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DOE-STD-1153-2019

DOE STANDARD

A GRADED APPROACH FOR EVALUATING RADIATION DOSES TO AQUATIC AND TERRESTRIAL BIOTA

U.S. Department of Energy **AREA ENVIR**

Washington, DC 20585

Foreword

Department of Energy (DOE) activities may expose plants and animals to radioactive materials in environmental media or to radioactive materials released in waste streams. This technical standard provides methods, models and guidance within a graded approach that DOE personnel and contractors may use to characterize radiation doses to aquatic and terrestrial biota that are exposed to radioactive materials.

DOE Order 414.1D, *Quality Assurance*, defines the process for establishing a quality assurance program and employing a graded approach to be used to implement this standard. DOE elements may use a graded approach to implement the biota dose evaluations and associated guidance contained in this technical standard to address requirements for radiological protection of the environment contained in DOE Orders, specifically DOE Order 458.1, *Radiation Protection of the Public and the Environment*. The graded approach presented in this standard is also intended for use the RESRAD-BIOTA code. The RESRAD-BIOTA dose evaluation code was specifically designed to complement the graded approach and the Biota Concentration Guides (BCGs) contained herein.

These methods (and the BCGs contained in them) are not intended to be used as design criteria, indicators of the severity of accidental releases of radioactive material, or guides for mitigating the consequences of accidental releases. Furthermore, this technical standard does not apply to the irradiation of biota for experimental purposes nor to research or experimental studies.

This Standard uses the word “shall” to denote a requirement of this Standard; the word “should” denote a recommendation of this Standard; and, the word “may” denote permission, but not a requirement or a recommendation of this Standard. To satisfy this Standard, program participants need to meet all applicable “shall” statements.

DOE technical standards, such as this Standard, do not establish requirements. However, all or part of the provisions in a DOE standard can become requirements under the following circumstances:

a. They are explicitly stated as such in DOE requirements document; or
b. The organization makes a commitment to meet the standard in a contract or in an implementation plan or program plan required by a DOE requirements document.

Acknowledgements

DOE-STD-1153-2002, *A Graded Approach for Evaluating Radiation Doses to Aquatic and Terrestrial Biota*, was developed by the Department’s Air, Water and Radiation Division and a Core Team of the Biota Dose Assessment Committee (BDAC). The BDAC was a technical standards topical committee organized under the DOE Technical Standards Program. The BDAC was convened to assist in developing and promoting technical standards and associated guidance for DOE-wide applications in assessing radiation dose to biota; to serve as a major forum within DOE for obtaining technical assistance, discussing technical issues and sharing lessons learned regarding biota dose standards and assessment methods; and to serve as a technical resource and advisory group for DOE program and field elements in the design and review of site-specific biota dose assessments.

The current technical standard is a revision to DOE-STD-1153 and was prepared by the Office of Public Radiation Protection (AU-22) and a team of DOE subject matter experts. In this revision, the document

has been made more user friendly, duplicate material has been deleted, and more realistic examples have been added to assist the user in preparation of compliance documents. The team consisted of Katharine McLellan, AU-22; Michael W. McNaughton, Los Alamos National Laboratory (LANL); G. Timothy Jannik, Savannah River National Laboratory; Jeffrey J. Whicker, LANL; Ronald W. Warren, Nevada National Security Site; Patricia Scofield, Oak Ridge National Laboratory; Jessica Gillis, LANL; Elizabeth Ruedig, LANL and Charley Yu, Argonne National Laboratory (ANL). We are grateful to them for their contributions.

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Definitions

As defined and used in this technical standard:

Absorbed Dose (D) is the average energy imparted to matter by ionizing radiation per unit mass of irradiated material at the place of interest in that material. More specifically, for any radiation type and any medium, absorbed dose (D) is the total energy (e) absorbed per unit mass (m) of material: D = e/m. The absorbed dose is expressed in units of rad (gray), where 1 rad = 0.01 joule/kg material (1 gray = 100 rad). For the purposes of this technical standard, the absorbed dose in an organism is assumed to be the average value over the whole organism.

Allometric refers to the relative growth of a part in relation to the entire organism.

Alpha Particle is a helium-4 nucleus consisting of two protons and two neutrons, given off by the decay of many heavy elements, including uranium and plutonium. Because the particles are slow moving as well as heavy, a sheet of paper can block alpha radiation. However, once an alpha emitter is in living tissue, it can cause substantial damage because of the high ionization density along its path.

Aquatic Biota is plant or animal life living in or on water.

Area Factor is the correction factor for exposure and residence time for the selected organism for finite area of contamination.

Arithmetic Mean is the most commonly used measure of central tendency, commonly called the "average." Mathematically, it is the sum of all the values of a set divided by the number of values in the set:

$$\bar{X} = \frac{\sum_{i=1}^{n} X_i}{n}$$

Assessment Endpoint is an explicit expression of the environmental value that is to be protected, operationally defined by an ecological entity and its attributes. For example, salmon are valued ecological entities; reproduction and age class structure are some of their important attributes. Together "salmon reproduction and age class structure" form an assessment endpoint.

Average - See "Arithmetic Mean."

Beta Particle is an electron. It has a short range in air. Beta particles are moderately penetrating and can cause skin burns from external exposure, but can be blocked by a sheet of plywood.

Bias is a consistent underestimation or overestimation of the true values representing a population.

Bioaccumulation is the equilibrium ratio of the contaminant concentration in the fresh weight of biota relative to the contaminant concentration in an environmental medium resulting from the uptake of the contaminant from one or more routes of exposure. This ratio is typically described through a bioaccumulation factor (B_{iv}). In technical literature, this ratio may also be called "concentration ratio (CR)" or "wet-weight concentration ratio (B_{iv}s)". This ratio is considered (and sometimes called) a

"lumped parameter" because it simplifies various complex ecological, physical, and chemical transfer pathways into a single, empirically derived parameter.

Biomagnification is the tendency of some contaminants to accumulate to higher concentrations at higher levels in the food web through dietary accumulation.

Biota is plant and animal life of a particular region.

Biota Concentration Guide (BCG) is the limiting concentration of a radionuclide in soil, sediment, or water that would not cause dose rate criteria for protection of populations of aquatic and terrestrial biota (as used in this technical standard) to be exceeded.

Carnivore is a flesh-eating animal.

Chronic refers to an extended continuous exposure to a stressor or the effects resulting from such an exposure.

Community is an assemblage of populations of different species within a specified location in space and time.

Concentration Ratio: See Bioaccumulation above. In International Commission on Radiological Protection (ICRP) 114 (ICRP 2012), the concentration ratio (CR) is defined as:

$$CR = \frac{\left[\text{Activity concentration in biota whole body } \left(\frac{\text{Bq}}{\text{kg}}\text{ whole weight}\right)\right]}{\text{Activity concentration in soil } \left(\frac{\text{Bq}}{\text{kg}}\right), \text{sediment } \left(\frac{\text{Bq}}{\text{kg}}\right), \text{or filtered water } \left(\frac{\text{Bq}}{\text{L}}\right)}$$

Conceptual Model is a written description and visual representation of predicted relationships between ecological entities and the stressors to which they may be exposed.

Data Quality Objectives (DQOs) are qualitative and quantitative statements that clarify technical and quality objectives for a study, define the appropriate type of data, and specify tolerable levels of uncertainty that a data user is willing to accept in the decision. DQOs specify the problem to be solved, the decision, decision inputs, boundaries of the study, the decision rule, and the limits of uncertainty.

Deterministic Effects are those for which the severity is a function of dose, and for which a threshold usually exists.

Discharge Point is a conduit through which any radioactively contaminated gas, water, or solid is discharged to the atmosphere, waters, or soils.

Distribution Coefficient is the ratio of the mass of solute species absorbed or precipitated on the soil or sediment to the solute concentration in the water. This ratio is typically described through a K_d factor.

Ecological Relevance is one of three criteria for assessment endpoint selection. Ecologically relevant endpoints reflect important characteristics of the system and are functionally related to other endpoints.

Ecological Risk Assessment is the process that evaluates the likelihood that adverse ecological effects may occur or are occurring as a result of exposure to one or more stressors.

Effluent is any treated or untreated air emission or liquid discharge, including storm water runoff.

Effluent Monitoring is the collection and analysis of samples or measurements of liquid, gaseous, or airborne effluents for the purpose of characterizing and quantifying contaminant levels and process stream characteristics, assessing radiation exposures to members of the public and the environment, and demonstrating compliance with applicable standards.

Environmental Medium is a discrete portion of the total environment, animate or inanimate, that may be sampled or measured directly.

Environmental Surveillance is the collection and analysis of samples of air, water, soil, foodstuffs, biota, and other media and the measurement of external radiation and radioactive materials for purposes of demonstrating compliance with applicable standards, assessing radiation exposures to members of the public, and assessing effects, if any, on the local environment.

Error is the difference between an observed or measured value and its true value.

Evaluation Area is the area over which a specific dose evaluation is defined. This is the area of overlap between a contaminated area and the exposed biotic population(s).

Exposure is the co-occurrence or contact between the endpoint organism and the stressor (e.g., radiation or radionuclides).

Facility means a building, structure, or installation subject to the regulations/standards pertinent to this technical standard.

Forb is an herb other than grass.

Fresh Weight is the weight or mass of a biota sample that includes the water in a fresh or living specimen. It may also be called "fresh mass" or "wet weight" and it may be reported with units such as "grams-wet" or "g-wet".

Gamma Rays are high-energy, electromagnetic photons that are highly penetrating; several inches of lead or several feet of concrete are necessary to shield against them.

Geometric Mean is mathematically expressed as the n^{th} root of the product of all values in a set of n values:

$$\bar{X}_g = \left[\prod_{i=1}^{n} X_i\right]^{\frac{1}{n}}$$

or as the antilogarithm of the arithmetic mean of the logarithms of all the values of a set of n values:

$$\bar{X}_g = \text{antilog}\left[\frac{\sum_{i=1}^{n}\log(X_i)}{n}\right]$$

The geometric mean is generally used when the logarithms of a set of values are normally distributed, as is the case for much of the monitoring and surveillance data.

Geometric Standard Deviation is mathematically expressed as the antilog of the standard deviation of the logarithms of the measurements:

$$S_g = \text{antilog}\left[\sum_{i=1}^{n}\left[\frac{\log(X_i) - \frac{\sum_{i=1}^{n}\log(X_i)}{n}}{n-1}\right]^2\right]^{\frac{1}{2}} \quad X_i \neq 0$$

Grab Sample is a single sample acquired over a short interval of time.

Herbivore is a plant-eating animal.

Isotopes are nuclides with the same atomic numbers.

Lentic refers to living in or relating to still waters (as lakes, ponds, or swamps).

Lotic refers to living in or relating to actively moving water (as streams or rivers).

Lumped parameter – See Bioaccumulation above. In the previous Biota Standard, the term "lumped parameter" was used to describe a single simplifying factor that is used in the model to represent various complex ecological, physical, and chemical pathways and mechanisms such as the bioaccumulation factor and distribution coefficient.

Median is the middle value of a set of data when the data are ranked in increasing or decreasing order. If there is an even number of values in the set, the median is the arithmetic average of the two middle values; if the number of values is odd, it is the middle value.

Mode refers to the value occurring most frequently in a data set.

Monitoring is the use of instruments, systems, or special techniques to measure liquid, gaseous, solid, and/or airborne effluents and contaminants.

Nuclide refers to an atomic species characterized by specific constitution of its nucleus, e.g., by its number of protons, its number of neutrons and its nuclear energy state.

Phylogenetic refers to the evolution of a genetically related group of organisms as distinguished from the development of the individual organism.

Poikilothermic refers to a cold-blooded organism.

Population is an aggregate of individuals of a species within a specified location in space and time.

Proportional Sample is a sample consisting of a known fraction of the original stream.

Quality Assurance (QA) refers to those planned and systematic actions necessary to provide adequate confidence that a measurement represents the sampled population. Quality assurance includes quality control (QC), which comprises all those actions necessary to control and verify the features and characteristics of a material, process, product, or service to specified requirements.

Quality Control (QC) refers to those actions necessary to control and verify the features and characteristics of a material, process, product, service, or activity to specified requirements. The aim of quality control is to provide quality that is satisfactory, adequate, dependable, and economical.

Rad is a unit of absorbed dose of ionizing radiation defined as 100 rad is equal to 1 Gy. The Gray is the SI unit of measure of absorbed dose.

Radiation (Ionizing) refers to alpha particles, beta particles, photons (gamma rays or x-rays), high-energy electrons, neutrons and any other particles capable of producing ions.

Radiation weighting factor is a dimensionless multiplicative factor used to convert physical dose (Gy) to equivalent dose (Sv) to place biological effects from exposure to different types of radiation on a common scale.

Radioactive Material refers to any material or combination of materials that contain radionuclides that spontaneously emit ionizing radiation.

Radionuclide is an unstable nuclide that undergoes spontaneous transformation, emitting radiation. There are approximately 2,200 known radionuclides, both man-made and naturally occurring. A radionuclide is identified by the number of neutrons and protons in the atomic nucleus and its energy state.

Random Error refers to variations of repeated measurements made within a sample set that are random in nature and individually not predictable. The causes of random error are assumed to be indeterminate or non-assignable. Random errors are generally assumed to be normally distributed.

Random Samples are samples obtained in such a manner that all items or members of the lot, or population, have an equal chance of being selected in the sample.

Range is the difference between the maximum and minimum values of a set of values.

Reference Animals and Plants (RAP) is a hypothetical entity, with the assumed basic biological characteristics of a particular type of animal or plant as described to the generality of the taxonomic level of family, with defined anatomical, physiological and life history properties that can be used for the purpose of relating exposure to dose and dose effects for that type of living organism.

Relative Biological Effectiveness (RBE) is defined as the ratio of the absorbed dose of a reference radiation (normally gamma rays or X rays) required to produce a level of biological response to the absorbed dose of the radiation of concern required to produce the same level of biological response, all other conditions being kept constant.

Representative Individual (biota) is an individual organism within a population that receives a radiation dose which is equivalent to the value of the appropriate measure of central tendency (e.g., mean, median, mode) of the distribution of doses received by that population. The individual is assumed to be representative of the population as a whole.

Representative Person is an individual receiving a dose that is representative of the more highly exposed individuals in the population.

Representative Sample is a sample taken to depict the characteristics of a lot or population as accurately and precisely as possible. A representative sample may be a "random sample" or a "stratified sample" depending upon the objective of the sampling and the characteristics of the conceptual population.

Riparian Organisms are those organisms related to, living, or located on the bank of a natural watercourse (as a river) or sometimes of a lake or a tidewater.

Safety Factor is a factor applied to an observed or estimated toxic concentration or dose to arrive at a criterion or standard that is considered safe.

Sample has two definitions: 1) A subset or group of objects selected from a larger set, called the "lot" or "population;" and 2) an extracted portion or subset of an effluent stream or environmental media.

Sampling is the extraction of a prescribed portion of an effluent stream or of an environmental medium for purposes of inspection and/or analysis.

Sequential Sampling refers to timed samples collected from an effluent stream.

Site refers to the land or property upon which DOE facilities or activities are located and access to which is subject to Departmental or DOE contractor control.

Source (Radioactive) is either (1) a known amount of radioactive material emanating a characteristic amount of energy in the form of alpha, beta, gamma, neutron, or x-ray emissions (or a combination of such emissions), or (2) a single process or release point that contributes to or causes a release to the environment and that can be separated from other processes by a break in the flow of material.

Standard Deviation is an indication of the dispersion of a set of results around the average of samples collected or the mean of a population; it is the positive square root of the sample variance. For samples taken from a population, the standard deviation, s, is calculated as:

$$s = \left[\frac{\sum_{i=1}^{n}(X_i - \bar{X})^2}{n-1}\right]^{\frac{1}{2}}$$

Where:

- $\bar{X}$ = average value of the samples measured;
- n = number of samples measured; and
- X_i = individual measurement for sample i

For a finite population, the standard deviation (σ) is:

$$\sigma = \left[\frac{\sum_{i=1}^{N}(X_i - \mu)^2}{N}\right]^{\frac{1}{2}}$$

Where:

- μ = mean value of the population; and
- N = number of values within the population.

Stochastic Effects are those for which the probability of occurrence is a function of dose, but the severity of the effects is independent of dose.

Stratified Sample (Stratified Random Sample) refers to a sample consisting of various portions that have been obtained from identified subparts or subcategories (strata) of the total lot or population. Within each category or stratum, the samples are taken randomly. The objective of taking stratified samples is to obtain a more representative sample than might be obtained by a completely random sampling.

Systematic Error is the condition in which there is a consistent deviation of the results from the actual or true values by a measurement process. The cause for the deviation, or bias, may be known or unknown; however, it is considered "assignable" (i.e., the cause can be reasonably determined).

Terrestrial Biota is plant and animal life living on or in land.

Variability is a general term for the dispersion of values in a data set.

Variance is a measure of the variability of samples within a subset or the entire population. Mathematically, the sample variance (s^2) is the sum of squares of the differences between the individual values of a set and the arithmetic average of the set, divided by one less than the number of values:

$$s^2 = \frac{\sum_{i=1}^{n}(X_i - \bar{X})^2}{n-1}$$

Where:

- X_i = individual measurement for sample i
- $\bar{X}$ = average value of the samples measured; and
- n = number of samples measured.

