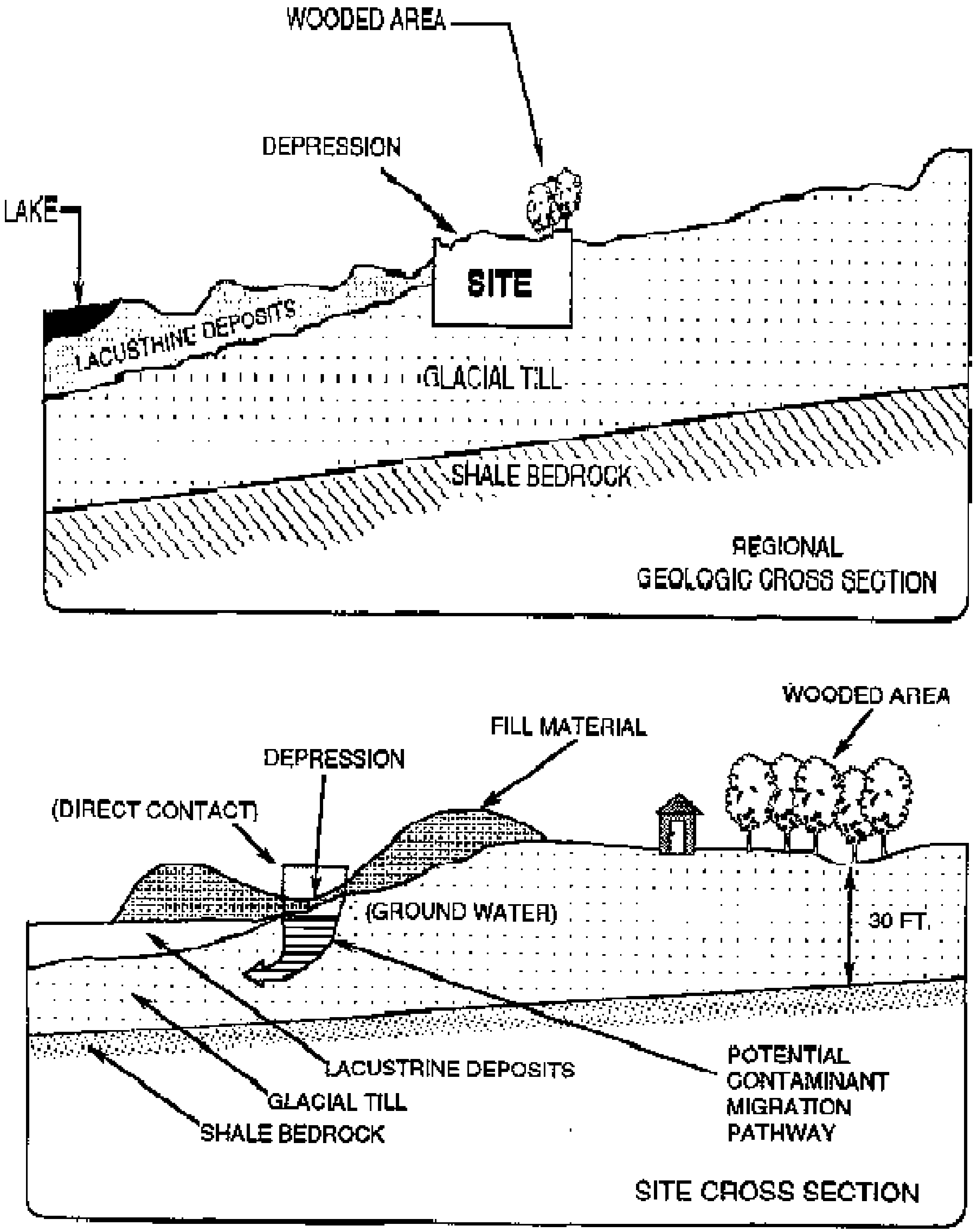

Figure A-3. Example Site Sketch (adapted from U.S. EPA, 1987)

Attachment B

Soil Screening DQOs for Surface Soils and Subsurface Soils

Table B.1
Soil Screening DQOs for Surface Soils Using the Max Test

DQO Process Steps	Soil Screening Inputs/Outputs
State the Problem	
Identify scoping team	Site manager and technical experts (e.g., health physicists, risk assessors, statisticians)
Develop conceptual site model (CSM)	CSM development (described in Step 1)
Define exposure scenarios	Direct ingestion of soil, inhalation of fugitive dusts, external radiation exposure, and ingestion of homegrown produce in a residential setting;
Specify available resources	Sampling and analysis budget, scheduling constraints, and available personnel
Write brief summary of contamination problem	Summary of the surface soil contamination problem to be investigated at the site
Identify the Decision	
Identify decision	Do mean soil concentrations for particular radionuclides (e.g., radionuclides of potential concern) exceed appropriate screening levels?
Identify alternative actions	Eliminate area from further study under CERCLA or Plan and conduct further investigation
Identify Inputs to the Decision	
Identify inputs	SSLs for each pathway for specified radionuclides Measurements of surface soil radionuclide concentration
Define basis for screening	Soil Screening Guidance for Radionuclides
Identify analytical methods	Feasible analytical methods (both field and laboratory) consistent with program-level requirements
Define the Study Boundaries	
Define geographic areas of field investigation	The entire NPL site, (which may include areas beyond facility boundaries), except for any areas with clear evidence that no contamination has occurred
Define population of interest	Surface soils (usually the top 15 centimeters)
Divide site into strata	Strata may be defined so that radionuclide concentrations are likely to be relatively homogeneous within each stratum based on the CSM and field measurements
Define scale of decision making	Exposure areas (EAs) no larger than 0.5 acre each (based on residential land use)
Define temporal boundaries of study	Temporal constraints on scheduling field visits
Identify practical constraints	Potential impediments to sample collection, such as access, health, and safety issues
Develop a Decision Rule	
Specify parameter of interest	"True mean" (µ) individual radionuclide concentration in each EA. However, since the determination of the "true mean" would require the collection and analysis of many samples, another sample statistic, the maximum composite concentration, or "Max Test" is used.
Specify screening level	Screening levels calculated using available parameters and site data (or generic SSLs if site data are unavailable)
Specify "if..., then..." decision rule	Ideally, if the "true mean" EA concentration exceeds the screening level, then investigate the EA further. If the "true mean" is less than the screening level, then no further investigation of the EA is required under CERCLA.

