

Table 1. EPA's Hazard Ranking System Criteria for Establishing Radionuclide Contamination/Releases*

Based on:	Criteria for Establishing Observed Contamination or Observed Releases of Radionuclides
Direct Observation	Applies to All Radionuclides
	<ul style="list-style-type: none"> (i) For each migration pathway, a material that contains one or more radionuclides has been seen entering the atmosphere, surface water, or ground water, as appropriate, or is known to have entered ground water or surface water through direct deposition, or (ii) For the surface water migration pathway, a source area containing radioactive substances has been flooded at a time that radioactive substances were present and one or more radioactive substances were in contact with the flood waters.
Analysis of Radionuclide Concentrations in Samples (ground water, soil, air, surface water, benthic, or sediment samples)	Applies to Naturally Occurring Radionuclides and Man-made Radionuclides With Ubiquitous Background Concentrations in the Environment
	<ul style="list-style-type: none"> (i) Measured concentrations (in units of activity, for example pCi per kilogram [pCi/kg], pCi per liter [pCi/L], pCi per cubic meter [pCi/m³]) of a given radionuclide in the sample are at a level that: <ul style="list-style-type: none"> (a) Equals or exceeds a value 2 standard deviations above the mean site-specific background concentration for that radionuclide in that type of sample, or (b) Exceeds the upper-limit value of the range of regional background concentration values for that specific radionuclide in that type of sample. (ii) Some portion of the increase must be attributed to the site to establish the observed release (or observed contamination). (iii) For the soil exposure pathway only, the radionuclide must also be present at the surface or covered by 2 feet or less of cover material (for example, soil) to establish observed contamination. **
	Applies to Man-made Radionuclides Without Ubiquitous Background Concentrations in the Environment:
<ul style="list-style-type: none"> (i) Measured concentrations (in units of activity) of a given radionuclide in the sample equals or exceeds the sample quantitation limit for that specific radionuclide in that type of media and is attributable to the site. <ul style="list-style-type: none"> (a) However, if the radionuclide concentration equals or exceeds its sample quantitation limit, but its release can also be attributed to one or more neighboring sites, then the measured concentration of that radionuclide must also equal or exceed a value either 2 standard deviations above the mean concentration of that radionuclide contributed by the neighboring sites or 3 times its background concentration, whichever is lower. (ii) If the sample quantitation limit cannot be established: <ul style="list-style-type: none"> (a) use the EPA contract-required quantitation limit (CRQL) in place of the sample quantitation limit in establishing an observed release (or observed contamination) if the sample analysis was performed under the EPA Contract Laboratory Program, or (b) use the detection limit in place of the sample quantitation limit if the sample analysis is not performed under the EPA Contract Laboratory Program. (iii) For the soil exposure pathway only, the radionuclide must also be present at the surface or covered by 2 feet or less of cover material (for example, soil) to establish observed contamination.** 	
Gamma Radiation Exposure Rate Measurements	Applies to Gamma-Emitting Radionuclides
	<ul style="list-style-type: none"> (i) The gamma radiation exposure rate in microroentgens per hour (μR/hr) using a survey instrument held 1 meter away from the ground surface (or 1 meter away from an aboveground source), equals or exceeds 2 times the site-specific background gamma radiation exposure rate. (ii) Some portion of the increase must be attributable to the site to establish observed contamination. (iii) The gamma-emitting radionuclides do not have to be within 2 feet of the surface of the source.

* Source: *Hazard Ranking System; Final Rule*, Environmental Protection Agency, 55 FR 51532, December 14, 1990.

** Note: This criterion should not be interpreted to mean that radionuclides present in soils at depths greater than 2 feet below the surface would not warrant investigation and potential response action, but only that such materials may not be readily detected by surface measurements.

Q4. How should the areal extent and depth of radioactivity contamination be determined?

- A. As noted in Q1, a conceptual site model should be developed to identify reasonable boundaries for investigating the nature and extent of contamination. General guidance for site characterization activities is provided in *Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA* (U.S. EPA 1988a).

The choice of a specific method or methods to characterize sites contaminated with radioactive substances depends on several factors, including the decay characteristics of the radionuclides potentially present at the site, suspected contamination patterns, and activity concentrations. For gamma-emitting radionuclides in near-surface sources, walk-over radiation surveys are typically conducted to characterize the areal extent of contamination. For subsurface contamination, borehole logging for gamma emitters, core sampling programs for radionuclides that emit only alpha or beta particles, or a combination of both types of methods, may be advisable. In addition to measurements to determine volumetric contamination in environmental media, measurements of surface contamination on building and equipment surfaces may also be required. Additional discussion of measurement techniques and their limitations is provided in MARSSIM (U.S. EPA et al. 1997). For site-specific assessments, readers should consult the appropriate EPA Regional Radiation Program Office or Regional Superfund Office.