For a finite population, the variance (σ^2) is the sum of squares of deviations from the arithmetic mean, divided by the number of values in the population:

$$\sigma^2 = \frac{\sum_{i=1}^{N}(X_i - \mu)^2}{N}$$

Where:

- μ = mean value of the population; and
- N = number of values within the population.

Acronyms and Abbreviations

λ_{bio}	biological decay constant
λ_{eff}	the combination of biological and radiological decay constants
λ_{rad}	radiological decay constant
ACRP	Advisory Committee on Radiation Protection
AF	Area Factor
ASTM	American Society for Testing and Materials
B_{iv}	bioaccumulation factor
BCG	Biota Concentration Guide
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
CR	Concentration Ratio
CV	coefficient of variation
D	Absorbed dose
DCRL	Derived Consideration Reference Level
H	Equivalent dose
DOE	U.S. Department of Energy
DQOs	data quality objectives
EE/CA	engineering evaluation/cost analysis
EH	DOE's Office of Environment, Safety, and Health
EMS	Environmental Management System
EPA	U.S. Environmental Protection Agency
ERA	Ecological Risk Assessment
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
K_d	solid/solution distribution coefficient
M&O	management and operating (contractor)

NCRP	National Council on Radiation Protection and Measurements
NEA	Nuclear Energy Agency
NEPA	National Environmental Policy Act
NIST	National Institute of Standards and Technology
NOAEL	No Observed Adverse Effects Levels
NRC	U.S. Nuclear Regulatory Commission
NRDA	Natural Resource Damage Assessment
PRA	Population-relevant attribute
QA	Quality assurance
QC	Quality control
QF	Quality factor
RAPs	Reference Animals and Plants
RBE	Relative biological effectiveness
RESRAD	RESidual RADioactivity
RCRA	Resource Conservation and Recovery Act
RI/FS	Remedial investigation/feasibility study
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation
USFWS	U.S. Fish and Wildlife Service
W	Radiation weighting factor
w_t	Tissue or organ weighting factor

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1. Introduction

Under the Atomic Energy Act, as amended, the U.S. Department of Energy (DOE) is responsible for the safe conduct of its activities, including facility operation, waste management and disposal activities, and remediation of environmental contamination. These activities may result in releases of radionuclides to the air and water, accumulation of radionuclides in soil and sediment, and the potential for plants, animals, and members of the public to be exposed to radiation. DOE Order 458.1, *Radiation Protection of the Public and the Environment*, requires radiological activities that have the potential to impact the environment to be conducted in a manner that protects populations of aquatic animals, terrestrial plants, and terrestrial animals in local ecosystems from adverse effects due to radiation and radioactive material released from DOE operations. Dose limits below which deleterious effects on populations of aquatic and terrestrial organisms have not been observed, as discussed by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR 2008 Annex E) (2011) and the International Commission on Radiation Protection (ICRP) Publication 124 (2014), are considered by DOE to be relevant to the protection of all aquatic and terrestrial biota on DOE sites.

1.1 Purpose

This DOE technical standard provides a graded approach (including screening methods and methods for detailed analyses) and related guidance that DOE and DOE contractors may use to evaluate compliance with specified criteria on radiation dose to populations of aquatic animals, terrestrial plants, and terrestrial animals due to anthropogenic sources at DOE sites.

This standard replaces the previous DOE-STD-1153-2002, *A Graded Approach for Evaluating Radiation Doses to Aquatic and Terrestrial Biota*. This technical standard provides dose evaluation methods that can be used to meet the requirements for protection of biota in DOE Order 458.1. This technical standard uses the biota dose rate criteria specified below within a graded approach to demonstrate that populations of plants and animals are adequately protected from the effects of ionizing radiation:

DOE Category	**Average Dose Rate Criteria**
Aquatic Animals	Absorbed dose $\leq$ 1 rad/day (10 mGy/d)
Riparian Animals	Absorbed dose $\leq$ 0.1 rad/d (1 mGy/d)
Terrestrial Plants	Absorbed dose $\leq$ 1 rad/d (10 mGy/d)
Terrestrial Animals	Absorbed dose $\leq$ 0.1 rad/d (1 mGy/d)

Table 1-1 Absorbed dose to Aquatic and Riparian Animals and Terrestrial Plants and Animals from exposure to radiation or radioactive materials to the aquatic or terrestrial environment.

The specific methods and guidance in this technical standard are acceptable for use by DOE and DOE-contractors when evaluating doses to biota in relation to the above dose rate criteria. The methods and guidance in this technical standard should be useful to ecological risk assessors who must evaluate risks to biota from radionuclides that occur on DOE sites. Using the graded approach provided in this technical standard, risk assessors can use soil, sediment, and water radionuclide concentration data to

determine whether radionuclide concentrations at a site are likely to result in doses in excess of those listed above and would, therefore, have the potential to impact resident populations of plants and animals. The methods can give risk assessors an immediate qualitative assessment of the importance of doses of ionizing radiation to the resident receptors. The dose equations in this technical standard also provide methods of estimating upper-bound (e.g., conservatively derived) doses to specific plants and animals. The remainder of this chapter discusses the basis and background to the dose rate guidelines. Readers that are just interested in applying the method may wish to skip to Chapter 2.

1.2 Background

1.2.1 Interest and Need for Biota Dose Evaluation Methods

There is national interest in establishing a regulatory framework (e.g., to include standards or criteria) and supporting evaluation methodologies for demonstrating protection of the environment from the effects of ionizing radiation. Regarding environmental protection, the ICRP statement that "...if man is adequately protected then other living things are also likely to be sufficiently protected" (ICRP 1977; 1991) uses human protection to infer environmental protection from the effects of ionizing radiation. This assumption is most appropriate in cases where humans and other biota inhabit the same environment and have common routes of exposure. Exceptions include the following conditions:

- Human access to a contaminated area is restricted but access by biota is not restricted;
- Unique exposure pathways exist for plants and animals that do not affect exposure of humans;
- Rare or endangered species are present; or
- Other stresses on the plant or animal population are significant.

The inclusion of radiation as a stressor within ecological risk assessments is also a consideration. Ecological risk assessments at contaminated sites considered for remediation under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) generally require an assessment of all stressors, including radiation impacts on contaminated ecosystems (EPA 1998).

In 1999, the International Atomic Energy Agency (IAEA) convened a technical committee examining protection of the environment from the effects of ionizing radiation and provided recommendations and discussion points for moving forward with the development of protection frameworks and dose assessment methods. The resulting IAEA Technical Document, "Protection of the Environment from the Effects of Ionizing Radiation" (1999) references multi-tiered screening as a potentially cost-effective and easy way of demonstrating compliance with radiation. DOE considers National Council on Radiation Protection and Measurements (NCRP), ICRP, other federal agencies' recommendations in establishing appropriate limits for protection of biota.

Benefits of a Screening Process

"A multi-tiered screening approach is normally used in ecological risk assessments. Screening may also be a potentially cost-effective and easy way of demonstrating compliance with radiation criteria or standards for protection of the environment. Screening values should be used to identify radionuclides in situations of concern, and to determine whether these radionuclides warrant further assessment, or if they are at levels that require no further attention. In practice, this initial screening is expected to be sufficient in the majority of cases. When initial screening fails, additional analysis or assessment may be needed. A two- or three-tiered scheme would help ensure that the magnitude of the assessment effort would be scaled to the likelihood and severity of environmental impacts." (IAEA 1999)

In 2003, the International Conference on the Protection of the Environment from the Effects of Ionizing Radiation was held in Stockholm. The primary objective of the Stockholm conference was to promote the development of a coherent international policy on the protection of the environment from the effects of ionizing radiation by taking explicit account of the protection of species other than humans (IAEA 2003). In specifying this, the international community gathered in Stockholm set the following expectations:

1. The UNSCEAR should continue to provide findings on the sources and effects of ionizing radiation that can be used as the authoritative scientific basis for future international efforts in environmental radiation protection.
2. The ICRP should continue to issue recommendations on radiation protection, including specific recommendations for the protection of non-human species.
3. The IAEA should establish appropriate international undertakings, including international standards and mechanisms for their worldwide application, to restrict releases of radioactive materials into the environment over time, in order that not only humans but also the non-human component of the environment is protected adequately. IAEA should continue to foster information exchange by organizing international meetings on this subject.

In response to these expectations, UNSCEAR published UNSCEAR 2008 Annex E on the effects of ionizing radiation on non-human biota (2011), IAEA revised the International Basic Safety Standards to include protecting people and the environment from harmful effects of radiation (2014b), and the ICRP published the following series of reports:

1. ICRP Publication 91, *A Framework for Assessing the Impact of Ionising Radiation on Non-human Species* (2003), recommended that a more comprehensive approach be developed to protect all living matter and proposed a framework for assessing the impacts on non-human species.
2. ICRP Publication 103, *Recommendations of the ICRP* (2007), extended the system of radiological protection to explicitly address the protection of the environment including non-human species. The basis for using Reference Animals and Plants (RAPs) in flora and fauna assessments is provided.
3. ICRP Publication 108, *Environmental Protection: the Concept and Use of Reference Animals and Plants* (2008b), provided details on the use of RAPs and provided a range of Derived Consideration Reference Levels for each RAP.

4. ICRP Publication 114, *Environmental Protection: Transfer Parameters for Reference Animals and Plants* (2009), provided transfer parameters for the RAPs.
5. ICRP Publication 124, *Protection of the Environment under Different Exposure Situations* (2014), consolidates the ICRP recommendations on environmental protection and provides guidance on their application.

The methods and guidance provided in this DOE technical standard will continue to serve as a platform for national and international discussion of radiation protection frameworks, standards, and dose assessment methods for biota. Although DOE is not required to strictly follow international standards, DOE considers NCRP, ICRP, other Federal agency guidance in establishing appropriate standards.

1.2.2 Basis for Biota Dose Rate Criteria Applied in this Technical Standard

DOE Order 458.1 specifies that when actions taken to protect humans from radiation and radioactive materials are not adequate to protect biota, evaluations must be done to demonstrate compliance and specific requirements in one or more of the following ways:

- Use of the graded approach established in this standard;
- Use of an alternative approach to demonstrate that the dose rates to representative biota populations do not exceed the dose rate criteria, Table 1-1, in this standard; or
- Use of an ecological risk assessment to demonstrate that radiation and radioactive material released from DOE operations will not adversely affect populations within the ecosystem.

The dose rate criteria for controlling radiological impacts from DOE activities to representative biota populations shall not exceed the dose rate criteria in Table 1-1 of this technical standard. The dose rate criteria used in this technical standard is consistent with the intent of DOE Order 458.1, and the intent of ICRP Publication 124 (2014).

In ICRP 124 (2014), Derived Consideration Reference Levels (DCRLs) that are specific to each of the different types of RAPs have been defined. A DCRL can be considered as a band (over one order of magnitude) of dose rate within which there is some chance of deleterious effects to the RAP from ionizing radiation. DCRLs can be used as points of reference to inform on the appropriate level of effort that should be expended on environmental protection. ICRP recommends that DCRLs should be used under all circumstances where there is, or may be, an incremental environmental exposure of significance above the natural background locally experienced by the relevant biota. For existing exposure situations (typical for most DOE sites), the upper bound of the relevant DCRL band should be used for protection of different types of biota within a given area, with consideration being given to possible cumulative effects. The dose rate criteria used in this technical standard for the aquatic animal, riparian animal, terrestrial plant, and terrestrial animal are generally consistent with the DCRL bands for the applicable Reference Animals and Plants (RAPs) documented in ICRP 124 (2014) and Figure 1-1.

DOE Category & Criteria	Reference Organism	DCRL mGy/d	DCRL rad/d
Aquatic Animals 10 mGy/d 1 rad/d	Crab	10 to 100	1 to 10
	Trout	1 to 10	0.1 to 1
	Flatfish	1 to 10	0.1 to 1
Riparian Animals 1 mGy /d 0.1 rad/d	Frog	1 to 10	0.1 to 1
	Duck	0.1 to 1	0.01 to 0.1
Terrestrial Plants 10 mGy/d 1 rad/d	Pine tree	0.1 to 1	0.01 to 0.1
	Wild grass	1 to 10	0.1 to 1
Terrestrial Animals 1 mGy/d 0.1 rad/day	Deer	0.1 to 1	0.01 to 0.1
	Bee	10 to 100	1 to 10
	Earthworm	10 to 100	1 to 10
	Rat	0.1 to 1	0.01 to 0.1
None	Brown seaweed	10 to 100	1 to 10

Figure 1-1 Comparison of DOE biota dose rate criteria with international recommendations for DCRL bands from ICRP (2014)

The biota dose rate criteria specified in this technical standard are based on the current state of science and knowledge regarding effects of ionizing radiation on plants and animals. They should not be interpreted as a "bright line" that, if exceeded, would trigger a mandatory regulatory or remedial action. Rather, they should be interpreted and applied more as "Dose Rate Guidelines" that provide an indication that populations of plants and animals could be impacted from exposure to ionizing radiation and that further investigation and action is likely necessary.

1.2.3 Protection of Populations

The intent of the graded approach (i.e., the screening and analysis methods) is to protect populations of aquatic animals, terrestrial animals, and terrestrial plants from the effects of exposure to anthropogenic ionizing radiation. As shown in Figure 1-2, certain taxa are more sensitive to ionizing radiation than others. Based on this observation, protecting the more sensitive taxa will adequately protect other, less sensitive taxa. Hence, in cases where site-specific evaluations may be required, receptors should be selected that:

- Are important to the structure and function of the community;
- Are expected to receive a comparatively high degree of exposure (e.g., expected to receive a radiation dose to reproductive tissues which is relatively high per unit of radionuclide present in the ecosystem, in comparison with other receptors in the same community); and

- Have an established degree of radiosensitivity (i.e., radiation effects have a likelihood of occurring at the exposure levels being evaluated, in comparison with other receptors in the same community).

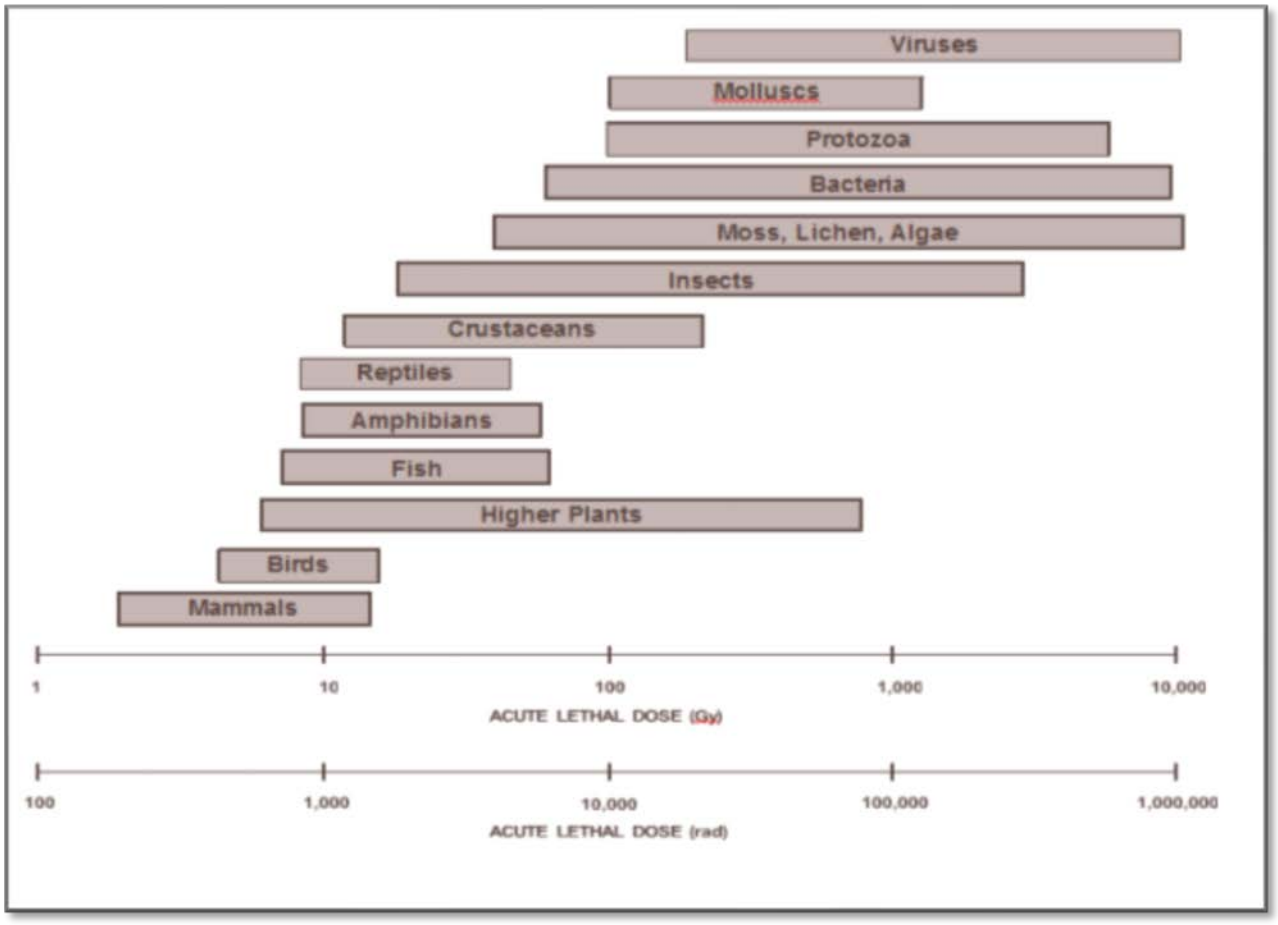


Figure 1-2 Approximate Acute Lethal Dose Ranges for Various Taxonomic Groups (Whicker and Schulz 1982; UNSCEAR 1996.)