Table B.1
Soil Screening DQOs for Surface Soils Using the Max Test (continued)

DQO Process Steps	Soil Screening Inputs/Outputs
Specify Limits on Decision Errors*	
Define baseline condition (null hypothesis)	The EA needs further investigation
Define the gray region**	From 0.5 SSL to 2 SSL
Define Type I and Type II decision errors	Type I error: Do not investigate further ("walk away from") an EA whose "true mean" exceeds the screening level of 2 SSL Type II error: Investigate further when an EA "true mean" falls below the screening level of 0.5 SSL
Identify consequences	Type I error: potential public health consequences Type II error: unnecessary expenditure of resources to investigate further
Assign acceptable probabilities of Type I and Type II decision errors	Goals: Type I: 0.05 (5%) probability of not investigating further when "true mean" of the EA is 2 SSL Type II: 0.20 (20%) probability of investigating further when "true mean" of the EA is 0.5 SSL
Define QA/QC goals	Analytical laboratory precision and bias requirements 10% laboratory analyses for field methods
Optimize the Design	
Determine how to best estimate "true mean"	Samples composited across the EA as physical estimates of EA mean ($\bar{x}$). Use maximum composite concentration as a conservative estimate of the true EA mean.
Determine expected variability of EA surface soil radionuclide concentrations	A conservatively large expected coefficient of variation (CV) from prior data for the site, field measurements, or data from other comparable sites and expert judgment. A minimum default CV of 2.5 should be used when information is insufficient to estimate the CV.
Design sampling strategy by evaluating costs and performance of alternatives	Lowest cost sampling design option (i.e., compositing scheme and number of composites) that will achieve acceptable decision error rates
Develop planning documents for the field investigation	Sampling and Analysis Plan (SAP) Quality Assurance Project Plan (QAPP)

* Since the DQO process controls the degree to which uncertainty in data affects the outcome of decisions that are based on that data, specifying limits on decision errors will allow the decision maker to control the probability of making an incorrect decision when using the DQOs.

** The gray region represents the area where the consequences of decision errors are minor, (and uncertainty in sampling data makes decisions too close to call).

Table B.2
Soil Screening DQOs for Subsurface Soils

DQO Process Steps	Soil Screening Inputs/Outputs
State the Problem	
Identify scoping team	Site manager and technical experts (e.g., health physicists, risk assessors, hydrogeologists, statisticians).
Develop conceptual site model (CSM)	CSM development (described in Step 1).
Define exposure scenarios	Migration of radionuclides from soil to potable ground water.
Specify available resources	Sampling and analysis budget, scheduling constraints, and available personnel.
Write brief summary of contamination problem	Summary of the subsurface soil contamination problem to be investigated at the site.
Identify the Decision	
Identify decision	Do mean soil concentrations for particular radionuclides (e.g., radionuclides of potential concern) exceed appropriate SSLs?
Identify alternative actions	Eliminate area from further action or study under CERCLA or Plan and conduct further investigation.
Identify Inputs to the Decision	
Identify decision	Migration to ground water SSLs for specified radionuclides Measurements of subsurface soil radionuclide concentration
Define basis for screening	Soil Screening Guidance for Radionuclides
Identify analytical methods	Feasible analytical methods (both field and laboratory) consistent with program-level requirements.
Specify the Study Boundaries	
Define geographic areas of field investigation	The entire NPL site (which may include areas beyond facility boundaries), except for any areas with clear evidence that no contamination has occurred.
Define population of interest	Subsurface soils
Define scale of decision making	Sources (areas of contiguous soil contamination, defined by the area and depth of contamination or to the water table, whichever is more shallow).
Subdivide site into decision units	Individual sources delineated (area and depth) using existing information or field measurements (several nearby sources may be combined into a single source).
Define temporal boundaries of study	Temporal constraints on scheduling field visits.
Identify (list) practical constraints	Potential impediments to sample collection, such as access, health, and safety issues.