Q5. What field radiation survey instruments should be used and what are their lower limits of detection?

- A. Selection of appropriate radiation detection instruments for site characterization depends on the decay characteristics of the radionuclides potentially present at the site, suspected contamination patterns, and activity concentrations, among other factors. Numerous documents have been written on this topic. For a general discussion on radiation survey instruments, readers are directed to MARSSIM (U.S. EPA 402-R-96-018) and Chapter 10 of RAGs Part A (U.S. EPA, 1989a). For supplemental information regarding the usability of analytical data for performing a baseline risk assessment at sites contaminated with radioactivity, readers should refer to "Guidance for Data Usability in Risk Assessment, Part B" (U.S. EPA, 1992d). For site-specific applications of field radiation survey instruments, readers should contact their appropriate Regional Radiation Program Office or Regional Superfund Office.

Q6. What sample measurement units for radiation risk assessment are typically used?

- A. Concentrations of radionuclides in environmental media are typically expressed in terms of "activity" of the radionuclide per unit mass (for soil, sediment, and food-

stuffs) or volume (for water and air) of the environmental medium. Two different systems of units for radioactivity are currently in common usage: the International System (SI) units and the "conventional" or "traditional" units which were used before the advent of the SI system. The principal unit of radioactivity in the SI system is the becquerel (1 Bq = 1 disintegration/second), while the basic conventional unit of activity is the Curie (1 Ci = 3.7×10^{10} Bq). Since most radiation standards in the U.S. are expressed in conventional units, this system is used for the purpose of this document. Concentrations of radionuclides in environmental media at contaminated sites are typically far below Curie quantities, and are commonly expressed in units of picocuries (1 pCi = 10^{-12} Ci = 3.7×10^{-2} Bq). Typical conventional units for reporting environmental measurements are pCi/g for soil (dry-weight), pCi/L for groundwater or surface water, and pCi/m³ for air.

A special unit, the working level (WL), is used as a measure of the concentration of short-lived radon decay products in air. WL is any combination of short-lived radon decay products in one liter of air that will result in the ultimate emission of 1.3×10^5 million electron volts (MeV) of alpha energy. The Working Level Month (WLM) is the exposure to 1 WL for 170 hours (1 working month).

In addition to radionuclide concentrations in environmental media, the radiation "exposure" rate is often reported. Radiation exposure, in this context, refers to the transfer of energy from a gamma radiation field to a unit mass of air. The unit for radiation exposure is the roentgen (1 R = 2.58×10^{-4} coulombs of charge per kg of air). Exposure rates at contaminated sites are typically expressed in units of microroentgens/hour (μ R/hr).

Radionuclide concentrations on building or equipment surfaces are specified in units of the activity concentrations of the radionuclide of concern in a specified surface area, typically dpm (disintegration per minute) per 100 cm² or pCi per 100 cm².

Q7. What sample measurement units for remedial action evaluation may be used?

For remedial action evaluations it is often useful to express radionuclide concentrations in terms of mass (mass concentration). The carcinogenic effects of a radionuclide are due to its disintegration rate that occurs during its decay process, **concentrations of radionuclides are generally measured in terms of activity for health evaluation purposes.** Mass units, however, provide insight and information into treatment selection, treatment compatibility, and treatment efficiency, particularly for remedial actions involving mixed waste. The practice of using activity concentration should continue for response actions at CERCLA sites. Mass concentration estimates contained in proposed and final site decision documents [e.g., proposed plans, Record of Decisions (RODs)] may

include, in addition to activity measurements, estimates of concentrations in terms of mass consistent with those used for non-radiological contaminants. Typically units for expressing mass in environmental media for soil and water are mg/kg for soil and mg/l for water. These mass units also can be expressed as parts per million (ppm) for soil and water, which is equivalent to mg/kg and mg/l. To estimate the radionuclide concentrations in ppm, the following equations are given below:

$$\text{mg/kg}_{\text{soil}} = (2.8 \times 10^{-12}) \times A \times T_{1/2} \times \text{pCi/g}$$

$$\text{mg/l}_{\text{water}} = (2.8 \times 10^{-15}) \times A \times T_{1/2} \times \text{pCi/l}$$

$$\text{ppm}_{\text{soil}} = (2.8 \times 10^{-12}) \times A \times T_{1/2} \times \text{pCi/g}$$

$$\text{ppm}_{\text{water}} = (2.8 \times 10^{-15}) \times A \times T_{1/2} \times \text{pCi/l}$$

where A is the radionuclide atomic weight and $T_{1/2}$ is the radionuclide half-life in years. Most radionuclides have half-lives ranging from a few years to 10,000 years, which means that for most radionuclides, an activity of 1 pCi/g would mean the concentration value of the radionuclide would be well under 1×10^{-6} ppm.