1.3 The Biota Dose Methodology

The graded approach for evaluating radiation dose to biota is intended to be simple, defensible, and more easily understood. It also has broad applicability from aquatic animals through terrestrial species and addresses radiation dose in small organisms (e.g., mice) and large carnivores (e.g., cougars). The method provides a logical and consistent departure point should additional in-depth evaluation of dose be required. Should additional analysis be required, the method allows for, and encourages, the use of existing data either from the technical literature or from site-specific monitoring whenever possible. Lastly, the method is useful in evaluating the potential impacts of combined media: water, sediment, and soil.

2 Overview and Implementation of the DOE Graded Approach

DOE's graded approach for evaluating radiation doses to aquatic and terrestrial biota consists of a three-step process which is designed to guide a user from an initial, conservative general screening to, if needed, a more rigorous analysis using site-specific information (see Figure 2-1). The three-step process includes:

- Data assembly;
- General screening; and
- Analysis as necessary.

Any of the steps within the graded approach may be used at any time, but the general screening methodology will usually be the simplest, most cost-effective, and least time-consuming. Table 2-1 provides a summary of DOE's graded approach.

The RESRAD-BIOTA (RESidual RADioactivity) model (ISCORS 2004) is the recommended tool for implementing the screening and analysis methods contained in this technical standard.

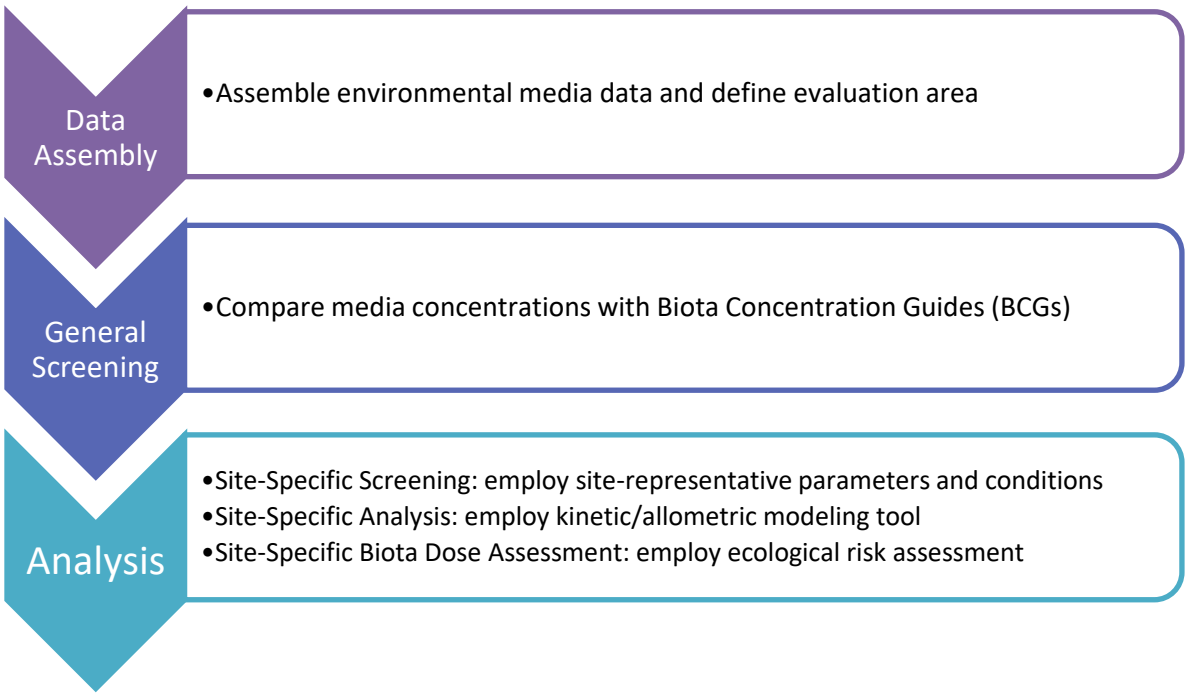


Figure 2-1 Overview of the DOE Graded Approach for Evaluating Radiation Doses to Aquatic and Terrestrial Biota

Table 2-1 Summary of DOE's Three-Step Process for Evaluating Radiation Doses to Aquatic and Terrestrial Biota

1. Data Assembly	Knowledge of sources, receptors, and routes of exposure for the area to be evaluated is summarized. Measured radionuclide concentrations in water, sediment, and soil are assembled for subsequent screening.
2. General Screening	Maximum measured radionuclide concentrations in an environmental medium (e.g., water, sediment, soil) are compared with a set of DOE BIOTA BCGs. Each radionuclide-specific BCG represents the limiting radionuclide concentration in an environmental medium which would not result in recommended dose standards for biota to be exceeded.
3. Analysis	This phase consists of three increasingly more detailed steps of analysis.
(a) Site-Specific Screening	Site-specific screening, using more realistic site-representative bioaccumulation factors (B_{iv}s) in place of conservative default parameters. Use of mean radionuclide concentrations in place of maximum values, taking into account time dependence and spatial extent of contamination, may be considered.
(b) Site-Specific Analysis	Site-specific analysis employing a kinetic modeling tool (applicable to riparian and terrestrial animal organism types) provided as part of the graded approach methodology. Multiple parameters which influence the organism's internal dose (e.g., body mass, consumption rate of food/soil, inhalation rate, lifespan, biological elimination rates) can be modified to represent site and organism- specific characteristics. The kinetic model employs allometric equations relating body mass to these internal dose parameters.
(c) Site-Specific Biota Dose Assessment	An actual site-specific biota dose assessment involving the collection and analysis of biota samples. The dose assessment would involve a problem formulation, analysis, and risk characterization protocol consistent with the widely-used ecological risk assessment paradigm.

2.1 Key Features of the Graded Approach

The graded approach was designed for flexibility and acceptability:

- It provides users with a tiered approach for demonstrating compliance with biota dose rate criteria that is generally cost-effective and easy-to-implement;
- It allows for the use of measured radionuclide concentrations in environmental media typically collected as part of routine environmental surveillance programs;
- It is designed for multiple applications. The technical standard is applicable to demonstrations of compliance with biota dose rate criteria and for use in ecological risk assessments of radiological impact;
- It provides a framework that supports the use of site-specific information;
- It incorporates ecological risk assessment (ERA) concepts and provides guidance for site-specific biota dose assessments, employing the widely-used ERA paradigm; and

- It provides users with "a place to start" and "an analysis path forward." The BCG's are not stand-alone criteria. Exceedance of BCGs leads the user to the more-detailed tiers of analysis as needed in a stepwise manner.

2.2 Principal and Alternative Uses of the Graded Approach

The principal driver and basis of need for developing the graded approach was to provide DOE field and program elements with methods for demonstrating compliance with DOE biota dose rate criteria and recommendations for radiological protection of the environment. Thus, many of the decisions that are traditionally made when conducting a case-specific ERA (e.g., choice of indicator receptors; defining receptor exposure profiles; selection of effects endpoints) were made at a programmatic level and incorporated into the screening phase of the graded approach *a priori.* For example, the thresholds for adverse effects were set at the recommended criteria for protection of natural populations of biota. Those are the appropriate effects levels for demonstrating compliance with DOE requirements and recommendations for the protection of the environment from ionizing radiation.

The graded approach and BCGs can be used in support of other types of environmental assessments, provided that the user ensures that issues specific to the alternative application are appropriately addressed. Examples of other types of environmental assessments that the graded approach could potentially support include: ERAs at hazardous waste sites (i.e., Superfund sites), assessments for waste disposal and other facilities, and assessments at various stages of the Natural Resource Damage Assessment (NRDA) process. These typically include retrospective assessments of previously contaminated areas. These could also include prospective assessments of migrating contaminants (e.g., groundwater plumes) and planned releases (e.g., National Environmental Policy Act (NEPA) alternatives analysis).

If the graded approach is used for these or other purposes, then the programmatic objectives and the methods and model assumptions should be re-evaluated and discussed with the relevant decision makers and stakeholders, preferably via the Data Quality Objectives process (USEPA 2006) or comparable processes to ensure that the results obtained through application of the graded approach will support the management goals and objectives of the environmental assessment.

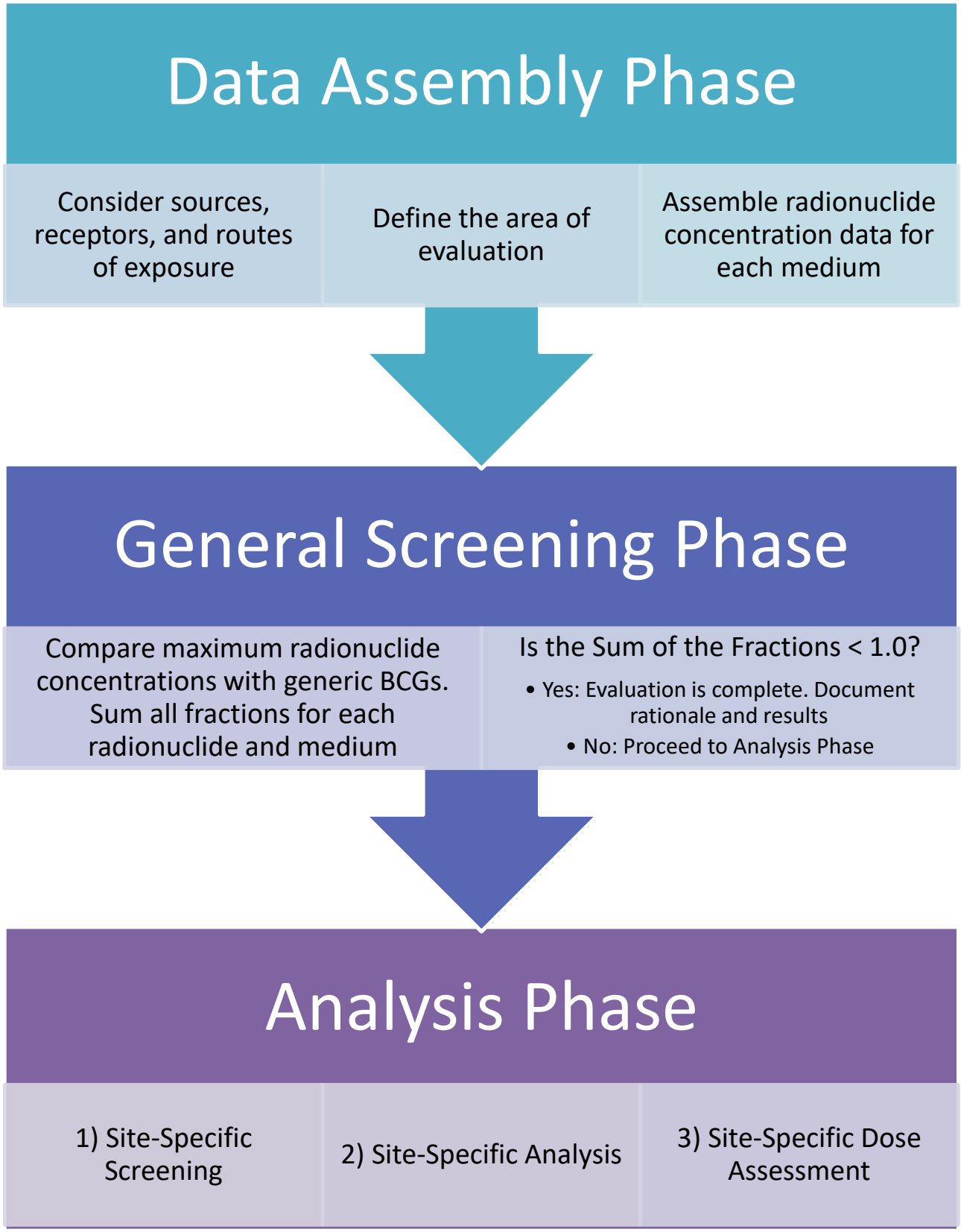
2.3 Relationship of the Graded Approach to Ecological Risk Assessment

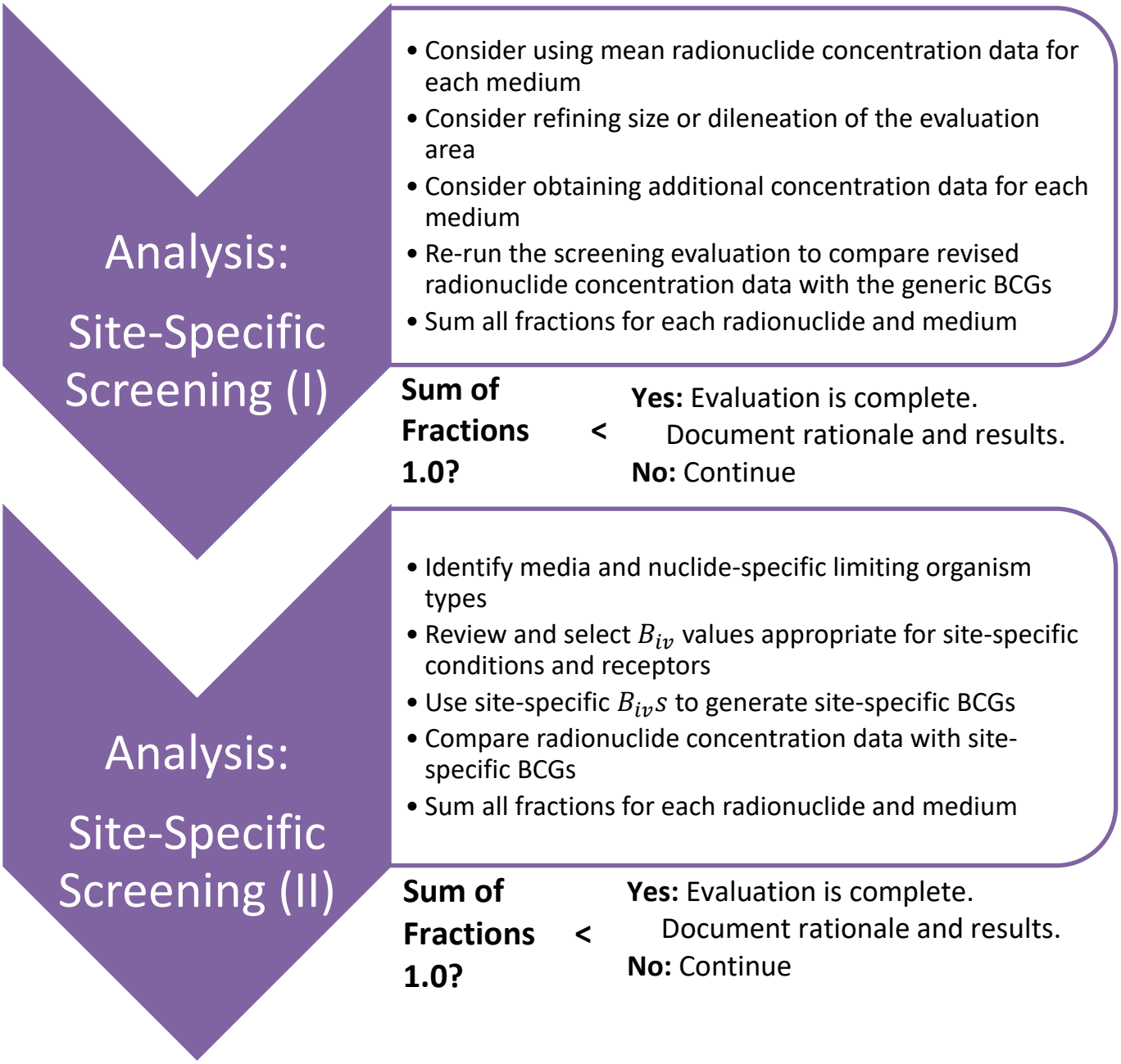
The graded approach for evaluating radiation doses to aquatic and terrestrial biota is consistent with the standard ERA paradigm (USEPA 1998). The ERA structure provides a process for organizing and evaluating information to determine the nature, likelihood, and magnitude of potential impacts on environmental receptors (Suter 1993). ERAs are typically done in successively rigorous tiers, each of which includes the three general ERA steps (Suter et al. 2000). The first and simplest tier is a scoping assessment, which establishes the need for an ERA. The second tier consists of a screening ERA, which is relatively simple and conservative in its application and assumptions. The third tier is a definitive ERA, which provides a relatively detailed and realistic assessment of the nature and magnitude of risks. The graded approach moves from a simple and relatively conservative screening evaluation to a more detailed and realistic assessment. Each step in the graded approach addresses, either explicitly or implicitly, all of the aforementioned ERA components. That is, the graded approach is a framework for organizing the successively rigorous ERA tiers, but with a particular emphasis on ionizing radiation.

The ERA process can be applied to the evaluation of radiation as a stressor, but not without some modifications and provision of additional guidance. There are some noteworthy technical issues concerning the evaluation of radiation that require further consideration and elaboration. Some issues are the same as for chemicals, but some are unique to radionuclides.