Table B.2
Soil Screening DQOs for Subsurface Soils(continued)

Develop a Decision Rule	
Specify parameter of interest	Mean soil radionuclide concentration in a source (i.e., discrete radionuclide concentrations averaged within each boring).
Specify screening level	SSLs calculated using available parameters and site data (or generic SSLs if site data are unavailable).
Specify "if..., then..." decision rule	If the mean soil concentration exceeds the SSL, then investigate the source further. If mean soil concentration in a source is less than the SSL, then no further investigation is required under CERCLA.
Specify Limits on Decision Errors	
Define QA/QC goals	Analytical laboratory precision and bias requirements 10% laboratory analyses for field methods
Optimize the Design	
Determine how to estimate mean concentration in a source	For each source, the highest mean soil boring concentration (i.e., depth-weighted average of discrete radionuclide concentrations within a boring).
Define subsurface sampling strategy by evaluating costs and site-specific conditions	Number of soil borings per source area; number of sampling intervals with depth.
Develop planning documents for the field investigation	Sampling and Analysis Plan (SAP) Quality Assurance Project Plan (QAPP)

Attachment C

Radiological Properties for SSL Development

Attachment C

Radiological Properties for SSL Development

C.1 Radionuclides Included in Generic Soil Screening Analysis

Principal radionuclides are radionuclides with half-lives greater than six months. The decay products of any principal radionuclide down to, but not including, the next principal radionuclide in its decay chain are called associated radionuclides and consist of radionuclides with half-lives less than six months. It is assumed that a principal radionuclide is in secular equilibrium with its associated radionuclides at the point of exposure. This assumption is reasonable because it usually takes about three years or longer to clean up a site. Principal and associated radionuclides for which generic Soil Screening Levels have been calculated are listed in Table C.1. Associated decay chains are indicated, as well as principal radionuclide half-life and the terminal nuclide or radionuclide (i.e., the principal radionuclide or stable nuclide that terminates an associated decay chain).

Table C.1 Radionuclides Included in Generic Soil Screening Analysis

Principal Radionuclide[a]			Terminal Nuclide or Radionuclide[c]	
Nuclide	Half-life (yr)	Associated Decay Chain[b]	Nuclide	Half-life (yr)
Ac-227+D	22	[Th-227 (98.6%, 19 d) Fr-223 (1.4%, 22 min)] Ra-223 (11 d) Rn-219 (4 s) Po-215 (2 ms) Pb-211 (36 min) Bi-211 (2 min) [Tl-207 (99.7%, 5 min) Po-211 (0.3%, 0.5 s)]	Pb-207	stable
Ag-108m	127	-	Pd-108 (91%) [Cd-108 (98%} Ag-108 (9%) Pd-108 (2%)]	stable stable 2 min stable
Ag-110m	0.7	-	Cs-110 (99%) [Cd-110 (99.7%) Ag-110 (1%) Pd-110 (0.3%)]	stable stable 25 s stable
Am-241	432	-	Np-237	2100000[1]
Am-243+D	7400	Np-239 (2 d)	Pu-239	24000
Bi-207	38	-	Pb-207	stable
C-14	5730	-	N-14	stable
Cd-109	1.3	-	Ag-109	stable
Ce-144+D	0.8	[Pr-244 (9%, 17 min) Pr-244m (2%, 7 min)]	Nd-144	stable
Cl-36	300000	-	S-36	stable
Cm-243	28	-	Am-243 (0.2%)[e]	7400
Cm-244	18	-	Pu-240	6600
Co-57	0.7	-	Fe-57	stable
Co-60	5	-	Ni-60	stable
Cs-134	2	-	Ba-134 (~100%)	stable
Cs-135	3000000	-	Ba-135	stable
Cs-137+D	30	Ba-137m (95%, 3 min)	Ba-137	stable
Eu-152	13	-	Sm-152 (72%) Gd-152 (28%)	stable 1.1E+14
Eu-154	8	-	Gd-154 (~100%)	stable
Eu-155	5	-	Gd-155	stable
Fe-55	3	-	Mn-55	stable
Gd-153	0.7	-	Eu-153	stable
H-3	12	-	He-3	stable
I-129	16000000	-	Xe-129	stable
K-40	1300000000	-	Ca-40 (89%) Ar-40 (11%)	stable

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[1] Note: 2.1E+6 = 2.1x10^{+6}

Table C.1 Radionuclides Included in Generic Soil Screening Analysis

Principal Radionuclide[a]			Terminal Nuclide or Radionuclide[c]	
Nuclide	Half-life (yr)	Associated Decay Chain[b]	Nuclide	Half-life (yr)
Mn-54	0.9	-	Cr-54	stable
Na-22	3	-	Ne-22	stable
Nb-94	20000	-	Mo-94	stable
Ni-59	75000	-	Co-59	stable
Ni-63	100	-	Cu-53	stable
Np-237+D	2100000	Pa-233 (27 d)	U-233	160000
Pa-231	33000	-	Ac-227	22
Pb-210+D	22	Bi-210 (5 d) Po-210 (138 d)	Pb-206	stable
Pm-147	3	-	Sm-147	1.10000e+11
Pu-238	88	-	U-234	240000
Pu-239	24000	-	U-235	700000000
Pu-240	6500	-	U-236	2300000
Pu-241	14	-	Am-241	432 y
Pu-242	380000	-	U-238	4500000000
Pu-244+D	93000000	U-240 ~100%, 14) Np-240	Pu-240	6500
Ra-226+D	1600	Rn-222 (4 d) Po-218 (3 min) Pb-214 (~100%, 27 min) Bi-214 (20 min) Po-214 (~100%, 1 min)	Pb-210	22
Ra-228+D	8	Ac-228 (6 h)	Th-228	2
Ru-106+D	1	Rh-106 (30 s)	Pd-106	stable
Sb-125+D	3	Te-125m (23%, 58 d)	Te-125	stable
Sm-147	110000000000	-	Nd-143	stable
Sm-151	90	-	Eu-151	stable
Sr-90+D	29	Y-90 (64 h)	Zr-90	stable
Tc-99	210000	-	Ru-99	stable
Th-228+D	2	Ra-224 (4 d) Rn-220 (56 s) Po-216 (0.2 s) Pb-212 (11h) Bi-212 (61 min) [Po-212 (64%, 0.3 µs) Tl-208 (36%, 3 min)]	Pb-208	stable
Th-229+D	7300	Ra-225 (15 d) Ac-225 (10 d) Fr-221 (5 min) At-217 (32 ms) Bi-213 (46 min) [Po-213 (98%, 4 µs) Tl-209 (2%, 2 min)] Pd-209 (3 h)	Bi-209	stable
Th-230	77000	-	Ra-226	1600