Q8. Are radionuclides included in EPA's Contract Laboratory Program (CLP)? If not, where should comparable radioanalytical services be obtained?

A. Radionuclides are not standard analytes in EPA's CLP program. However, EPA has published guidance for radionuclide methods in Chapter 10 of *RAGS Part A* (U.S. EPA, 1989a). In addition, EPA's *Radiochemistry Procedures Manual* (U.S. EPA, 1984) provides information for radionuclide-specific analytical techniques. For additional guidance on selection of radiological laboratories and analytical methods, readers should contact the appropriate Regional Radiation Program Office or Regional Superfund Office, NAREL, or RIENL.

Q9. How can I decide if the data collected are complete and of good quality?

A. EPA's *Guidance for Data Quality Assessment* (U.S. EPA, 1995), *Guidance for Data Useability in Risk Assessment, Part A* (U.S. EPA, 1992c) and *Part B* (U.S. EPA, 1992d), provide procedures and statistical tests that may be used to determine whether or not collected data are of the correct type, quality, and quantity to support their intended use. In addition, the MARSSIM (U.S. EPA et al. 1997) addresses quality assurance and quality control requirements for radiological data.

II. EXPOSURE ASSESSMENT

Q10. How does the exposure assessment for radionuclides differ from that for chemicals?

A. Exposure assessment for radionuclides is very similar to that for chemicals. Both nonradioactive chemical assessments and radionuclide assessments follow the same basic steps—i.e., characterizing the exposure setting, identifying exposure pathways and potential receptors, estimating exposure point concentrations, and estimating exposures/intakes. In addition to the exposure pathways considered for chemicals (e.g., ingestion of contaminated water, soil, or foodstuffs, and inhalation of contaminated air), external exposure to penetrating radiation (i.e., gamma radiation and x-rays) may be an important exposure pathway for certain radionuclides in near-surface soils. On the other hand, with the primary exception of tritium (H-3) as tritiated water or water vapor, dermal absorption is typically not a significant exposure pathway for radionuclides and generally need not be considered. (Other possible exceptions could include organic compounds containing radionuclides.) Figure 1 depicts typical exposure pathways for radionuclides; additional pathways that may be considered on a site-specific basis, where appropriate, are discussed in Q11. Additional discussion of radiation exposure pathways is provided in the *Radiation Exposure and Risk Assessment Manual (RERAM)*, June 1996 (EPA 402-R-96-016).

Q11. Can exposure pathways be added or deleted based on site-specific conditions?

A. Yes. Inclusion or deletion of exposure pathways should be based upon site-specific conditions, including local hydrology, geology, potential receptors, and current and potential future land use, among other factors. Accordingly, some exposure pathways may not be appropriate for a given site and may be deleted, if justification is provided. In other cases, exposure pathways that are typically not significant may be important for the site-specific conditions (e.g., ingestion of contaminated fish for recreational scenarios, ingestion of contaminated meat or milk from livestock for agricultural scenarios) and should be included in the assessment.

Q12. How should radioactive decay products be addressed?

A. All radionuclides, by definition, undergo radioactive decay. In this process, one unstable nucleus of an element transforms (decays) spontaneously to a nucleus of another element. As the unstable nucleus decays, energy is released as particulate or photon radiation, or both, and the radionuclide is transformed in atomic number and/or atomic mass. The resulting decay products, or progeny, may also be radioactive and undergo further decay. Various decay products may have different physical and chemical characteristics that affect their fate and transport in the environment as well as their radiotoxicity. In cases where decay products have greater radiotoxicity than the original radionuclide, the potential radiation dose and health risk may increase over time; in such cases, the exposure assessment should consider the change in concentrations of

all decay products over time, to determine the time of maximum potential impact.

Consideration of all potential radioactive decay products is a key element of the exposure assessment for radionuclides. Many of the computerized mathematical models available for simulating the behavior of radionuclides in the environment (see Q15) incorporate the ingrowth and decay of radioactive decay products as a function of time; these models are very useful in pinpointing the time of maximum dose or risk. Similarly, slope factors (see Q20) and dose conversion factors (see Q21) for some radionuclides may include consideration of radioactive decay products, where appropriate, to facilitate these considerations in estimating potential radiation dose and risk. However, such values typically assume that all decay products are present at the same concentration as the primary radionuclide (i.e., secular equilibrium), which may not be appropriate for all situations. Readers should consult their Regional Radiation Program Office or Regional Superfund Office for additional information regarding such limitations. See also section "Modeling Assessment of Future Exposures" in OSWER Directive 9200.4-18 (U.S. EPA 1997a) for information modeling decay products.