2.4 Step-By-Step Implementation of the Graded Approach

Presented in this section is an overview of the complete process for implementing the graded approach. This section is provided to help orient you to the step-by-step guidance corresponding to each phase of the graded approach which follows in Sections 3-7. A flowchart showing how to progress through each phase of the graded approach, and the components of each phase, is provided in Figure 2-2. Refer to this figure as you proceed through the step-by-step guidance presented in subsequent sections.


Data Assembly Phase
Consider sources, receptors, and routes of exposure
Define the area of evaluation
Assemble radionuclide concentration data for each medium
General Screening Phase
Compare maximum radionuclide concentrations with generic BCGs. Sum all fractions for each radionuclide and medium
Is the Sum of the Fractions < 1.0?
• Yes: Evaluation is complete. Document rationale and results
• No: Proceed to Analysis Phase
Analysis Phase
1) Site-Specific Screening
2) Site-Specific Analysis
3) Site-Specific Dose Assessment


Analysis:
Site-Specific
Screening (I)
• Consider using mean radionuclide concentration data for each medium
• Consider refining size or dileneation of the evaluation area
• Consider obtaining additional concentration data for each medium
• Re-run the screening evaluation to compare revised radionuclide concentration data with the generic BCGs
• Sum all fractions for each radionuclide and medium
Sum of Fractions 1.0?
<
Yes: Evaluation is complete. Document rationale and results.
No: Continue
Analysis:
Site-Specific
Screening (II)
• Identify media and nuclide-specific limiting organism types
• Review and select B_{iv} values appropriate for site-specific conditions and receptors
• Use site-specific $B_{iv}s$ to generate site-specific BCGs
• Compare radionuclide concentration data with site-specific BCGs
• Sum all fractions for each radionuclide and medium
Sum of Fractions 1.0?
<
Yes: Evaluation is complete. Document rationale and results.
No: Continue

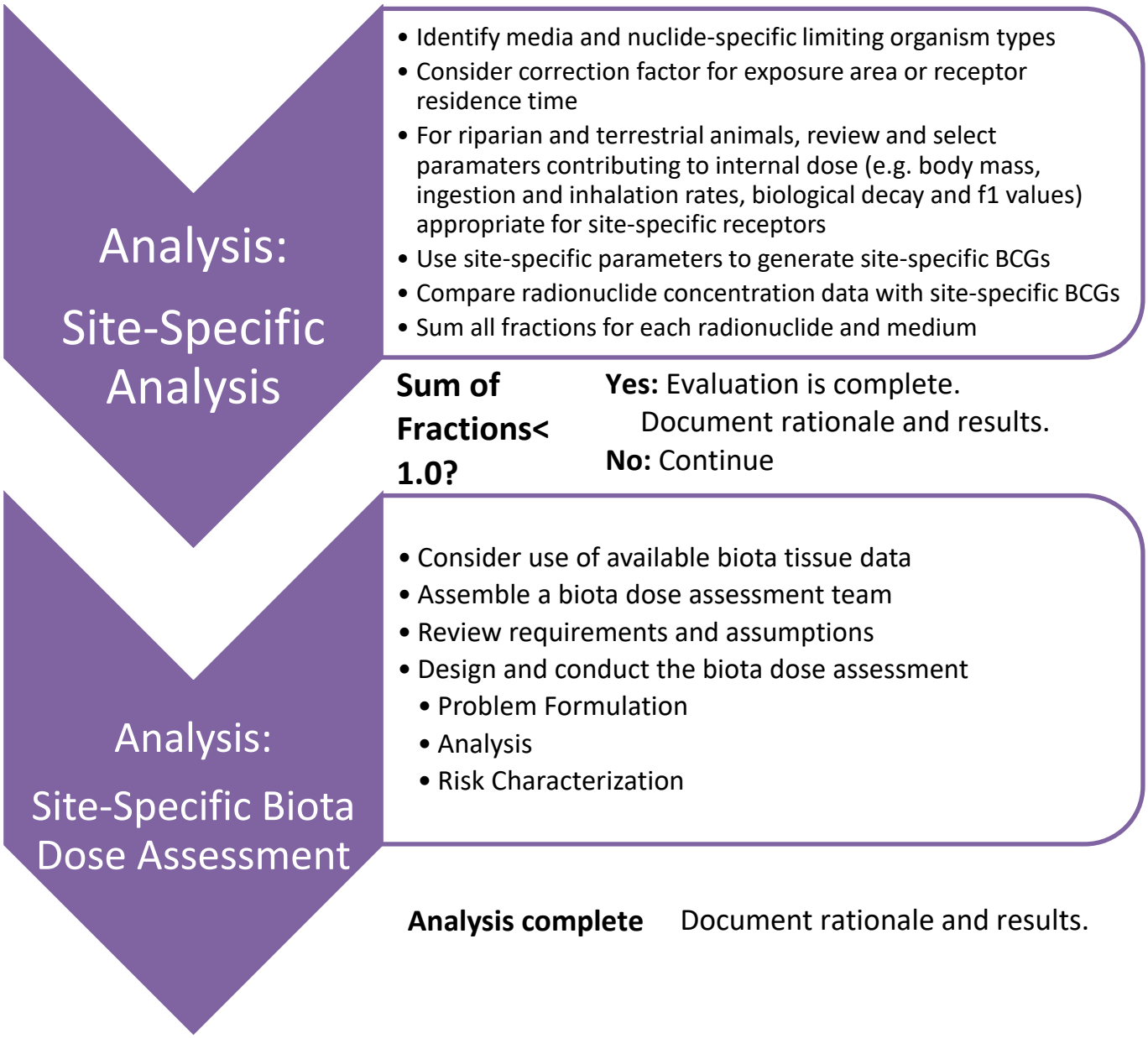


Figure 2-2 Flowchart illustrating step-by-step guidance for progressing through the DOE graded approach

2.5 Parameter Values that Can Be Modified in the Graded Approach

DOE's three-phased approach is designed to guide you from an initial conservative evaluation using general screening to, if needed, a more rigorous analysis using site-specific information. The amount of effort required for your biota dose evaluation and the information needed on site-specific conditions and receptors increases as you progress through the three phases of the graded approach, particularly during the analysis phase. The result will be a set of less conservative, more realistic site-representative BCGs. Table 2-2 provides a general summary of parameter values that can be modified or applied corresponding to each phase of the graded approach. Use this table as a reference when progressing through the step-by-step guidance provided in subsequent sections.

Table 2-2 Summary of parameter values that can, with technical justification, be modified corresponding to each phase of the graded approach

Phase	Parameters
Data Assembly	• Size of evaluation area • Radionuclide concentrations in environmental media • Presence of aquatic, riparian, or terrestrial biota populations
General Screening	• Initial general screening using maximum radionuclide concentrations: No parameter modifications are allowed
Analysis: *Site-Specific Screening*	• Use of mean radionuclide concentrations, taking into account time dependence and spatial extent of contamination, may be considered • Site-specific B_{iv} values in place of default values used in the general screening phase • Sediment K_d values may be modified, with technical justification, for aquatic system evaluations where only water or only sediment concentration data are available for the screening process
Site-Specific Analysis	• A correction factor for exposure area or receptor residence time for all organism types (Area Factor) may be considered • For riparian and terrestrial animals: • Food source B_{iv} value for riparian and terrestrial animals • Body mass • Uptake fraction of radionuclide ingested/absorbed (f_1) • Biological elimination rate constant of radionuclide exiting the organism (λ_{bio}) • Food intake rate and supporting parameters • Soil intake rate and supporting parameters • Inhalation rate and supporting parameters • Soil inhalation rate and supporting parameters • Water consumption rate • Maximum life span • Allometric equations provided can be modified
Site-Specific Biota Dose Assessment	• Design, collection, and direct analysis of environmental media and biota

3 Application Considerations

The principal application of the graded approach is to demonstrate that routine DOE operations and activities are in compliance with the biota dose rate criteria for protecting populations of plants and animals. In addition, the design of the graded approach (e.g., assumptions used; a multi-tiered screening and analysis approach; flexibility to allow use of site-specific information on sources, receptors, and routes of exposure) permits its application in ecological assessments of radiological impact and in other environmental assessment scenarios.

Table 3-1 Applications matrix summarizing intended and potential uses of the DOE Graded Approach

TYPES OF RECEPTORS		
Applications	**Intended / potential use**	**Considerations**
Populations of plants and animals	This is the primary intended use.	No further considerations
Individual plants and animals, including threatened and endangered species, and commercially or culturally valued species	Equations used within the graded approach are technically sound for application to individual organisms. Applying dose rate criteria intended for the protection of populations to evaluations of individuals may require further consideration.	Use of effects endpoints/dose rate criteria appropriate for protection of the individuals being evaluated; and/or application of safety factors, conservative exposure assumptions, and parameter values. Dose evaluations should be performed under the provisions of the applicable Federal and/or state statutes or regulations for rare and endangered species.
TYPES OF EXPOSURE		
Applications	**Intended / potential use**	**Considerations**
Chronic	The methodology assumes chronic exposure and equilibrium conditions.	The models and assumptions used in the graded approach assume equilibrium conditions.
Acute	The methodology is not intended to be used for assessing acute exposures.	The models and assumptions used in the graded approach assume equilibrium conditions that will occur over longer exposure horizons.
Accidents	Could be used to provide an indication of long-term "recovery" or health of the population over time following an accident. Equations and models used within the graded approach are technically sound for this application.	Accidents typically result in short-term, acute exposures for which the methodology is not intended. However, it can be applied for assessing long-term exposures due to accidents.
TYPES OF ENVIRONMENTS		
Applications	**Intended / potential use**	**Considerations**
Fresh water, coastal, and marine environments	The methodology is intended to be applied to fresh water environments, and can be applied to coastal and marine environments.	Care must be taken when selecting parameter values (e.g., receptor B_{iv}s; K_d values), as fresh water, coastal, and marine equilibrium chemistry differ considerably.
Table 3-1 (Cont'd) Applications Matrix Summarizing Intended and Potential Uses of the DOE Graded Approach		

Terrestrial environments	The methodology is intended to be applied to terrestrial environments	No further considerations.
COMPLIANCE / IMPACT ASSESSMENT		
Applications	**Intended / potential use**	**Considerations**
Demonstration that DOE activities are in compliance with biota dose rate criteria	This is a principal DOE application of the graded approach.	Population is defined as an aggregate of individuals of a species within a specified location and time. The fraction of the population of interest, and the fraction of time, exposed to anthropogenic ionizing radiation are important considerations in determining the dose to biota.
National Environmental Policy Act (NEPA)	The graded approach could be coupled with predictive dispersion codes that model a facility's effluents prior to construction, to estimate doses to biota in the Environmental Impact Statement. • Comparison of alternatives • Screen for issues needing analysis • Defining significance criteria • Mitigation action plan	Effects and assessment endpoints selected for use in the biota dose evaluation should be relevant to the management goals of the study.
Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA)	Screening for potential radiological impacts within an ecological risk assessment. • Remedial Investigation/ Feasibility Study (RI/FS) • Engineering Evaluation/ Cost Analysis (EE/CA)	Effects and assessment endpoints selected for use in the biota dose evaluation should be relevant to the management goals of the study.
Natural Resource Damage Assessments (NRDA)	Screening assessments.	Effects and assessment endpoints selected for use in the biota dose evaluation should be relevant to the management goals of the study.
Decommissioning	Could be used to evaluate doses to biota, and to predict future doses to biota, associated with pre- and post-site or facility decommissioning activities.	Effects and assessment endpoints selected for use in the biota dose evaluation should be relevant to the management goals of the study.
Resource Conservation and Recovery Act (RCRA)	• Mixing zone definition • Alternative concentration limits	Effects and assessment endpoints selected for use in the biota dose evaluation should be relevant to the management goals of the study.
Clean Water Act	Mixing zone assessments.	Effects and assessment endpoints selected for use in the biota dose evaluation should be relevant to the management goals of the study.

Many of the decisions that are traditionally made when conducting a case-specific assessment (e.g., choice of indicator receptors; defining receptor exposure profiles; selection of effects endpoints) were made at a programmatic level and incorporated into the screening phase of the graded approach *a priori* in order to demonstrate compliance with DOE biota dose rate criteria and recommendations. If the graded approach is used for other purposes (see Table 3-1), then the programmatic objectives and the methods should be reviewed and discussed with the relevant decision makers and stakeholders, preferably via the Data Quality Objectives process (USEPA 2006) to ensure that the results obtained through application of the graded approach will support the management goals and objectives of the environmental assessment.

3.1 Evaluating Doses to Individual Organisms (see Appendix A)

The equations and models used within the graded approach for estimating the dose per unit concentration of radionuclides in environmental media and for deriving the BCGs are also applicable to individual organisms. However, there are questions concerning the applicability of the biota dose rate criteria to individual organisms. While the biota dose rate criteria presented in Section 1.1 were derived based on dose-response information for the most radiosensitive of all species studied, and taking into account the most radiosensitive life stages, the question of whether these dose rate criteria can be applied to protection of individual members of a species, in contrast to protection of populations of species, requires further consideration. That is, for individual plants and animals, especially threatened and endangered species, the health effects of concern could be different from the effects of concern in protection of populations.

The application of safety factors to these dose rate criteria is one approach that has been used in evaluating doses to individual organisms (e.g., for culturally valued species). Use of safety factors, appropriate default parameter values, maximum radionuclide concentrations in environmental media, and 100 percent organism residence time and exposure are factors to consider in the application of the graded approach for evaluating doses to individuals. Specific cases where evaluation of individual organisms may be needed are discussed below.

3.1.1 Threatened and Endangered Species

Care must be taken by the user if the graded approach is applied in an evaluation of potential radiological impacts to endangered, threatened, rare, or otherwise sensitive species of plants and animals managed under the Federal Endangered Species Act or similar state laws or regulations pertaining to rare or endangered species (Endangered Species Act, 16 USC 1531 et seq.). It is the user's responsibility to select effects and assessment endpoints, and the required input parameter values that reflect actual or expected exposure profiles, for the individuals being evaluated. Protection of endangered species should be performed under the provisions of the applicable Federal and/or state statutes or regulations for rare and endangered species.

3.1.2 Commercially and Culturally Valued Species

Care must be taken by the user if the graded approach is applied in an evaluation of potential radiological impacts to these categories of species. These would include species that are routinely harvested for their economic value (e.g., salmon) or their cultural value (e.g., medicinal plants used by Native Americans). One issue is whether or not these species should be evaluated at the individual or

the population level. It is the user's responsibility to select effects and assessment endpoints, and the required input parameter values that reflect actual or expected exposure profiles, for the individuals being evaluated.

3.2 Evaluating Doses to Aquatic Plants

Available information about the effects of ionizing radiation on aquatic plants does not appear to be adequate to characterize their sensitivity to ionizing radiation, or to establish defensible recommendations (e.g., in the form of dose standards or criteria) for allowable exposures of populations or individuals. However, regarding this technical standard, indirect means can provide a general qualitative indication of the effects to aquatic plants relative to effects on other organisms. In general, one would expect substantially lower radiosensitivity in higher plants in comparison to the most sensitive birds, fishes and mammals (Whicker and Schultz 1982; Whicker 1997). Therefore, an evaluation using this technical standard that demonstrates protection of aquatic and riparian animals should provide an indication that aquatic plants are also likely protected. Alternatively, appropriate bioaccumulation factors B_{iv}s for aquatic plants could be used to calculate BCGs for aquatic plants. Refer to Appendix F: B_{iv}s and Appendix G: BCGs for guidance in this area.

3.3 Background and Reference Areas

In addition to originating from anthropogenic sources, radionuclides are naturally occurring and ubiquitous in the environment. Quantities of naturally occurring radionuclides in the environment can vary dramatically, depending on the geology of an area (Eisler 1994). The BCGs and the biota dose rate criteria for the protection of biota applied in this technical standard do not differentiate between radionuclides originating from anthropogenic and natural sources. It is important to recognize that it is the total weighted dose rate (i.e., taking into account all sources and types of radiation) to biota at the site that is to be evaluated. Therefore, background dose rates should be included in the total weighted dose rate and should not be subtracted from the dose rates at the site (Jones 2000). However, radiation dose rates at local background areas can be used to ensure that the site-related dose rates represent an actual increase in exposure. This is particularly important if remedial activities are being considered, so that limited resources are not applied to an effort to remediate background levels of radionuclides.

The solution is to compare the data from the contaminated site to that collected from one to several uncontaminated background or reference sites. These sites should be selected such that they are as comparable as possible to the contaminated site. Background sites should possess similar geological, physical, chemical, and biological attributes, while being uninfluenced by the activities or releases from the contaminated site. The level above which contaminated media are determined to be greater than background should be determined through the Data Quality Objectives process (USEPA 2006). Maximum site concentrations that are twice the mean background concentration have been commonly employed at hazardous waste sites to establish differences from background (Suter et al. 2000). Other comparison approaches are outlined in WADOE (1994), California EPA (1997), and Suter (1995). If the total weighted dose rate at the site is comparable to or less than that at the local background area, then it is unlikely that endemic biota populations are adversely affected from ionizing radiation at the site.

3.4 Frequency of Evaluations

Dose evaluations for aquatic and terrestrial biota shall be reviewed and reported in the annual site environmental reports that are required under DOE Order 231.1B, *Environment, Safety and Health Reporting*. More frequent evaluations may be required if new information or data suggests previous assessments may not be adequate to ensure compliance.