Table C.1 Radionuclides Included in Generic Soil Screening Analysis

Principal Radionuclide[a]		Associated Decay Chain[b]	Terminal Nuclide or Radionuclide[c]	
Nuclide	Half-life (yr)		Nuclide	Half-life (yr)
Th-232	14000000000	-	Ra-228	6
Tl-204	4	-	Pb-204 (97%) Hg-204 (3%)	stable stable
U-232	72	-	Th-228	2
U-233	160000	-	Th-229	7300
U-234	240000	-	Th-230	80000
U-235+D	700000000	Th-231 (26 h)	Pa-231	34000
U-236	2300000	-	Th-232	14000000000
U-238+D	4500000000	Th-234 (24 d) [Pa-234m (99.8%, 1 min) Pa-234 (0.2%, 7 h)]	U-234	240000
Zn-65	0.7	-	Cu-65	stable

[a] Radionuclides with half-lives greater than six months. “+D” designates principal radionuclides with associated decay chains.

[b] The chain of decay products of a principal radionuclide extending to (but not including) the next principal radionuclide or a stable nuclide. Half-lives are given in parentheses. Branches are indicated by square brackets with branching ratios in parentheses.

[c] The principal radionuclide or stable nuclide that terminates an associated decay chain.

[d] A hyphen indicates that there are no associated decay products.

[e] The branching decay for Pu-241 and Cm-243 involves multiple principal radionuclides and associated radionuclides.

C.2 Soil-water Partition Coefficients for Radionuclides

As with organic chemicals, development of SSLs for inorganics (including radionuclides) requires a soil-water partition coefficient (K_d) for each constituent. However, the simple relationship between soil organic carbon content and sorption observed for organic chemicals does not apply to inorganics (including radionuclides). The soil-water distribution coefficient (K_d) for inorganics (including radionuclides) is affected by numerous geochemical parameters and processes, including pH; sorption to clays, organic matter, iron oxides, and other soil constituents; oxidation/reduction conditions; major ion chemistry; and the chemical form of the radionuclide. The number of significant influencing parameters, their variability in the field, and differences in experimental methods result in as much as seven orders of magnitude variability in measured metal K_d values reported in the literature (see Table 43 in the Soil Screening Guidance: Technical Background Document (EPA 1996b)). This variability makes it much more difficult to derive generic K_d values for metals (including radionuclides) than for organics. Therefore, it is recommended that K_d values be measured for site-specific conditions. If the Kd is not measured site-specifically, then a conservative Kd should be used in calculating SSLs.

Tables C.2a and C.2b list the default K_d values for each element. Table C.2a is derived from the EPA Office of Radiation and Indoor Air's 1999 "Understanding Variation In Partition Coefficient, K_d, Values, Volume 1: The K_d Model of Measurement, And Application Of Chemical Reaction Codes, & Volume 2: Review Of Geochemistry And Available K_d Values For Cadmium, Cesium, Chromium, Lead , Plutonium, Radon, Strontium, Thorium, Tritium, And Uranium". The K_d values in Table C.2a are the most conservative values provided for each element in (EPA 1999). Each of these values are based on the chemical behavior that was considered to provide the most conservative K_d value for that element. Users that have measured pH values at their site that differ from the range given in this report, may want to consult Tables 5.4 to 5.9 in the TBD for alternative K_ds that are still conservative.

The K_d values in Table C.2b are the most conservative values provided by Sheppard and Thibault (Sheppard, 1990) for the remaining elements not addressed in (EPA 1999), that are not based on soil-to-plant transfer. EPA recommends that K_ds based on soil-to-plant uptake data should not be used when estimating migration of contaminants from soil to groundwater.

When estimating migration of contaminants from soil to groundwater for a contaminant which is not represented with a default K_d value in either Table C.2a and C.2b, site decision-makers should develop a site-specific K_d. Site decision-makers also may measure a site-specific K_ds to more accurately estimate contaminant migration rather than using the default values in either Tables C.2a or C.2b or Tables 5.4 to 5.9 in the TBD.

Table C.2a Default K_d Values for Selected Elements

Element	K_d value	Element	K_d value
Cs	10	Sr	1
H	0	Th	20
Pu	5	U	0.4
Rn	0		

Source: EPA, 1999

Table C.2b Sheppard and Thibault's Default K_d Values for Selected Elements

Element	K_d value	Element	K_d value	Element	K_d value
Ac	NDA	Eu	NDA	Pa	NDA
Ag	2.7	Fe	3.1	Pb	6
Am	8.2	Gd	NDA	Pm	NDA
Bi	NDA	I	0.03	Ra	3
C	0.8	K	NDA	Ru	5
Cd	2.7	Mn	4.9	Sb	NDA
Ce	35	Na	NDA	Sm	NDA
Cl	NDA	Nb	NDA	Tc	0.007
Cm	86	Ni	34	Tl	NDA
Co	0.1	Np	0.1	Zn	0.1

Source: Sheppard, 1990

NDA: No Default K_d Available. A K_d for this element must be developed on a site-specific basis to evaluate the potential for fate and transport of this contaminant from the soil to groundwater.