Q13. To what extent should generic and site-specific factors and parameter values be used in exposure assessments?

- A. For both radionuclide and chemical assessments, EPA recommends the use of empirically-derived, site-specific factors and parameter values, where such values can be justified and documented. For generic assessments, EPA recommends the use of the default parameter values provided in OSWER Directive 9285.6-03 *Standard Default Exposure Factors* (U.S. EPA, 1991c) and the *Exposure Factors Handbook* (U.S. EPA, 1990, 1997b).

Q14. How should exposure point concentrations be determined?

- A. As for chemical contaminants, exposure point concentrations of radionuclides in environmental media and radiation exposure rates (e.g., alpha, beta, gamma) should be either measured, modeled, or both. To the extent possible, measurement data should be used to evaluate current exposures. When measurements at the exposure locations cannot be made, or when predicting potential concentrations and exposures at future times, modeling is required (see Q15).

Q15. What calculation methods or multimedia radionuclide transport and exposure models are recommended by EPA for Superfund risk assessments?

- A. Currently, only the equations in RAGS Part B (U.S. EPA, 1991a) - which are used to develop risk-based preliminary remediation goals for hazardous chemicals and radio-

nuclides - are recommended by EPA for Superfund radiation risk assessments. (Note: The *Soil Screening Guidance for Radionuclides* (U.S. EPA 1998d) is expected to supersede the RAGS Part B algorithms when finalized.) Numerous computerized mathematical models have been developed by EPA and other organizations to predict the fate and transport of radionuclides in the environment; these include single-media models (e.g., ground water transport) as well as multi-media models. These models have been designed for a variety of goals, objectives and applications, but no single model may be appropriate for all site-specific conditions. While the Agency has approved individual models for specific applications (e.g., CAP88 or COMPLY for atmospheric transport calculations to demonstrate compliance with 40 CFR Part 61 requirements), no model has yet been formally endorsed for evaluating potential impacts from radionuclides in soil. For further information on selection of models appropriate to meet a specific-site characteristics and requirements, readers can refer to *Ground-Water Modeling Compendium* (U.S. EPA 1994c), and *A Technical Guide to Ground-Water Model Selection at Sites Contaminated with Radioactive Substances* (U.S. EPA 1994d). While these documents specifically address groundwater models, the model selection criteria and logic may be useful for other types of models as well.

Attachment 1 provides a bibliography of reference documents for numerous models currently available. Readers are strongly encouraged to consult with the appropriate EPA Regional Radiation Program Office or Regional Superfund Office in which the site is located for guidance on selection and use of radionuclide fate and transport models for site-specific applications.

Q16. How should Radon-222 (radon) and Radon-220 (thoron) exposures and risks be evaluated?

- A. Radon-222 (Rn-222) and Radon-220 (Rn-220) are radioactive gases that are isotopes of the element radon (Rn). Each is produced by the radioactive decay of an isotope of radium (Ra). For Rn-222 (also called radon), the parent radium isotope is Ra-226 and for Rn-220 (also called thoron), the parent radium isotope is Ra-224. (Although thoron is produced from the radioactive decay of Ra-224, it is often referred to as a decay product of Ra-228, which is a longer-lived precursor typically measured in environmental samples.) Each radon isotope gives rise to a series or chain of short-lived radioactive decay products that emit alpha particles which can damage lung tissues if inhaled. Of the two decay chains, the radon series is longer lived and more hazardous than the thoron series. Consequently, most (but not all) radon exposure and risk assessments deal with radon (Rn-222) arising from radium (Ra-226) contamination.

Structures built on radium-contaminated soil or constructed with radium-bearing materials can accumulate elevated concentrations of radon in indoor air. Some radiation protection standards which may be potential ARARs at a site, explicitly exclude dose or risk from radon and its decay products from consideration. Other potential ARARs and to-be-considered (TBC) information directly address radon and its decay products (e.g., allowable concentrations of radon decay products in indoor air under 40 CFR 192(b)(1) of a standard of 0.003 working level (WL) and a goal of 0.002 WL, as well as the U.S. EPA Guideline of 4 pCi radon-222 per liter of indoor air).