4 Data Assembly Phase

The DOE graded approach for evaluating radiation doses to aquatic and terrestrial biota was designed to minimize the need for additional data collection above and beyond environmental radionuclide concentration data typically available through routine environmental monitoring and surveillance programs. The data assembly phase encompasses three steps:

- Considering the sources of radioactivity, the key receptors, and the routes of exposure to these receptors;
- Defining the geographic area to be evaluated; and
- Assembling and organizing data on radionuclide concentrations in water, sediments, and soil for use in the general screening phase, and for use in the analysis phase, if needed.

Additionally, tissue data may be collected or estimated using field measurements to supplement the general screening phase. The three steps are interdependent and should be considered collectively when implementing the data assembly phase.

4.1 Step 1: Consider the Sources, Receptors, and Routes of Exposure

It is expected that general knowledge concerning sources, receptors, and routes of exposure will be sufficient for defining the geographic area of evaluation when implementing the general screening phase of the graded approach. However, more detailed information regarding these elements may need to be considered as you progress through the graded approach. For example, if the BCGs for the general screening evaluation are exceeded, you may wish to refine your input data for site-specific screening (e.g., using mean radionuclide concentration data in place of maximum values; re-defining the geographic area of evaluation). Alternatively, you may wish to move to the site-specific analysis component of the graded approach, which may require consideration of internal dose parameters relating to site-specific receptors and routes of exposure.

Detailed guidance on consideration of sources, receptors, and routes of exposure, for application in defining the area of evaluation and for use in the analysis phase is provided in Appendix C: Area Factors and Appendix H: Exposure Parameters.

4.1.1 Radiation Sources

Sources of radioactive material may be present in the environment at concentrations that are measurable using routine survey methods. Nuclide-specific information is preferred. Measurements of gross alpha radiation and/or gross beta radiation may be useful in defining the areas of contamination and the identification of localized areas of high concentration.

If long-lived radionuclides are present in measurable concentrations and receptors are exposed to them, an evaluation will be needed. Short-lived radionuclides (e.g., with a half-life less than 3 months), if continuously or regularly released into the environment, could be present on a regular basis. As a guide, radionuclides with half-lives less than 6 months that are discharged into the environment in measurable quantities at least twice in a given 12-month period may warrant an evaluation.

Table 4-1 General considerations for defining radiation sources

Biogeochemical Properties of Radionuclides	• The biogeochemical properties of the released radionuclides are important because they determine the forms of the material in environmental media (e.g., solid, liquid, gaseous, dissolved), hence, its mobility and bioavailability. For example, radionuclides that are easily dissolved in water are more likely to migrate and disperse throughout the environment. These properties are also important because they determine whether a material bioaccumulates and the degree to which bioaccumulation occurs.
Nature of the Sources of Contamination	• The sources of contamination may exist in place (e.g., in soil or sediment) with or without further inputs of released radionuclides. These sources may be on the surface, buried, or moving through the medium by one or more processes. Alternatively, the sources of contamination may be point or non-point discharges of radioactive materials into the air, water, or soil. • Where the sources of contamination are located in the environment, if and how they are discharged into the environment and their subsequent mobility through environmental media are important determinants of their distribution throughout the environment in space and time.

4.1.2 Receptors

The rationale used in identifying example representative organisms includes, but is not limited to, the following:

- The home range of the organism should be considered, with preference given to organisms with small home ranges;
- The organism should be susceptible (i.e., exposed *and* sensitive) to ionizing radiation. Organisms that are good accumulators of radionuclides but are not very radiosensitive are generally not the most appropriate organisms. For example, mammals and other vertebrates are generally more radiosensitive than are invertebrates. Higher plants are more radiosensitive than mosses and lichens;
- The organism should represent the major exposure pathways for aquatic and terrestrial biota;
- The organism should be indigenous to the evaluation area and utilize the principal habitat present in the evaluation area;
- The organism is one that the general public is familiar with pertaining to the potential exposures (i.e., internal and external exposures);
- The organism has a reasonable amount of data available about it in the published literature or from site-specific studies (e.g., in terms of characterizing its radiosensitivity; environmental transfer factor parameters needed for application in the biota dose evaluation);
- The organism should be appropriate to the ecosystem type being evaluated (e.g., regional differences in ecosystems); and

- The organism is one of the keystone or focal species for the ecosystem type being evaluated. It should be important to the function and structure of the ecosystem.

4.1.3 Routes of Exposure

Table 4-2 General considerations for defining routes of exposure

Environmental Media	• The environmental media in which the released radionuclides are found (e.g.,, water, soil, or sediment) set the boundaries for the mobility of the released radionuclides through and among media. For example, released radionuclides in water may be dissolved or suspended as particulates, and their concentrations may be diluted through natural processes (e.g., currents, waves). • Suspended particulates may be deposited in the sediments, re-suspended, or even eroded by the wind if the water evaporates. • Materials in the air may be dispersed over large distances, subsequently deposited in the water or on the soil. • Released radionuclides in the soil may exist as immobile particulates or mobile dissolved forms, and may move from one form to another in space and through time, depending on the pH and redox potential of the soil. Other factors such as carbonates, organic matter, and clay content and type can also be important.
Ecology of the Receptors	• The interactions of each receptor within its environment define the routes of its exposure. A species that burrows in the soil and preys on soil organisms will have a different exposure profile than herbivores that live on the surface. • The ecology determines how the receptor is exposed in time and space. Rates of exposure and total doses will vary among similar types of organisms, based on whether an organism is immobile, mobile and local, or mobile and migratory. • Depending upon the phase of the graded approach you are working in (i.e.,, if you are moving from general screening to a site-specific analysis) it may be useful to develop a site conceptual model of the type used in ecological risk assessments. Helpful references include ASTM (1995), EPA (1998), and Suter (1996). An ecological scoping checklist for assembling a conceptual model is provided in Ryti et al. (1999). An automated conceptual model builder is also available (DOE 1997).

4.2 Step 2: Define Your Area of Evaluation

In high level analyses, it is necessary to determine the spatial extent over which the graded approach will be applied. The assumptions regarding sources, receptors, and routes of exposure used in the development of the graded approach provide for conservative BCGs. In the derivation of the screening approach, the source medium to which the organisms are exposed is assumed to be infinite in extent and to contain uniform concentrations of radionuclides. The organisms are also assumed to be resident in the contaminated area (e.g., exposed to contaminated media) 100 percent of the time. Given these assumptions, the first approach shall be to use maximum radionuclide concentration data applicable to

your geographic area of interest (e.g., the entire site).[1] It is not necessary for levels where only concentration matters.

If use of the maximum concentrations over the entire site does not pass the general screening phase, then the boundaries of specific habitat / populations of interest should be defined. It is then within these boundaries that the evaluation will continue. Guidance on delineating evaluation areas can be found in Appendix C: Area Factors.

4.3 Step 3: Assemble and Organize Data on Radionuclide Concentrations in Environmental Media

The next step is to collect and organize relevant data on radionuclide concentrations in environmental media. Radionuclide concentrations in surface water and/or sediment and in soil are needed for implementing the graded approach. Acceptable sources of data include but are not limited to:

- Annual Site Environmental Reports;
- Effluent monitoring and environmental surveillance data;
- Remediation data; and
- Data from special site-specific studies (i.e., ecological studies conducted for other purposes).

The data should be organized by location and medium, and be applicable to the geographic area of evaluation identified in Step 2 above. Locations may be defined by management and administrative characteristics (e.g., remediation sites; operations areas; operable units), physical characteristics (e.g., watershed; pond; stream), or ecological characteristics (i.e., corresponding to habitat types). Maximum radionuclide concentrations in environmental media shall be used in the initial application of the general screening phase to provide the most conservative evaluation.[2]

4.3.1 Aquatic System Considerations

If you are conducting an aquatic system evaluation, note that use of radionuclide concentration data from co-located surface water and sediment samples is preferred and will result in a less conservative, more realistic evaluation. A mix of data from water and/or sediment samples collected from different locations within the vicinity of one another may be used, with justification. Note that where co-located samples are not available, only water or only sediment data may be used, but will result in a significantly more conservative evaluation. This is because the BCGs derived using individual water or sediment values involve the use of a conservative sediment distribution coefficient K_d to calculate the environmental media radionuclide concentration and dose contribution of either the missing water or sediment component.

[1] If the data set is large, it is statistically likely there will be outliers with concentrations that may be much higher than the majority of data suggests. In this case, a concept of using the mean concentration plus one standard deviation would be acceptably conservative.

[2] Data from very small areas with significantly higher concentrations (i.e., hot spots) should not be used, as it may not be representative of the entire area of evaluation.

4.3.2 Terrestrial System Considerations

If you are conducting a terrestrial system evaluation, you should consider the types of receptors resident in your area of evaluation and the appropriateness of your soil samples with regard to these receptors. For example, surface soil samples may not be representative of potential radionuclide exposure to deep-rooted plant receptors. Note that if you have a water body in your evaluation area, you must also conduct an aquatic system evaluation.

4.3.3 Aquatic and Terrestrial Tissue Data

Tissue concentration data are valuable for several reasons:

- They may be entered into RESRAD-BIOTA, bypassing the need for B_{iv}s;
- They may be combined with soil, sediment, or water data to calculate site-specific B_{iv}s; or
- They may be used to calculate internal doses (see Appendix E: Dose Conversion Factors and Table E-2).

For each radionuclide, Table E-2 lists the internal dose that results from a specific tissue concentration. For example, for Cs-137 the table lists 4.3E-6 Gy/y per Bq/kg (4.3E-5 rad/d per pCi/g). The reciprocal, 2.3E5 Bq/kg per Gy/y (2.3E4 pCi/g per rad/d) is the tissue concentration that will cause 1 Gy/y or 1 rad/day, respectively. Similarly, for Sr-90, 1.8E5 Bq/kg will cause 1 Gy/y and 1.7E4 pCi/g will cause 1 rad/day.

Note that tissue concentrations are often reported on the basis of dry-weight or ash-weight. These must be converted to wet-weight concentrations for comparison with Table E-2.

4.3.4 Field Instruments

Screening data may be obtained using field instruments such as those used by radiological control technicians. The general principles are described in McNaughton (2009), and an example for the use of field instruments to measure Cs-137 in deer is described in Padgett (2006).

Generally, the advantages include:

- Many measurements;
- Short times;
- Immediate results;
- Minimal disturbance; and
- Low cost.

The methods are generally sensitive enough for comparison with the default BCGs for soil. They may also be used to measure tissue concentrations, as described in Section 4.3.3 above. The method described by Padgett (2006) can be used with concentrations as low as 1 pCi/g, so it is not difficult to detect the concentration of 23,300 pCi/g that corresponds to 1 rad/d (see Appendix E.).

5 General Screening Phase

A major goal of the general screening phase is to provide a method to easily apply data on radionuclide concentrations in an environmental medium to evaluate compliance with the dose rate criteria for biota. In the general screening phase, data on radionuclide concentrations in environmental media are compared with a set of generic BCGs. Each radionuclide-specific DOE BCG represents the limiting radionuclide concentration in environmental media which would not result in DOE's established or recommended dose rate criteria for biota to be exceeded. These limiting radionuclide concentrations, or BCGs, are presented in Appendix G. These "look-up" tables allow for comparisons of radionuclide concentrations in environmental media with the BCGs.

RESRAD-BIOTA Model

Perhaps the easiest way to conduct and document a general screening phase is to enter the maximum concentrations of each radionuclide into the RESRAD-BIOTA software for a Level 1 evaluation for either a terrestrial or an aquatic ecosystem.

5.1 Compare Data on Radionuclide Concentrations in Environmental Media with Generic BCGs

A sum of fractions approach is used in comparing data on measured radionuclide concentrations in environmental media with the BCGs contained in the look-up tables. That is, when multiple radionuclides are present in multiple environmental media, the sum of fractions rule shall be applied to account for all sources of exposure. Hence, the sum of the ratios of the measured concentration of each radionuclide to its corresponding BCG for each medium shall then be summed across media, and the total sum of fractions shall not exceed 1.0.

Sum of Fractions Rule

When multiple radionuclides are present in multiple environmental media, the sum of fractions rule shall be applied to account for all sources of exposure.

For each environmental medium, for radionuclides A, B, ... N, with concentrations C_A C_B…C_N and corresponding screening BCG values $BCG_A, BCG_B, \ldots BCG_N$, this relationship for aquatic and terrestrial system evaluations is as follows:

Aquatic System Evaluation

$$\left[\frac{C_A}{BCG_A}+\frac{C_B}{BCG_B}+\cdots+\frac{C_N}{BCG_N}\right]_{\text{water}}+\left[\frac{C_A}{BCG_A}+\frac{C_B}{BCG_B}+\cdots+\frac{C_N}{BCG_N}\right]_{\text{sediment}}<1.0 \qquad \text{(Eq.1)}$$

Terrestrial System Evaluation

$$\left[\frac{C_A}{BCG_A}+\frac{C_B}{BCG_B}+\cdots+\frac{C_N}{BCG_N}\right]_{\text{water}}+\left[\frac{C_A}{BCG_A}+\frac{C_B}{BCG_B}+\cdots+\frac{C_N}{BCG_N}\right]_{\text{soil}}<1.0 \qquad \text{(Eq.2)}$$

If the sum of fractions (the summed ratios between the radionuclide concentrations in environmental media and the radionuclide-specific BCGs) is less than 1.0, the dose to an aquatic or terrestrial receptor

is below the biota dose limit, and you have passed the general screening evaluation. Proceed to Section 7, Documenting Your Biota Dose Evaluation Results. If the sum is greater than 1.0, further investigation is required (e.g., initiating site-specific screening or analysis).

Example: Using the Sum of Fractions Rule

Maximum radionuclide concentrations for water and soil collected within the evaluation area and available through the existing site environmental surveillance program were summarized. Maximum radionuclide concentrations for Cs-137 and Sr-90 in soil were 1.21 and 1.30 pCi/g, respectively. Maximum radionuclide concentrations for Cs-137 and Sr-90 in water were 49.6 and 84.5 pCi/L, respectively.

Applying the sum of fractions rule, and using the RESRAD *BCG values listed in*

Table G-3*, one obtains the following:*

$$Soil: \frac{1.21\,\frac{\text{pCi}}{\text{g}}}{800\,\frac{\text{pCi}}{\text{g}}} + \frac{1.3\,\frac{\text{pCi}}{\text{g}}}{800\,\frac{\text{pCi}}{\text{g}}} = 3.1 \times 10^{-3} \qquad Water: \frac{49.6\,\frac{\text{pCi}}{\text{g}}}{6 \times 10^{5}\,\frac{\text{pCi}}{\text{g}}} + \frac{84.5\,\frac{\text{pCi}}{\text{g}}}{5 \times 10^{4}\,\frac{\text{pCi}}{\text{g}}} = 1.63 \times 10^{-3}$$

$3.1 \times 10^{-3} + 1.63 \times 10^{-3} = 4.8 \times 10^{-3} (total\ sum\ of\ fractions)$

Conclusion: Because 0.005 is less than 1.0, the dose to a terrestrial receptor does not exceed the recommended dose rate criteria for protection of populations of terrestrial plants and animals. Note that the soil medium provides most of the contribution to dose.

5.1.1 Aquatic System Considerations

In situations where co-located water and sediment data are not available, in the general screening phase you must estimate the missing radionuclide concentration data through the use of "most probable" radionuclide-specific K_d values. Radionuclide-specific most probable K_d values are provided in Appendix D and shown on the RESRAD-BIOTA main menu if the sediment check box is not checked. The radionuclide concentration data estimated for the missing water or sediment medium is then used along with the radionuclide concentration data for the available medium in the sum of fractions calculation as described previously. Judgment should be applied in determining if measured radionuclide concentration data for water and sediment media can be considered as originating from co-located water and sediment samples. If measured radionuclide concentration data for water and sediment media are only available from separate locations, calculate the missing radionuclide concentration data for each missing medium, and apply the approach that results in the highest (e.g., most conservative) sum of fractions in your biota dose evaluation. If the sum of fractions is less than 1.0, the dose to an aquatic receptor is below the biota dose limit, and you have passed the general screening evaluation. Proceed to Section 7, Documenting Your Biota Dose Evaluation Results. If the sum is greater than 1.0, further investigation is required (e.g., initiating site- specific screening or analysis).

5.1.2 Terrestrial System Considerations

Typically, soil and water samples will not be co-located. Judgment should be applied to determine the likely source of drinking water for a terrestrial animal. Things to consider when making this judgment

are the home range of your site's terrestrial animals and the temporal availability of potential drinking water.

5.2 Dealing with High Background Levels of Naturally Occurring Radionuclides

Radiation dose rates at local background reference sites can be used to ensure that the site-related dose rates represent an actual increase in exposure. If the evaluation area is suspected or has been documented to have high background levels of naturally occurring radionuclides, these background levels may be taken into account when determining compliance of DOE activities with the biota dose rate criteria. For example, this may be a consideration for the two isotopes of radium (see BCGs for Ra-226 and Ra-228, Appendix G). Background levels for environmental media should be estimated based on data for the same or similar media types in uncontaminated areas. If the sum of fractions for measured radionuclide concentrations in media from the contaminated area exceeds 1.0, this sum should be compared with the sum of fractions calculated using measured radionuclide concentrations in media from the background area. If the sum of fractions from the contaminated area does not exceed that from the background area, the contaminated area has passed the screening evaluation. Proceed to Section 7, Documenting Your Biota Dose Evaluation Results and document the results of the comparison. If the contaminated area sum of fractions does exceed the background sum of fractions, proceed to the next phases of the graded approach.