C.3 Soil-to-Plant Transfer Factors

The soil-to-plant transfer factor is defined as the ratio of the concentration of the principal radionuclide in plant in pCi/g to the concentration of the radionuclide in soil in pCi/g. This factor is also known as the plant root uptake factor. The soil-to-plant or soil-to-vegetation transfer factor, for a given type of plant and for a given radionuclide can vary considerably from site to site with season and time after contamination. These variations depend on such factors as the physical and chemical properties of the soil, environmental conditions, and chemical form of the radionuclide in the soil. Furthermore, soil management practices such as ploughing, liming, fertilizing and irrigation can also effect the uptake of radionuclides by vegetation. Readers are referred to the TBD for a discussion of the variability of this parameter. This is a chemical/radionuclide specific parameter. The default values for different radionuclides are presented in Table C.3.

Table C.3 Default Soil-to-Plant Transfer Factors

Elem	TF_p	Elem	TF_p	Elem	TF_p	Elem	TF_p
H	4.8	Cu	0.13	In	0.003	W	0.018
Be	0.004	Zn	0.4	Sn	0.0025	Ir	0.03
C	5.5	Ge	0.4	Sb	0.01	Au	0.1
N	7.5	As	0.08	Te	0.6	Hg	0.38
F	0.02	Se	0.1	I	0.02	Tl	0.2
Na	0.05	Br	0.76	Xe	0	Pb	0.01
Al	0.004	Kr	0	Cs	0.04	Bi	0.1
P	1	Rb	0.13	Ba	0.005	Po	0.001
S	0.6	Sr	0.3	La	0.0025	Rn	0
Cl	20	Y	0.0025	Ce	0.002	Ra	0.04
Ar	0	Zr	0.001	Pr	0.0025	Ac	0.0025
K	0.3	Nb	0.01	Nd	0.0024	Th	0.001
Ca	0.5	Mo	0.13	Pm	0.0025	Pa	0.01
Sc	0.002	Tc	5	Sm	0.0025	U	0.0025
Cr	0	Ru	0.03	Eu	0.0025	Np	0.02
Mn	0.3	Rh	0.13	Gd	0.0025	Pu	0.001
Fe	0.001	Pd	0.1	Tb	0.0026	Am	0.001
Co	0.08	Ag	0.15	Ho	0.0026	Cm	0.001
Ni	0.05	Cd	0.3	Ta	0.02	Cf	0.001

Source: ANL, 1993.

Attachment D

Regulatory and Human Health Benchmarks Used for Radionuclide SSL Development

Attachment D

Regulatory and Human Health Benchmarks Used for Radionuclide SSL Development

D.1 Current Radionuclide Slope Factors

The slope factors listed in Table D.1 are taken from the Health Effects Assessment Summary Tables (HEAST) which may be found on the internet at the following address: http://www.epa.gov/superfund/programs/risk/calctool.htm. The slope factors are derived primarily from *Health Risks from Low-Level Environmental Exposure to Radionuclides, Federal Guidance Report No. 13, Part I -* , U.S. EPA, 1999 (also known as FGR13). Table D.1 lists cancer slope factors for each route of intake for principal radionuclides in units of picocuries (pCi).[1] Radionuclides are presented alphabetically by element.

Selected radionuclides and radioactive decay chain products are designated with the suffix "+D" (e.g., U-238+D, Ra-226+D, Cs-137+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. Decay chains are identified in Attachment C, Table C.1.

In most cases, site-specific analytical data should be used to establish the actual degree of equilibrium between each parent radionuclide and its decay products in each media sampled. However, in the absence of empirical data, the "+D" values for radionuclides should be used unless there are compelling reasons not to.

Note that there may be circumstances, such as long disposal times or technologically enhanced concentrations of naturally occurring radionuclides, that may necessitate the combination of the risks of a parent radionuclide and its decay products over several contiguous subchains. For example, Ra-226 soil analyses at a site might show that all radium decay products are present in secular equilibrium down to stable Pb-206. In this case, Ra-226 risk calculations should be based on the ingestion, inhalation and external exposure slope factors for the Ra-226+D subchain, plus the ingestion, inhalation and external exposure factors for the Pb-210+D subchain. For actual sites, users should consult with a health physicist or radiochemist (1) to evaluate the site-specific analytical data to determine the degree of equilibrium between parent radionuclides and decay members of contiguous decay chains and (2) to assist in the combination of appropriate slope factor values.

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[1] Slope factors are reported in the customary units of picocuries (1 pCi = 10^{-12} curies (Ci) = 3.7×10^{-2} nuclear transformations per second) for consistency with the system used for radionuclides in the IRIS database. If required, slope factors in Table 4 can be converted into the International System (SI) units of becquerels (1 Bq = 1 nuclear transformation per second) by multiplying each inhalation, ingestion, or external exposure value by 27.03. Users can calculate cancer risks using slope factors expressed in either customary units or SI units with equivalent results, provided that they also use air, water and soil concentration values in the same system of units.