Several EPA-approved methods are available for measuring radon and progeny concentrations in indoor air (EPA et al, 1997). Computer codes have been developed to predict radon concentrations in indoor air and potential human exposure, based on simplified equations and assumptions; these models may yield results that are meaningful on average (e.g., for a geographical region) but highly imprecise for an individual house or structure. Despite their widespread use, these codes should be used with caution and their estimates interpreted carefully.

Readers are encouraged to consult with the EPA Regional Radiation Program Office or Regional Superfund Office for specific guidance and recommendations concerning measurement of radon concentrations in indoor air, evaluation of potential exposures, and applicable

mitigation measures. Also, some states have their own radon testing and mitigation requirement or recommendations. Readers should also determine if any of the standards for radon are potential ARARs at their site (see Q 34).

Q17. How long a time period should be considered for possible future exposures?

- A. Section "Modeling Assessment of Future Exposures" in OSWER Directive 9200.4-18 (U.S. EPA 1997a) provides guidance for estimating future threats. Also, in some cases, Federal or State ARARs may include specific time-frame requirements for a given purpose, such as disposal of radioactive materials in an approved waste repository.

Q18. How should the results of the exposure assessment for radionuclides be presented?

- A. Results of the exposure assessment for radionuclides should be presented in two stages: (1) intake and external exposure estimates for use in risk characterization; and (2) estimates of radiation dose (see Q22 for discussion of specific dosimetric quantities that may be appropriate) for comparison with dose-based standards. Note that intake estimates for radionuclides should not be divided by body weight or averaging time as is done for chemical contaminants. Intake estimates for inhalation or ingestion pathways should include the total activity of each

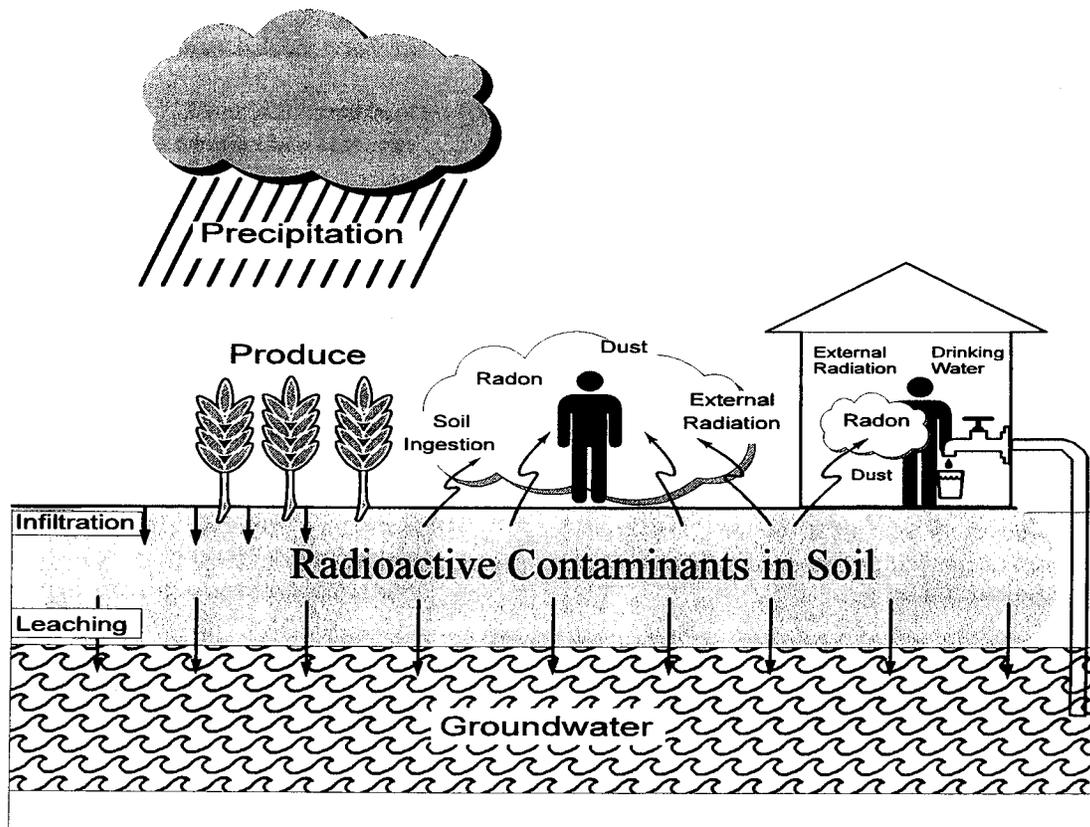


Figure 1. Typical Radionuclide Exposure Pathways