6 Analysis Phase

The analysis phase of the graded approach contains three increasingly more detailed components of analysis for evaluating doses to biota: site-specific screening, site-specific analysis, and site-specific biota dose assessment. In the analysis phase, you are also increasingly moving away from the default parameters and assumptions used in the general screening phase of the graded approach. The amount of effort required for your biota dose evaluation and the information needed about site-specific conditions and receptors increase as you progress through the three components of the analysis phase. The amount of specialized assistance (e.g., in health physics, radioecology, and eco-risk assessment) that might be needed also increases as you progress through the components of the analysis phase. In return, the result will be a set of less conservative, more realistic and site-representative BCGs. **The rationale for selection of site-specific parameters applied in this phase shall be sufficiently documented when reporting your biota dose evaluation results**. Each of the three analysis components is described below.

6.1 Site-Specific Screening (RESRAD-BIOTA Level 2 evaluation)

Site-specific screening allows you to apply knowledge of site-specific conditions and receptors in your biota dose evaluation in place of the default parameter values and assumptions used in the general screening phase of the graded approach. For example, use of mean radionuclide concentrations in place of values that were used in the level 1 screening, taking into account time dependence and spatial extent of contamination, may be considered. Parameters representative of site-specific receptors also may be considered. These considerations and their application in site-specific screening are discussed below.

6.1.1 Step 1: Assess Representativeness of Input Data on Radionuclide Concentrations in Environmental Media and Delineation of Evaluation Area

Questions to Consider in Determining Your Path Forward in Site-Specific Screening:

- *Can I use mean radionuclide concentrations rather than maximum values?*
- *Does it make sense to adjust or re-define my evaluation area, using knowledge of the spatial-temporal extent of my contamination with respect to receptor habitats?*
- *Are the "limiting organism types" corresponding to my media and radionuclides expected to be present in my evaluation area?*
- *Do I have site-representative parameters (e.g., B_{iv}, K_d values) that can be used in place of default values?*

Spatial and temporal variability relative to the distribution of contamination in the evaluation area can be taken into account when evaluating doses to biota. Each of the elements presented below should be considered collectively as you proceed through this step.

6.1.1.1 Consider Using Mean Radionuclide Concentrations

Determine if mean radionuclide concentrations can be used in place of maximum concentrations. For example, use of mean values is appropriate and permitted in situations where time-series data are

available and of sufficient quality. Spatial variability in the distribution of contamination can also be taken into account.

Location-specific data for individual radionuclides in specific environmental media are used in the screening process. When conducting a screening evaluation, it is important to use radionuclide concentrations that are estimated to be mean values or greater than mean values for the contaminated area. Only data at or above the mean are adequate for screening purposes because mean concentrations are assumed in this technical standard to approximate those concentrations to which a representative individual within a population would be exposed.

Available data may not be adequate to ascertain that radionuclide concentrations are likely at or above mean values for the contaminated area. Non-representative measurements may occur and result in values that are considerably higher (or lower) than the actual mean concentration. That is, concentrations are so far above the mean value that they falsely indicate that biota are receiving doses above the recommended, criteria, or so far below the mean value that they falsely indicate that biota are receiving doses below the recommended limits. In these cases, it is acceptable to account for both spatial and temporal distributions of radionuclides in the environment when estimating mean values of radionuclides for use in site-specific screening.

Radionuclide concentrations can be adjusted to account for site-specific spatial and temporal factors that will bring them closer to mean values. Consider the following examples:

- If the source of radionuclides is an intermittent discharge to the environment, concentrations of radionuclides discharged to the receiving environment may be adjusted over time based on discharge records.
- A correction factor for exposure area or organism residence time may be applied in the site-specific analysis component to account for intermittent sources of exposure that would affect all receptors in the evaluation area, or to account for the movements of organisms in and out of the contaminated area over time, for example, because of seasonal migration or diurnal migration in and out of the contaminated area.
- If the contamination exhibits a decreasing gradient of concentration away from the source, then mean concentrations of contaminants within the contaminated area may be used, taking into account the intersections with distinct habitats. Where available contaminant data are comprehensive, it would be possible to accurately estimate the size of the contaminated area and the distribution of contamination within that area. Statistical methods may be used to calculate mean values. The statistical methods selected should be widely-used methods referenced in standard statistical texts and/or recommended by a qualified statistician. However, where contaminant data are not sufficiently comprehensive to conduct rigorous statistical analyses but provide a semi-quantitative basis for estimating mean values, subjective judgment may be used with justification.
- If the area being considered has been documented to have high background levels of naturally occurring radionuclides, these background levels may be taken into account when determining compliance of DOE activities with the recommended biota dose limits. For example, this may be an important consideration for the two isotopes of radium (see BCGs for Ra-226 and Ra-228

in Appendix G). Background levels for water, soil and sediment media should be estimated based on data for the same or similar water, soil or sediment types in areas unaffected by facility effluents.

- If available data does not produce a representative value of contaminant concentrations, additional data may need to be collected to obtain more realistic estimates of mean values. Either or both of the following types of data may be needed: (a) data on the spatial distribution of concentrations of radionuclides within the contaminated area; and (b) data on the size of the contaminated area.

Both of these types of data are needed for estimating the mean concentrations of contaminants that are assumed to approximate the concentrations that a representative individual would encounter. In cases where very little data are available on the distributions of radionuclide concentrations, a preliminary survey may be needed.

6.1.1.2 Consider Using Less-Than-Detectable Values

Environmental media often include extremely low concentrations of radionuclides. Measurements of these radionuclides are typically referred to as "non-detects." It is possible to calculate net results that are less than zero (negative results). A common misconception is that negative or non-detect results should not be reported as is, but should be assigned a value of zero, the detection limit, or a fraction of the detection limit. These practices are not recommended because they bias the data. The best practice is to report and use all results in the summary statistics, whether positive, negative, or zero, as obtained. Refer to Chapter 8 of DOE Handbook 1216, *Environmental Radiological Effluent Monitoring and Environmental Surveillance* for more complete guidance on data analysis and statistical treatment of environmental datasets.

6.1.1.3 Consider Refining the Evaluation Area

It may be useful to re-assess your rationale for delineating the evaluation area i.e., breaking one large area into several smaller areas) through consideration of the quality and spatial-temporal distribution of radionuclide concentration data, the ecological susceptibility and habitats of the receptors, and the spatial distribution of contaminants with respect to these habitats. Refer to Appendix C, Section C.1: Area Factors for detailed guidance in this area.

6.1.1.4 Consider Obtaining Additional Radionuclide Concentration Data

Consider collecting additional radionuclide concentration data. For an aquatic system evaluation, consider using co-located water and sediment data if you have not already done so.

6.1.2 Step 2: Re-Run the Screening Evaluation Using Revised Radionuclide Concentration Data and/or Evaluation Area

Here you are comparing your refined data on measured radionuclide concentrations corresponding to your original or re-defined evaluation area, with the generic BCGs. This is done by re-entering these revised radionuclide concentration data for RESRAD-BIOTA Level 2. It is important to note that in this step you have not modified the initial, generic RESRAD-BIOTA Level 1 BCG values. They are the same generic BCGs that are used in the general screening phase of the graded approach. This step is

considered a site-specific screen in that you are now making site-specific judgements relative to your measured radionuclide concentration data and your evaluation area. If the sum of fractions is less than 1.0, then you have passed the site-specific screening evaluation. Proceed to Section 7, Documenting Your Biota Dose Evaluation Results. If the sum of fractions is greater than 1.0, then continue to progress through the graded approach.

Selecting a Site-Specific Receptor

The receptor should be important to the structure and function of the community. It should:

(1) be expected to receive a comparatively high degree of exposure (e.g., expected to receive a radiation dose to reproductive tissues which is relatively high per unit of radionuclide present in the ecosystem, in comparison to other receptors in the same community);

(2) have a comparably high degree of radiosensitivity (e.g., radiation effects of concern occur at relatively low doses, in comparison with other receptors in the same community); and

(3) exhibit a high degree of bioaccumulation.

6.1.3 Step 3: Assess Representativeness of Default Parameters/Assumptions for Generic BCGs; Select Site-Specific Parameters and Generate Site-Specific BCGs

This step allows you to replace default parameters used in the general screening phase with site-representative parameters for use in site-specific screening. Each of the elements presented below should be considered collectively as you proceed through this step.

6.1.3.1 Identify Radionuclide-Specific Limiting Medium and Organism Type

Review the radionuclide-specific BCGs used in the general screening phase of the graded approach. First, identify the environmental medium and individual radionuclides from your evaluation that provide the greatest contribution to potential dose (i.e., medium concentration: BCG ratios that represent the largest contributors to the sum of fractions). Then, for each of these radionuclides, identify the limiting organism type from which the generic BCGs were derived. Limiting organism types corresponding to generic BCGs are listed for each radionuclide in Appendix G. If you did not conduct a general screen prior to site-specific screening, go to the organism type table or spreadsheet that corresponds to the site-specific receptor you have chosen to use in your analysis.

The site-specific receptor you select should be important to the structure and function of the community, in that protection of this organism within your evaluation area assures that all other organisms in your evaluation area are also protected. Some examples of receptors that could serve as good indicators of radiological impact are provided in Appendix C (Section C.1.4).

6.1.3.2 Review and Select Site-Specific Bioaccumulation Factors

The general screening phase (Level 1) uses a conservative default bioaccumulation factor (B_{iv}) in the estimation of internal radionuclide concentrations of an organism. This B_{iv}, along with dose conversion factors, determines the internal dose to an organism. The B_{iv} is based largely on empirical measurements of radionuclides in biological tissues of organisms collected in contaminated habitats. In cases where empirical measurements are unavailable or limited, the B_{iv} is based on a conservative value derived using uncertainty analysis on the kinetic/allometric method (see Appendix F). The B_{iv} serves as

a "natural integrator" of internal contamination, in that, it inherently reflects all pathways of intake by an organism. Here, in site-specific screening, B_{iv} values representative of site-specific conditions and receptors can be used to generate site-specific BCGs in place of the default B_{iv} values that were used in generating the generic BCGs. This site-specific screening result is a less conservative, but more realistic, evaluation of potential doses to biota for your area of evaluation.

The initial values of the B_{iv} were specifically chosen to produce conservative (i.e., overly protective) BCGs. It is recognized that actual B_{iv} for a single radionuclide may range over several orders of magnitude, depending upon biotic and abiotic features of the environment. The default B_{iv} values (and other input parameters) are contained in a set of organism type tables (Tables F-1 – F-4) and similar values are available in RESRAD-BIOTA. Review and select B_{iv} values representative of site-specific conditions and receptors you have selected for your evaluation area. These site-specific B_{iv} are entered into the appropriate organism type spreadsheet in RESRAD-BIOTA and used to generate site-specific BCGs. Sources for B_{iv} values representative of your site-specific conditions and receptors include:

- Your own derived values for site-specific receptors; and
- Values published in the scientific literature or in site-specific technical reports (i.e., from specialized ecological studies) for receptors that are comparable to site-specific receptors in your evaluation area.

6.1.3.3 Review and Select Site-Representative K_d Values

For aquatic system evaluations where co-located water and sediment samples are not available, recall that in the general Level 1 screening phase a default most probable K_d is used to calculate the environmental media radionuclide concentration and dose contribution of either the missing water or sediment component. Site-specific screening allows you to consider the use of a site-representative K_d value in place of the default most probable value that was used in the general screening phase. Minimum, maximum, and most probable K_d values for each radionuclide are provided in Appendix D, Tables D-1 andD-2. Sources of K_d values representative of your site-specific conditions include:

- Your own site-derived K_d values; and
- Values published in the scientific literature or in site-specific technical reports.

Site-representative K_d values can be entered into RESRAD-BIOTA Level 2 evaluations and used in generating site-specific BCGs.

6.1.4 Step 4: Re-Run Screening Evaluation and Compare Data on Radionuclide Concentrations in Environmental Media with Newly-Generated Site-Specific BCGs

The use of B_{iv} values appropriate for site-specific conditions or receptors should result in more realistic, site-representative BCGs. When using RESRAD-BIOTA, the generic Level 1 BCGs are automatically updated with the newly generated BCGs, allowing for easy evaluation. If the sum of fractions (the summed ratios between the radionuclide concentrations in environmental media and the radionuclide-specific BCGs) is less than 1.0, the dose to the aquatic or terrestrial receptor is below the biota dose limit. If the sum is greater than 1.0, further analysis is required.

6.2 Site-Specific Analysis (RESRAD-BIOTA Level 3 evaluation)

In site-specific analysis, a kinetic/allometric model is employed to conduct a more rigorous analysis of riparian animal and terrestrial animal organism types. Here you are conducting a very site-specific evaluation (essentially estimating an upper-bound dose) to a site-specific riparian or terrestrial animal of known characteristics (e.g., body mass, behavior, internal exposure pathways, and parameters). Recall that the general and site-specific screening approaches use a B_{iv} value in the estimation of internal dose to an organism. As mentioned earlier, the B_{iv} serves as a "natural integrator" of internal contamination, in that, it inherently reflects all pathways of intake by an organism. In site-specific analysis, simplistic, first-order kinetic modeling is used to examine the internal pathways of exposure for riparian animal and terrestrial animal receptors in greater detail. Appropriate parameters representing individual mechanisms (e.g., ingestion; inhalation) that contribute to internal dose are applied in place of the B_{iv} (one value which reflects all mechanisms contributing to internal dose). Appropriate values (e.g., organism body mass; ingestion rate; inhalation rate; biological uptake and elimination rates) that are representative of site-specific conditions and receptors are used in the estimation of internal dose and generation of site-specific BCGs. Allometric equations relating body size to many of these parameters (e.g., ingestion rate; inhalation rate; life span) are used in the estimation of internal dose. Alternatively, you can enter your own values in place of allometrically derived parameters. A correction factor for exposure area or organism residence time may also be applied for all organism types in site-specific analysis.

6.2.1 Step 1: Assess Representativeness of Default Parameters/Assumptions for Kinetic/Allometric Models; Select Site-Specific Parameters and Generate Site-Specific BCGs

This step allows you to examine and replace default parameters, assumptions, and allometric relationships used in kinetic/allometric models to derive BCGs for riparian animals and terrestrial animals. A correction factor for exposure area or organism residence time may also be applied for all organism types. Each of the elements presented below should be considered collectively when implementing this step.

6.2.1.1 Identify Radionuclide-Specific Limiting Medium and Organism Type

Review the radionuclide-specific BCGs used in the general or site-specific screening portions of the graded approach. First, identify the environmental medium and individual radionuclides from your evaluation that provide the greatest contribution to potential dose (i.e, medium concentration: BCG ratios that represent the largest contributors to the sum of fractions). Then, for each of these radionuclides, identify the limiting organism type from which the general or site-specific BCGs were derived. Limiting organism types corresponding to general BCGs are listed for each radionuclide in Appendix G, and in the corresponding RESRAD-BIOTA tables. If the riparian animal or terrestrial animal organism types are listed, then you may consider the guidance in Sections 6.2.1.2 – 6.2.1.4 below. If riparian or terrestrial animals are not listed as the limiting organism types, then you need only consider Section 6.2.1.2. If you did not conduct a general or site-specific screen prior to site-specific analysis, the proceeding statement applies to the site-specific receptor you have chosen to use in your analysis.

6.2.1.2 Consider Correction Factor for Exposure Area or Receptor Residence Time

A correction factor for exposure area or receptor residence time should be among the first parameters that you consider in site-specific analysis. Temporal and spatial variability can be taken into account when evaluating doses to biota. For example:

- radionuclides will typically be distributed non-uniformly in the environment; and
- organisms are typically distributed non-uniformly within the environment such that exposure may vary among individuals in an affected population (i.e., organisms may migrate into and out of areas of greater and lesser contamination).

The general and site-specific screening portions of the graded approach assume for conservative purposes that an organism's residence time in the evaluation area is 100 percent and that the contaminated media are available 100 percent of the time to provide a source of exposure. These assumptions can be modified in site-specific analysis.

Correction Factor for Receptor Residence Time

The term "residence time" as used in the graded approach refers to the fraction of time that biota resides in a radioactively contaminated area. In site-specific analysis, a correction factor for residence time (i.e., as a fraction of time) may be applied to take into account a specific receptor's home range, movements, and behavior relative to the evaluation area. This correction factor is entered into the "Area Factor" box on the dose conversion factors (DCF)/Exposure tab on the Organism edit screen of RESRAD-BIOTA. This is then factored into RESRAD-BIOTA generating site-specific BCGs.

Correction Factor for Exposure Area

Radionuclides will typically be distributed non-uniformly in the environment. In site-specific analysis, a correction factor for contaminated area (i.e., as a fraction of time) can be applied to take into account an intermittent source of exposure to all receptors in the evaluation area. This correction factor is entered into the "Area Factor" box on the DCF/Exposure tab on the Organism edit screen of RESRAD-BIOTA. This is then factored into RESRAD-BIOTA generating site-specific BCGs.

6.2.1.3 Riparian and Terrestrial Animals: Review and Select Parameters Representative of Site-specific Conditions and Receptors

In site-specific analysis you can also modify the individual parameters that relate to internal exposure pathways for site-specific conditions and receptors. RESRAD-BIOTA is designed for easy modification of these parameters and subsequent generation of site-specific BCGs that are derived using these new parameter values. Refer back to Table 2-2 for a complete list of parameters that can be modified when conducting a site-specific analysis.