Table D.1 Radionuclide Cancer Morbidity - Slope Factors (1)

	Slope Factor (Morbidity Risk Coefficient) Lifetime Excess Cancer Risk per Unit Exposure					
Radionuclide	Water Ingestion (risk/pCi)	Food Ingestion (risk/pCi)	Soil Ingestion (risk/pCi)	Inhalation (risk/pCi)	External Exposure (risk/yr per PCi/g soil)	Notes
Ac-227+D	4.86E-10	6.53E-10	1.16E-09	2.09E-07	1.47E-06	2
Ag-108m+D	8.14E-12	1.12E-11	1.92E-11	2.67E-11	7.19E-06	2
Ag-110m+D	9.88E-12	1.37E-11	2.37E-11	2.83E-11	1.30E-05	2
Am-241	1.04E-10	1.34E-10	2.17E-10	2.81E-08	2.76E-08	
Am-243+D	1.08E-10	1.42E-10	2.32E-10	2.70E-08	6.36E-07	2
Bi-207	5.66E-12	8.14E-12	1.49E-11	2.10E-11	7.08E-06	
C-14	1.55E-12	2.00E-12	2.79E-12	7.07E-12	7.83E-12	3
Cd-109	5.00E-12	6.70E-12	1.14E-11	2.19E-11	8.73E-09	
Ce-144+D	3.53E-11	5.19E-11	1.02E-10	1.10E-10	2.44E-07	2
Cl-36	3.30E-12	4.44E-12	7.66E-12	2.50E-11	1.74E-09	
Cm-243	9.47E-11	1.23E-10	2.05E-10	2.69E-08	4.19E-07	
Cm-244	8.36E-11	1.08E-10	1.81E-10	2.53E-08	4.85E-11	
Co-57	1.04E-12	1.49E-12	2.78E-12	2.09E-12	3.55E-07	
Co-60	1.57E-11	2.23E-11	4.03E-11	3.58E-11	1.24E-05	
Cs-134	4.22E-11	5.14E-11	5.81E-11	1.65E-11	7.10E-06	
Cs-135	4.74E-12	5.88E-12	7.18E-12	1.86E-12	2.36E-11	
Cs-137+D	3.04E-11	3.74E-11	4.33E-11	1.19E-11	2.55E-06	2
Eu-152	6.07E-12	8.70E-12	1.62E-11	9.10E-11	5.30E-06	
Eu-154	1.03E-11	1.49E-11	2.85E-11	1.15E-10	5.83E-06	
Eu-155	1.90E-12	2.77E-12	5.40E-12	1.48E-11	1.24E-07	
Fe-55	8.62E-13	1.16E-12	2.09E-12	7.99E-13	0	
Gd-153	1.52E-12	2.22E-12	4.26E-12	6.55E-12	1.62E-07	
H-3	5.07E-14	6.51E-14	9.25E-14	5.62E-14	0	4
I-129	1.48E-10	3.22E-10	2.71E-10	6.07E-11	6.10E-09	5
K-40	2.47E-11	3.43E-11	6.18E-11	1.03E-11	7.97E-07	
Mn-54	2.28E-12	3.11E-12	5.14E-12	5.88E-12	3.89E-06	
Na-22	9.62E-12	1.26E-11	1.97E-11	3.89E-12	1.03E-05	
Nb-94	7.77E-12	1.11E-11	2.05E-11	3.77E-11	7.29E-06	
Ni-59	2.74E-13	3.89E-13	7.33E-13	4.66E-13	0	
Ni-63	6.70E-13	9.51E-13	1.79E-12	1.64E-12	0	
Np-237+D	6.74E-11	9.10E-11	1.62E-10	1.77E-08	7.97E-07	2
Pa-231	1.73E-10	2.26E-10	3.74E-10	4.55E-08	1.39E-07	
Pb-210+D	1.27E-09	3.44E-09	2.66E-09	1.39E-08	4.21E-09	2
Pm-147	1.69E-12	2.48E-12	4.88E-12	1.61E-11	3.21E-11	
Pu-238	1.31E-10	1.69E-10	2.72E-10	3.36E-08	7.22E-11	
Pu-239	1.35E-10	1.74E-10	2.76E-10	3.33E-08	2.00E-10	
Pu-240	1.35E-10	1.74E-10	2.77E-10	3.33E-08	6.98E-11	
Pu-241	1.76E-12	2.28E-12	3.29E-12	3.34E-10	4.11E-12	
Pu-242	1.28E-10	1.65E-10	2.63E-10	3.13E-08	6.25E-11	
Pu-244+D	1.44E-10	1.90E-10	3.14E-10	2.93E-08	1.51E-06	2
Ra-226+D	3.86E-10	5.15E-10	7.30E-10	1.16E-08	8.49E-06	2
Ra-228+D	1.04E-09	1.43E-09	2.29E-09	5.23E-09	4.53E-06	2
Ru-106+D	4.22E-11	6.11E-11	1.19E-10	1.02E-10	9.66E-07	2
Sb-125+D	5.13E-12	7.21E-12	1.32E-11	1.93E-11	1.81E-06	2
Sm-147	3.74E-11	4.77E-11	7.59E-11	6.88E-09	0	
Sm-151	5.55E-13	8.07E-13	1.59E-12	4.88E-12	3.60E-13	
Sr-90+D	7.40E-11	9.53E-11	1.44E-10	1.13E-10	1.96E-08	2
Tc-99	2.75E-12	4.00E-12	7.66E-12	1.41E-11	8.14E-11	
Th-228+D	3.00E-10	4.22E-10	8.09E-10	1.43E-07	7.76E-06	2
Th-229+D	5.28E-10	7.16E-10	1.29E-09	2.25E-07	1.17E-06	2
Th-230	9.10E-11	1.19E-10	2.02E-10	2.85E-08	8.19E-10	
Th-232	1.01E-10	1.33E-10	2.31E-10	4.33E-08	3.42E-10	
Tl-204	5.85E-12	8.25E-12	1.54E-11	2.45E-12	2.76E-09	
U-232	2.92E-10	3.85E-10	5.74E-10	1.95E-08	5.98E-10	
U-233	7.18E-11	9.69E-11	1.60E-10	1.16E-08	9.82E-10	
U-234	7.07E-11	9.55E-11	1.58E-10	1.14E-08	2.52E-10	
U-235+D	7.18E-11	9.76E-11	1.63E-11	1.01E-08	5.43E-07	2
U-236	6.70E-11	9.03E-11	1.49E-10	1.05E-08	1.25E-10	
U-238+D	8.71E-11	1.21E-10	2.10E-10	9.35E-09	1.14E-07	2

Radionuclide	Water Ingestion (risk/pCi)	Food Ingestion (risk/pCi)	Soil Ingestion (risk/pCi)	Inhalation (risk/pCi)	External Exposure (risk/yr per PCi/g soil)	Notes
Zn-65	1.17E-11	1.54E-11	2.45E-11	5.81E-12	2.81E-06	

Notes:

1. A curie (Ci), the customary unit of activity, is equal to 3.7 x 10^{10} nuclear transformations per second. 1 picocurie (pCi) = 10^{-12} Ci. If required, slope factors in Table D.1 can be converted into the International System (SI) units of becquerels (1 Bq = 1 nuclear transformation per second) by multiplying each inhalation, ingestion, or external exposure value by 27.03. Users can calculate cancer risks using slope factors expressed in either customary units or SI units with equivalent results, provided that they also use air, water, food and soil concentration values in the same system of units.

2. For each radionuclide listed, slope factors correspond to the risks per unit intake or exposure for that radionuclide only, except when marked with a "+D". In these cases, the risks from associated short-lived radioactive decay products (i.e., those decay products with radioactive half-lives less than or equal to 6 months) are also included, based on an assumption of secular equilibrium. These decay chains are identified in Table C.1 of Attachment C.

3. The inhalation slope factor listed represents inhalation of C-14 as a particulate. Alternative values for inhalation of C-14 as a gas are 3.36E-15 risk/pCi for carbon monoxide and 1.99E-14 risk/pCi for carbon dioxide.

4. The inhalation slope factor for H-3 represents inhalation of titiated water vapor, which is considered the most likely form in the environment. Alternative values of inhalation of H-3 include 1.99E-13 risk/pCi for particulates, 5.62E-18 risk/pCi for elemental hydrogen gas, and 1.28E-13 risk/pCi for organic forms. Similarly, the ingestion slope factor values for H-3 represent ingestion of tritiated water, which is considered the most likely form in the environment. Alternative values for ingestion of organically bound forms of H-3 in water, food, and soil are 1.12E-13 risk/pCi, 1.44E-13 risk/pCi, and 2.02E-13 risk/pCi, respectively.

5. The food ingestion slope factor for I-129 represents ingestion of milk. For ingestion of non-dairy foodstuffs, a lower value of 1.93E-10 risk/pCi ingested would apply. The inhalation slope factor for I-129 represents inhalation of particulates; alternative values for inhalation of I-129 vapor are 1.24E-10 for inhalation of methyl iodide and 1.60E-10 for inhalation of other compounds in vapor form.

D.2 MCLs for Radionuclides in Drinking Water

Current MCLs for radionuclides are set at 4 mrem/yr for the sum of the doses from beta particles and photon emitters, 15 pCi/L for gross alpha particle activity (including Ra-226, but excluding uranium and radon), and 5 pCi/L combined for Ra-226 and Ra-228. The current MCLs for beta emitters specify that MCLs are to be calculated based upon an annual dose equivalent of 4 mrem to the total body or any internal organ. It is further specified that the calculation is to be performed on the basis of a 2 liter per day drinking water intake using the 168 hours data listed in "*Maximum Permissible Body Burdens and Maximum Permissible Concentrations of Radionuclides in Air or Water for Occupational Exposure,*" NBS Handbook 69 as amended August 1963, U.S. Department of Commerce (U.S. DOC, 1963). These calculations have been done for most beta emitters and published as part of the EPA Office of Water Supply's National Interim Primary Drinking Water Regulations, Report EPA-570/9-76-003 (U.S, EPA, 1976). The calculated MCLs are included in Table D.2. For those beta emitters not included in EPA-570/9-76-00, MCLs have been calculated, for purposes of this guidance, using the existing MCL methodology, and are also included in Table D.2.