6.2.1.4 An Important Note Concerning the Use of Available Biota Tissue Data

It is important to note that the use of measured concentrations of radionuclides in tissues of plants and animals in estimating internal dose is a reasonable and acceptable approach if adequate data are available. That is, if it can be justified that the available tissue data:

- Are representative of species within the evaluation area that are capable of receiving the highest dose; and
- Reflect a representative sampling of the population within the evaluation area.

These considerations are especially important in cases where biota tissue data becomes available as a result of opportunistic sampling (e.g., road kills; hunting). If available biota tissue data is determined to be inadequate, then collection and analysis of biota from the evaluation area will be required. The internal dose conversion factors for biota and external dose conversion factors for water, sediment and soil used to derive the generic BCGs in the graded approach are provided in Appendix E. These values, together with your measured radionuclide concentrations in water, sediment and soil, and biota tissue data, can be used to estimate an upper-bound dose to a receptor.

6.2.1.5 Riparian and Terrestrial Animals: Review and Select Food Source Parameter Values Representative of Site-Specific Receptors

The kinetic/allometric method for deriving riparian and terrestrial animal BCGs uses a radionuclide-specific food source parameter in calculating the internal dose contribution for these organism types. The method uses radionuclide-specific default B_{iv}s for aquatic animals and terrestrial plants (Appendix F) as the default food source parameter values for riparian and terrestrial animals respectively. You may review the appropriateness of these default food source parameter values (i.e., B_{iv}s and their source organisms) and replace these with food source parameter values B_{iv}s corresponding to organisms which are more representative of the expected food sources for the riparian or terrestrial animal you have selected to use in your site-specific analysis. When using RESRAD-BIOTA, changing the radionuclide-specific B_{iv} values in the aquatic animal and terrestrial plant spreadsheets will automatically change the riparian animal and terrestrial animal BCG values, respectively. These new site-specific BCGs will also show up on the Results screen and BCG Report, allowing for easy comparisons with previously entered radionuclide concentration data.

Entering Site-Representative Parameters for Riparian Animals and Terrestrial Animals in RESRAD Biota

First, click on the edit button below the appropriate Organism Type in RESRAD-BIOTA, then select the "Input Source" tab.

1) *If you have data for representative or maximum radionuclide concentrations in the tissue of the organism of interest, change the values in the "UseTissue" column from "No" to "Yes." Then click on the "Input" tab and the "Tissue Concentrations" tab to allow this data to be entered.*
2) *If you do not have representative tissue concentrations for organism of interest, the Kinetic/Allometric Method can be used to obtain more realistic dose estimates by the following:*
    a. *In the "UseAllom" column on the "Input Source" tab, change the values from "No" to "Yes" to allow these parameters to be modified.*
    b. *Click on the "Input" tab then on the "Allometric" tab to access the individual parameters (e.g., body mass; ingestion rate; inhalation rate; radionuclide uptake and retention factors) related to mechanisms providing an internal dose may be modified.*

Changing the radionuclide-specific food source B_{iv} values for the aquatic animal and terrestrial plant will automatically change the BCG values in the riparian animal and terrestrial animal spreadsheets, respectively.

6.2.2 Step 2: Re-Run the RESRAD-BIOTA and Compare Data on Radionuclide Concentrations in Environmental Media with Newly-Generated Site-Specific BCGs

The use of parameter values and a correction factor appropriate for site-specific conditions or receptors should result in more realistic, site-representative BCGs. If the sum of fractions (the summed ratios between the radionuclide concentrations in environmental media and the radionuclide-specific BCGs) is less than 1.0, the dose to the aquatic or terrestrial receptor organism is below the biota dose limit. Proceed to Section 7, Documenting Your Biota Dose Evaluation Results. If the sum is greater than 1.0, further analysis is required.

6.3 Site-Specific Biota Dose Assessment (RESRAD-BIOTA Level 3 evaluation)

6.3.1 Determine if Additional Analysis is Warranted

While the majority of the graded approach centers on the use of measured radionuclide concentrations in environmental media for comparison with the BCGs, the site-specific biota dose assessment component of the analysis phase centers on the actual collection and analysis of biota from the evaluation area. This is so that measured concentrations of radionuclides in the tissues of biota can then be used to more realistically estimate the internal dose contribution to a site-specific receptor.

Additional analysis may be warranted if biota dose evaluations using the screening and analysis methods described to this point continue to indicate that there is a potential adverse impact from radiation as a stressor to populations of biota (i.e., the BCGs are exceeded). An important point is that exceeding the BCGs should not force a mandatory decision regarding remediation of the evaluation area, but rather is an indication that further investigation is likely necessary.

There are many factors that should be considered when deciding how to respond following a determination that the BCGs are exceeded (e.g., ecological relevance and susceptibility of the affected population; size of the contaminated area and persistence of contaminants; impacts of remediation alternatives).

If radionuclide concentrations in environmental media exceed the BCGs, two courses of action may be taken. It may be desirable to perform detailed dose assessments for relevant receptors but given the potentially large expense that such a site-specific assessment could incur, removing the sources of ionizing radiation by reducing or eliminating discharges, or remediating existing environmental contamination, should also be considered. Site-specific conditions, especially the cost of eliminating discharges and/or remediating contaminated areas, will determine which approach is the most desirable.

Should Additional Analysis or Remedial Action be Considered?

Factors to consider if initial general screening, site-specific screening, and site-specific analysis elements of the graded approach indicate a potential radiological impact to populations of biota within the evaluation area:

- *The geographical extent of the contamination*
- *The magnitude of potential or observed effects of the contamination relative to the level of biological organization affected*
- *The likelihood that these effects could occur or will continue to occur*
- *The presence of genetically-isolated populations*
- *The ecological relationship of the affected area to the surrounding habitat*
- *The preservation of threatened or endangered species, or commercially or culturally valued species*
- *The recovery potential of the affected ecological resources and expected persistence of the radionuclides of concern under present site conditions*
- *The short- and long-term effects of the remedial alternatives on the habitat and the surrounding ecosystem*
- *Information obtained through a "lines of evidence" approach*

6.3.2 Recommended Approaches to Designing and Conducting the Site-Specific Dose Assessment

It is strongly recommended that all dose assessments be designed and conducted following the *Guidelines for Ecological Risk Assessment* (EPA 1998). Use of these guidelines will help ensure that the resulting dose assessments are technically sound. In addition, some of the steps in the ecological risk process (i.e., development of a site conceptual model) will be useful for assessing toxicological risks associated with some radionuclides (e.g., uranium isotopes) as well as the ecological risks from other co-occurring substances or stressors within the contaminated area (e.g., hazardous chemicals). The site conceptual model will also be useful for understanding the large-scale distribution of contaminants and the sources of ecological risk to the populations within and beyond the study area. If multiple stressors are present and need to be evaluated, then appropriate guidance concerning cumulative risk assessment should be considered (i.e., see EPA 1997b).

In addition to the references found in EPA's *Guidelines for Ecological Risk Assessment*, the following references and materials may be useful.

- Bilyard, C. R., H. Beckert, J. J. Bascietto, C. W. Abrams, S. A. Dyer, and L. A. Haselow. 1997. *Using the Data Quality Objectives Process During the Design and Conduct of Ecological Risk Assessments*. DOE/EH-0544, U.S. Department of Energy, Office of Environmental Policy and Assistance, Washington, D.C prepared by Pacific Northwest National Laboratory, Richland, Washington.
- Sample, B. E., M. S. Aplin, R. A. Efroymson, G. W. Suter II, and C. J. E. Welsh. 1997. *Methods and Tools for Estimation of the Exposure of Terrestrial Wildlife to Contaminants*. ORNL/TM-13391, prepared for U.S. Department of Energy, Office of Environmental Policy and Assistance by Oak Ridge National Laboratory, Oak Ridge, Tennessee.

- U.S. Department of Energy. 2015. *Environmental Radiological Effluent Monitoring and Environmental Surveillance.* DOE-HDBK-1216-2015, U. S. Department of Energy, Washington, D.C.
- U.S. Department of Energy. 1998. *Compendium of EPA-Approved Analytical Methods for Measuring Radionuclides in Drinking Water.* Office of Environmental Policy and Assistance, Assistant Secretary for Environment, Safety and Health, U.S. Department of Energy, Washington, D.C.
- U.S. Environmental Protection Agency (EPA). 1997. *Ecological Risk Assessment Guidance for Superfund: Process for Designing and Conducting Ecological Risk Assessments.* EPA 540-R-97-006 (Interim Final June 5, 1997), U.S. EPA, Washington, D.C.
- U.S. Environmental Protection Agency (EPA). 2006. *Guidance on Systematic Planning Using the Data Quality Objectives Process.* EPA/240/B-06/001, U.S. EPA, Washington, D.C.

7 Documenting Your Biota Dose Evaluation Results

At a minimum, your results shall be documented in your Annual Site Environmental Report (DOE O 231.1B, 2011). The following information shall be summarized in the Annual Site Environmental Report, and described in more detail within a report retained on file for future reference:

- Specify the biota dose rate criteria being complied with, such as those presented in this technical standard. Note DOE Order 458.1 does not specify dose limits for biota but does specify use of a process;
- Identify the methods used to demonstrate compliance with these criteria. Cite the method used (i.e., this technical standard). Describe the process used (e.g., general screening phase, site- specific analysis, actual biota dose assessment involving the collection and analysis of biota);
- Describe the area(s) of evaluation, sources of exposure, organism types, media types, and radionuclide data used in the evaluation;
- Summarize the results (e.g., sum of fractions for media and radionuclides are less than 1; doses calculated are less than biota dose rate criteria) for the site area(s) of evaluation; and conclusions;
- Summarize why the evaluation was conducted and how the results will be used (e.g., to demonstrate compliance with DOE dose rate criteria, for use in outreach activities, in response to stakeholder or regulator requests, or for use in an eco-risk assessment.); and
- All detailed information used in calculations (e.g., site-specific parameters selected and the rationale for their use) shall be described and retained on file for future reference and for sharing as lessons learned.

Appendix A. Evaluating Dose to Individual Organisms: Guidance on the Applicability of the Graded Approach

A.1. Considerations on the Meaning of "Individual" Organism

At the outset, the concept of an “individual” organism needs to be understood. A system for protection of an “individual” organism, such as the system for radiation protection of humans, is never intended to apply to each and every specific, identifiable individual (i.e., a named member of the public).

Rather, the concept of an “individual” organism refers to a *reference* organism that is intended to represent typical characteristics within a particular population group. The main reason for use of the concept of a reference individual organism is that the characteristics of specific, identifiable organisms (e.g., individual radiosensitivities, the behavior of radionuclides in the body of an individual) can never be known. In radiation protection of humans, for example, compliance with the dose limits for individual workers or members of the public is demonstrated by calculating doses to a hypothetical construct called Reference Person. Calculating a limiting dose (and risk) to a reference individual organism, provides reasonable confidence that no real population of individuals will experience unacceptable doses (and risks), but it cannot be ensured that unacceptable outcomes will never happen to a specific individual organism.

A.2. Applicability of Methods and Models in the DOE Graded Approach to Evaluations of Individual Organisms

The graded approach for evaluating radiation doses to aquatic and terrestrial biota developed by DOE, taken as a whole, can be viewed as consisting of two components:

- Methods or models for calculating dose to biota per unit concentration of radionuclides in environmental media (water, sediment, and soil); and
- A set of dose rate criteria for aquatic animals, terrestrial plants, and terrestrial animals, which represent dose levels of concern based on current information on dose-response relationships in a variety of organisms.

An ecological risk assessment may also be done instead.

By combining calculated doses per unit concentration of radionuclides in environmental media with the dose rate criteria, BCGs are obtained. The BCGs then are compared with measured concentrations to assess compliance with the dose rate criteria. The models for calculating dose per unit concentration of radionuclides in environmental media clearly apply to individual organisms. Thus, these models are directly applicable to individual organisms (i.e., for application to individual members of threatened and endangered species). DOE does not apply the dose rate criteria to protection of individual members of a species, instead the criteria applies to protection of populations of species.

A.3. Applicability of Biota Dose Rate Criteria to Protection of Individual Organisms

The dose rate criteria used by DOE are based on studies of dose-response relationships in *populations* of aquatic animals, terrestrial plants, and terrestrial animals. The particular biological endpoints for which dose-response relationships have been obtained include early mortality and impairment of reproductive

capability, the latter including effects on reproductive tissues and the embryo/fetus or seeds. Since reproductive effects in a population generally occur at lower doses than early mortality, the dose-response relationships for reproductive effects were used to derive the dose rate criteria. Thus, at first sight, it would appear that the dose rate criteria should be applied only when protection of populations of organisms is of concern, but they may also be appropriate when protection of individual members of a species is of concern.

However, the following points about the dose rate criteria should be noted. First, even if protection of populations is the primary concern, effects on populations of organisms can be inferred only by considering effects in individual organisms comprising a given population. In determining effects on populations, one would essentially need to count the number of impaired organisms in an irradiated population compared with the number of similarly impaired organisms in an unexposed population. Second, the dose rate criteria are based on the lowest dose at which any reproductive effects are observed in any species of aquatic animals, terrestrial plants, or terrestrial animals. Thus, if it is assumed that the species studied include those which are among the more radiosensitive, the dose rate criteria intended to reasonably ensure that there would be no significant effects at a population level should ensure that there would be no observable effects on individual members of a species, bearing in mind that there is always a background of similar effects from all causes, which limits the ability to observe or differentiate radiation-induced effects.

A.4. Use of the DOE Graded Approach for Evaluating Dose to Individual Organisms: Application Considerations

In examining the models and methods contained in the graded approach, and the basis for the biota dose rate criteria one key difference between applying them to protection of individuals or protection of populations is in regard to the extent to which calculated doses could be averaged over the spatial extent of contamination and over time. In protecting populations, considerable averaging over space and time could be allowed and still ensure adequate protection. In protecting individuals, however, it could be more appropriate to allow little or no averaging over space and time. Thus, in protecting individuals organisms, use of the maximum concentrations of radionuclides in the environment at any location and at any time could be more appropriate.

Use of safety factors, appropriate default parameter values, maximum radionuclide concentrations in environmental media, and 100 percent organism residence time and exposure may support the application of the graded approach for evaluating doses to individuals.

A.5. Consideration of Deterministic vs. Stochastic Effects

There is one additional caution that should be considered when applying the dose rate criteria to individual organisms, such as those for a threatened and endangered species. The dose rate criteria were derived from observed dose-response relationships for effects that generally are assumed to be deterministic in character, meaning that there should be no observable effects at doses below some threshold. However, there also is a possibility that stochastic radiation effects could be important in exposures of biota.

Information on stochastic effects in biota was considered in the 1996 UNSCEAR report on *Effects of Radiation on the Environment* (UNSCEAR 1996). The effects studied were at the cellular level, and include scorable cytogenetic effects (effects on DNA). The UNSCEAR report concluded that as long as the dose was kept below the dose rate criteria derived from dose-response relationships for reproductive effects, stochastic effects should not be significant at a population level.

However, the discussion in the UNSCEAR report leaves open the question of whether stochastic effects could cause harm in an individual organism (e.g., induction of a tumor that would result in premature death of an individual compared with the normal life span). There are two difficulties with interpreting the available data. First, the data on scorable cytogenetic effects appear to be considerably limited compared with the data on early mortality and reproductive effects. Second, although the available data in mammals and arthropods appear to indicate that scorable cytogenetic effects can be observed at dose rates roughly 100 times lower than the lowest dose rates causing early mortality and roughly 10 times lower than the lowest dose rates causing reproductive effects, it is difficult to interpret the significance of these effects in regard to harm to an individual organism (i.e., induction of tumors). For example, effects on DNA in humans who live in areas of unusually high natural background are easily observed, but increased incidence of cancers has not been observed in these populations.

Therefore, it is difficult to know how to apply the available information on scorable cytogenetic effects in a system for protection of individuals or populations. The best that can be said is that observations of these effects provide one more piece of information that could be used in evaluating the consequences of radiation exposures of biota and in deciding how to respond to those consequences.

Appendix B: Relative Biological Effectiveness (RBE)

B.1. Summary of Guidance

Radiation weighting factor (W_R) is a parameter used in dose calculation and is meant to account for the varying impacts that differing radiation types have on tissue (at identical radiation doses W_R values are estimated from cellular data measuring relative biological effectiveness (RBE) factors (i.e., the inverse ratio of doses causing the same level of effect) and are used to harmonize the different types of ionizing radiation (e.g., alpha, electrons, and photons). The use of W_R allows a dosimetrist to weight absorbed dose rates according to the biological harm inflicted by a certain type of radiation exposure.

The use of radiation weighting factors in biota dose assessment is complex; the ICRP (2008b) has acknowledged this and promises forthcoming guidance on the issue. To accommodate this complexity, the default effects thresholds and radiation weighting factors used in the graded approach (and RESRAD-BIOTA) can be adjusted. In RESRAD-BIOTA for example, the expected safe level of radiation exposure in populations of terrestrial animals might be divided by a modifying factor (i.e, 20) when evaluating the potential for adverse effects on individuals of a threatened or endangered species. Conversely, UNSCEAR has adopted the default radiation weighting factor of 10 for alpha particles and might be reduced to 5, to be consistent with new data concerning deterministic effects in biota as a consequence of radiation exposure. At that time, the RESRAD Biota code will need to be updated along with the affected Tables in Appendix E referenced in this standard.