In July 1991, EPA proposed to revise the MCLs for Ra-226 and Ra-228 to 20 pCi/L for each, change the methodology used for determining a 4 mrem/yr dose for the sum of the doses from beta particles and photon emitters, alter the definition of alpha particle activity to exclude Ra-226, and establishing new MCLs of 300 pCi/L for Rn-222 and 20 µg/L (30 pCi/L) for uranium (56 FR 33050). EPA is under Court Order to either finalize the 1991 proposal for radionuclides (except for radon), or to ratify existing standards by November 2000. On April 21, 2000 EPA solicited comment in a Notice of Data Availability (NODA) on three options for a uranium MCL: 1) 20 μg/l **and** 20 pCi/l as a preferred option, 2) 40 μg/l **and** 40 pCi/l, and 3) 80 μg/l **and** 80 pCi/l (65 FR 21576). In this NODA, EPA indicated that changes would not be made to the existing MCLs for radium, alpha particle activity, and beta particles and photon emitters. The 1996 Amendments to the Safe Drinking Water Act (SDWA) require EPA to propose a MCL for radon by August 1999, and to finalize the MCL by August 2000. To comply with the requirements of the amended SDWA, on August 6, 1997, EPA withdrew its 1991 proposal for Rn-222 (62 FR 42221). EPA issued a new proposal for Rn-222 (65 FR 21576). EPA proposed an MCL of 300 pCi/l with an alternative MCL of 4,000 pCi/l if a state or local indoor radon mitigation program was established.

Table D.2 Radionuclide Drinking Water MCLs

Radionuclide	Current MCL[a, b] (pCi/L)	Proposed MCL (pCi/L)	Risk Base Limit (RBL)[e] (pCi/L)	Mass Equiv to MCL, Proposed MCL, or RBL (mg/L)
Ac-227			0.24	3.3E-12
Ag-108m			5.8	2.2E-10
Ag-110m	90			1.9E-11
Am-241	15			4.4E-09
Am-243	15			7.5E-08
Bi-207	200			4.4E-09
C-14	2,000			4.5E-07
Cd-109	600			2.3E-10
Ce-144	30			9.1E-12
Cl-36	700			2.1E-05
Cm-243	15			2.9E-10
Cm-244	15			1.9E-10
Cm-248	15			3.5E-06
Co-57	1,000			1.2E-10
Co-60	100			8.9E-11
Cs-134	80			6.2E-11
Cs-135	900			7.8E-04
Cs-137	200			2.3E-09
Eu-152	200			1.1E-09
Eu-154	60			2.3E-10
Eu-155	600			1.3E-09
Fe-55	2,000			8.3E-10
Gd-153	600			1.7E-10
H-3	20,000			2.1E-09
I-129	1			5.7E-06
K-40			1.9	2.7E-4
Mn-54	300			3.9E-11
Na-22	400			6.4E-11
Nb-94			6.1	3.3E-8
Ni-59	300			3.7E-06
Ni-63	50			8.5E-10
Np-237	15			2.1E-05
Pa-231	15			3.2E-07
Pb-210			0.054	7.1E-13
Pm-147	587			6.3E-10
Pu-238	15			8.8E-10

Table D.2 Radionuclide Drinking Water MCLs

Radionuclide	Current MCL[a, b] (pCi/L)	Proposed MCL (pCi/L)	Risk Base Limit (RBL)[e] (pCi/L)	Mass Equiv to MCL, Proposed MCL, or RBL (mg/L)
Pu-239	15			2.4E-07
Pu-240	15			6.6E-08
Pu-241			27	2.6E-10
Pu-242	15			3.8E-06
Pu-244	15			8.5E-04
Ra-226	5[c]			5.1E-09
Ra-228	5[c]			1.8E-11
Ru-106	30			9.0E-12
Sb-125	300			2.9E-10
Sm-147	15			6.5E-01
Sm-151	1,000			3.8E-08
Sr-90	8			5.9E-11
Tc-99	900			5.3E-05
Th-228	15			1.8E-11
Th-229	15			7.1E-08
Th-230	15			7.4E-07
Th-232	15			1.4E-01
Tl-204	300			6.5E-10
U-232		20[d]		9.4E-10
U-232		(20 μg/l)[d]		2.0E-02
U-233		20[d]		2.1E-06
U-233		(20 μg/l)[d]		2.0E-02
U-234		20[d]		3.2E-06
U-234		(20 μg/l)[d]		2.0E-02
U-235		20[d]		9.3E-03
U-235		(20 μg/l)[d]		2.0E-02
U-236		20[d]		3.1E-04
U-236		(20 μg/l)[d]		2.0E-02
U-238		20[d]		6.0E-02
U-238		(20 μg/l)[d]		2.0E-02
Zn-65	300			3.6E-11

Notes:

[a] Existing MCL is 4 mrem/yr to the whole body or an organ, combined from all beta and photon emitters.

[b] Existing MCL is 15 pCi/L, with the concentration level combined for all alpha emitters, except radon and uranium.

[c] Existing MCL is 5 pCi/L combined for Ra-226 and Ra-228.

[d] Preferred EPA proposed MCL standard is 20 μg/l and 20 pCi/l for uranium, with EPA soliciting comments on options of 40 μg/l **and** 40 pCi/l, and 80 μg/l **and** 80 pCi/l. The preferred proposed MCL standard for uranium of 20 μg/l and 20 pCi/l is represented in this table.

[e] Risk Based Limits calculated for 30-year exposure duration and 10^{-6} risk. These were calculated using equation 11´ in *Risk Assessment Guidance for Superfund* (RAGS)*: Volume i: Human Health Evaluation Manual (Part B, Development of Risk-based Preliminary Remediation Goals)*, (page 37). The equations were adjusted to account for radioactive decay.