To be conservative, all DOE sites should use a radiation weighting factor of 10 (which may be reduced to 5 in the future) for alpha particles when calculating internal absorbed dose to aquatic and terrestrial biota for the purpose of demonstrating protection with the applicable dose rate criteria applied in this technical standard. The result of this calculation should be reported in rem.

The reader should be aware that RESRAD-BIOTA does not have an input field for W_R and instead requires the user to enter RBE. While RBE and W_R are not the same quantity, for the purposes of using RESRAD-BIOTA, they should be treated as such.

B.2. Statement of Issue

The dose rate criteria to aquatic and terrestrial biota adopted in this technical standard are expressed in terms of absorbed dose. These dose rate criteria are based on studies of radiation effects in biota resulting from exposure to photons having a low linear energy transfer (LET); e.g., NCRP (1991) and IAEA (1992). For biota exposed to alpha particles, which are high-LET radiations, consideration must be given to increasing absorbed dose by a factor representing the RBE of this type of radiation.[3] The increased RBE of alphas, relative to gamma or beta radiations, arises due to increased tissue damage from higher LET radiations. Using W_R in this situation accounts for this increased tissue damage.

[3] The RBE of any radiation is defined as the ratio of the absorbed dose of a reference radiation (normally gamma rays or X rays) required to produce a level of biological response to the absorbed dose of the radiation of concern required to produce the same level of biological response, all other conditions being kept constant.

The use of a radiation weighting factor is of concern only in estimating dose to biota resulting from internal exposure to alpha-emitting radionuclides. Alpha particles are assumed not to contribute to the absorbed dose from external exposure, due to their very short range in matter.

B.3. Background on Radiation Weighting Factor

In human dosimetry, W_r is used to correct for differing RBEs of radiation (e.g., alpha vs neutron vs beta vs gamma). RBEs generally depend on LET and the particular biological effect of concern.[4] For alpha particles of any energy, the assumption for humans is that W_r=20 (ICRP 1991, ICRP 2007). This value represents the increased RBE for the stochastic effects of alpha particles in humans (NCRP 1990).

Controversy exists around the practice of applying a radiation weighting factor for alpha particles to the calculated absorbed dose to biota. Some investigators argue that a radiation weighting factor of 20, based on the value W_r=20 used in radiation protection of humans, may be inappropriate for biota (Baker and Soldat 1992; Amiro 1997, ICRP 2008b). They argue a value of W_r = 20 is inappropriate because the radiation effects of concern are not the same for humans versus biota (i.e., stochastic risk vs deterministic risk). The NCRP recommends omitting a W_r value altogether for biota, arguing that the conservative models used to estimate tissue concentrations of alpha-emitting radionuclides offer sufficient conservativism to be protective (NCRP 1991). Others (e.g., Blaylock et al., 1993, Jones 2000) have applied the human W_r=20 value in biota dose assessment.

The ICRP (2008b) has acknowledged the problem of W_r in biota dosimetry and has promised forthcoming guidance on the issue. However, as discussed previously, all DOE sites should use a W_r of 10 for alpha particles when calculating internal absorbed dose to aquatic and terrestrial biota for the purpose of demonstrating protection with the applicable dose rate criteria applied in this technical standard.

B.4. Data on Deterministic RBEs for High-LET Radiations

RBE data for deterministic radiation effects have been reviewed and evaluated by the ICRP (1990). The RBEs at low doses and dose rates for different types of high-LET radiation estimated by the ICRP may be summarized as follows.

- The RBE for deterministic effects induced by 1-5 MeV neutrons varies from 4 to 12, and the average value based on the results of 19 determinations is about 7.
- The RBE for deterministic effects induced by 5-50 MeV neutrons varies from 1 to 10, and the average value based on the results of 31 determinations is about 5.
- The RBE for deterministic effects induced by heavy ions (C, Ne, and Ar) varies from 1 to 8, and the average value based on the results of 19 determinations is about 4.
- The data on deterministic effects induced by alpha particles are much less extensive than the data for the other high-LET radiations, but two separate determinations yielded estimated RBEs of about 7 and 10.

[4] The radiation weighting factor (W_r) replaced the average quality factor ($\bar{Q}$) in ICRP report 60 (1991).

- The average RBE for deterministic effects, based on all determinations, is about 5.

The information summarized above leads to the conclusion that, for high-LET radiations, the radiation weighting factor for deterministic effects is substantially less than the corresponding radiation weighting factor used in radiation protection of humans. Based on this information, the radiation weighting factor for deterministic effects induced by alpha particles appears to lie in the range of about 5-10.

Appendix C: Guidance for Defining the Evaluation Area, Temporal and Spatial Averaging, and Estimating Mean Values

C.1. Area Factors: Defining the Evaluation Area

As stated in Section 5, the approach in the general screening phase should be to use maximum radionuclide concentration data applicable to the largest area of interest (i.e., the entire site). If the screening analyses using the default BCGs identify a need for additional analyses, then mean radionuclide concentrations may be applied in the site-specific screening phase of the graded approach. The definition of the evaluation area is an important aspect of any spatial averaging of radionuclide concentrations that may be applied in the graded approach. This section provides an approach for defining the evaluation area which uses the intersections of contaminated areas and populations of interest to define the areas over which concentrations can be averaged.

The selection of an appropriate biota dose evaluation area is governed by the principles of susceptibility and ecological relevance (EPA 1999). For large DOE sites, the entire site would, in most cases, be too large an evaluation area, because most of the biota on the reservation would not be exposed to the contamination. Focus should be on most exposed and most radiosensitive biota populations or on areas where it has been deemed important to protect individual organisms (i.e., endangered species). Biota which do not come into contact with contaminants, do not receive dose, and the inclusion of non-contaminated areas in the calculation of mean concentrations could result in low doses not representative of the actual impacts to the affected biota. On the other hand, the individual operable unit, waste trench, or contamination source would, in most cases, be too small to be ecologically meaningful and bias doses high. Although biota living in a 100 m^2 waste trench may be affected by trench contaminants, the loss of, or effects to, these individuals will likely have little impact on the population of small mammals in the region or on a broader scale ecosystem function. There are operations that utilize short high-energy beams that would cause a large dose to any small creatures that got in the way of the beam. Such unlikely and infrequent exposures would not have significant effect on the populations and should not be used as a scenario in the graded approach. Beyond these criteria, the scale of application depends greatly on site-specific conditions.

It is possible, however, to provide general guidance for selecting an appropriately scaled application area. This guidance is not meant to be prescriptive. Each step of the process involves a significant element of professional judgment and policy; and requires appropriate justification and documentation. In particular, the environmental monitoring organization at the site will be required to determine, justify, and document appropriate boundaries for areas with similar environmental concentrations of the same radionuclides (referred to hereafter as contaminated areas). Similarly, the site ecologists will need policy guidance and will be required to determine, justify, and document appropriate boundaries defining populations of interest or similar habitat types for which populations could be inferred.

The intersection of contaminated areas and the population or habitat boundaries define the areas over which concentrations can be averaged if use of the maximum concentrations at any locations does not show compliance with the dose rate criteria. This kind of analysis is most easily done using area maps, and Geographic Information Systems (GIS) will prove an invaluable tool. The following steps can be applied to determine this intersection.

C.1.1. Determine whether this method is necessary

First, use the default BCGs in the general screening phase with the input contaminant concentrations set at the highest concentrations, or a representative maximum value as discussed previously, found in your area of interest (e.g., the entire site or the evaluation area), based on local sampling guidance and procedures. If you pass the general screening phase, no further consideration is necessary. If use of the maximum concentrations at any location does not pass the general screening phase, then proceed below.

The following steps of the process center on determining the boundaries of the contaminated areas and their relationship to biota populations. This will likely involve consideration of:

- Boundaries presented by the quality, quantity, and distribution of available environmental radionuclide data, and resulting from the design of the site environmental monitoring and surveillance program;
- Boundaries presented by the susceptibility, ecological relevance, and habitat of receptors relative to the radionuclide contamination; and
- Boundaries resulting from the management and administration of facilities and operations areas on the site (e.g., location and extent of waste management facilities, production facilities, operable units, and operations areas).

C.1.2. Determine and map the boundaries of the contaminated areas

One possible set of boundaries might be the initial isopleths of a contamination plume, but there are other possibilities, particularly if the radionuclides present, their historical deposition, or their present environmental concentrations differ from location to location. The environmental monitoring organization should determine the most meaningful and justifiable boundaries across their site, ensuring consistency for subsequent analyses as much as possible

C.1.3. Determine the receptors

In order to have an understanding of the appropriate boundaries for exposed biota, it is necessary to understand which organisms are used in the graded approach.

The choice of organisms used in this methodology, as illustrated in Table C-1, evolved from consideration of the existing and radiation dose rate criteria for biota. Biota dose rate criteria had been set for aquatic animals, and were being considered for terrestrial plants and animals. Accordingly, the screening methodology had to accommodate these three general categories. A fourth, riparian animal, was added after recognizing that the riparian pathways of exposure combined aspects of both the terrestrial and aquatic systems.

Four organism types and their corresponding dose rate criteria were used in deriving the screening and analysis methods contained in this technical standard. The principal exposure pathways considered for aquatic animal (1 rad/d), riparian animal (0.1 rad/d), terrestrial plant (1 rad/d), and terrestrial animal (0.1 rad/d) organism types are shown in Appendix H. Dose evaluations for site-specific receptors (as

defined by the user in the analysis phase of the graded approach) should reflect consideration of all relevant exposure pathways depicted in these figures.

C.1.4. Example receptors that could serve as good indicators of radiological impact

Selected examples of representative organisms from several DOE sites that could be used in the analysis phase of the graded approach as indicators of radiological impact are provided in Table C-1. These examples are provided for illustrative purposes and are not all-inclusive. It is the user's responsibility to select site-specific organisms appropriate for the area being evaluated and to document the rationale for their selection.

Table C-1 Examples of representative organisms that could serve as indicators of radiological impact

AQUATIC ANIMALS	AQUATIC PLANTS	RIPARIAN ANIMALS	TERRESTRIAL ANIMALS	TERRESTRIAL PLANTS
Savannah River Site and the Southeast				
largemouth bass	pondweed	beaver	hipsid cotton rat	loblolly pine
channel catfish	cat-tail	raccoon	cotton mouse	longleaf pine
redbreast sunfish		alligator	coyote	bald cypress (also a riparian plant)
				swamp tupelo (also a riparian plant)
Oak Ridge Site				
catfish		mink	White-footed mouse	small vascular plants such as grasses and shrubs
carp		muskrat	deer mouse	pine trees
suckers		raccoon	cottontail rabbit	
sunfish			red and gray foxes	
Idaho National Engineering and Environmental Laboratory				
			sage grouse	sage brush
		great basin spadefoot toad	Coyote	
Pacific Northwest National Laboratory				
bass		raccoon	deer mouse	gray rabbit brush
carp		beaver	great basin pocket mouse	reed canary grass
sculpin			mule deer	mulberry tree
salmonids			coyote	
			great blue heron	
			bat	
			king bird	

C.1.5. Determine and map the boundaries of discrete habitat types

Optimally one would have knowledge of the species that reside within the radiologically contaminated area with particular interest in those with characteristics listed in the previous section as well as endangered, threatened, rare, or otherwise sensitive species of plants and animals. Site ecologists can

then define the habitat for the most limiting (most exposed and radiosensitive) species of each organism type (terrestrial plant, terrestrial animal, aquatic animal, and riparian animal) which would act as the appropriate boundaries encompassing the population(s) of interest. The site ecologists should use best professional judgment and all available data to justify these habitat boundaries.

C.1.6. Overlay the maps and identify the intersections

Each area of discrete habitat that lies within a discrete contaminated area can be appropriately defined as an assessment area. This may occur in several ways:

- A single contaminated area may be completely covered by a single habitat (Figure C-1 (a)). In this case, the contaminated area bounds the assessment area. An example of this kind of intersection might be a small pond with uniformly contaminated sediment;
- A single contaminated area might also intersect multiple habitats (Figure C-1 (b)). This might be the case at any site which releases airborne contaminants from a stack. In this case, there will be multiple assessment areas bounded by habitat type;
- Multiple contaminated areas of the same type may intersect a single discrete habitat (Figure C-1, (c)), in which case it is acceptable to integrate or average over multiple contaminated areas within a single habitat type; or
- Finally, there may be multiple habitats of the same type that intersect one or more areas with radionuclides in the same environmental concentrations (Figure C-2). In this case, arguing that habitats of the same type have similar species assemblages and similar structure and function, these intersections could be assumed to be one assessment area, even though they are separated in space.

In all these examples, it is important that contamination levels or parameters only be averaged over the intersection of the contaminated area and the habitat type of interest and not the areas between the intersections. If the areas outside the intersection were included, the averages would not likely be representative of the habitat type and/or contaminant levels of interest. The contaminated areas outside this intersection will be included in a different intersection of habitat type and contaminated area.

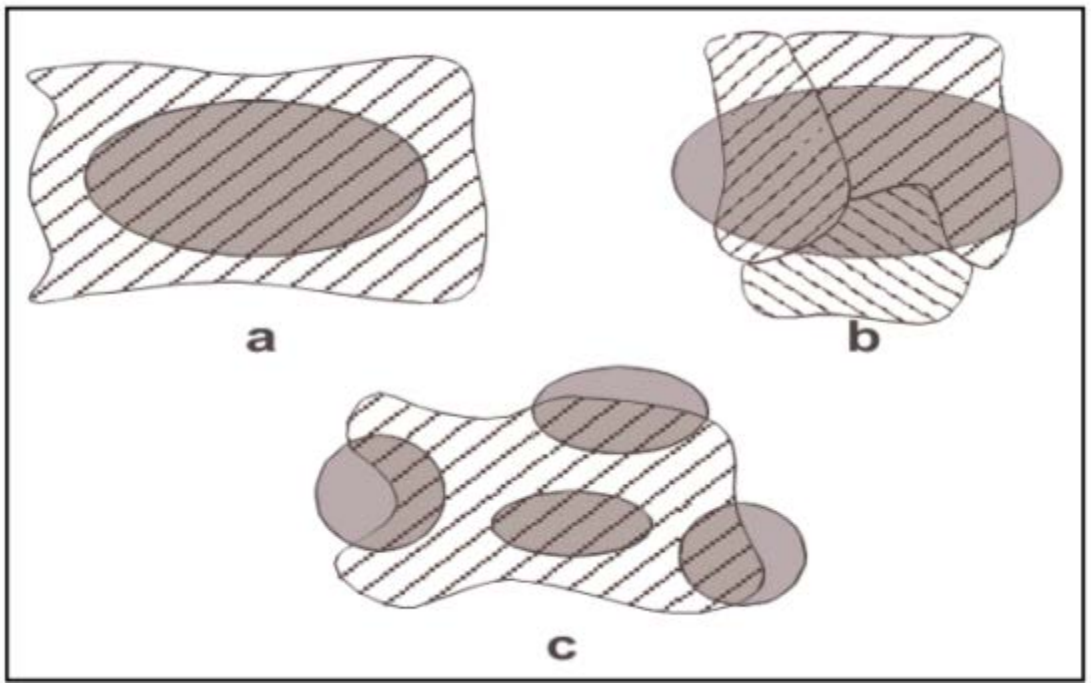


Figure C-1 Hypothetical maps of contaminated areas and discrete habitat used to determine appropriately scaled assessment areas. Shading indicates contaminated areas. The cross-hatching indicates habitat types. Three cases are considered: (a) a single contaminated area, (b) multiple habitats in a single contaminated area and (c) a discrete habitat in multiple contaminated areas.

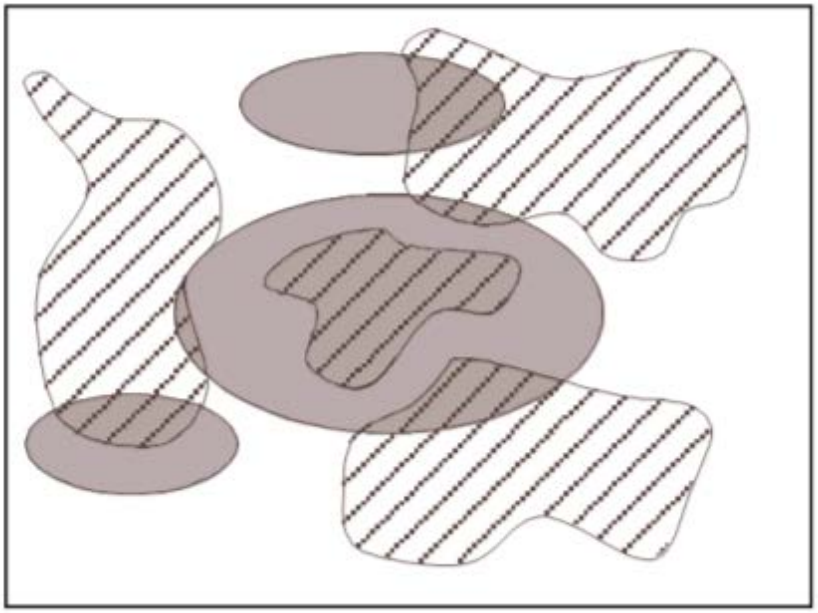


Figure C-2 A hypothetical map of multiple areas with the same contamination intersecting multiple patches of the same discrete habitat type used to determine appropriately scaled assessment areas.

C.2. Temporal Averaging Regarding Application of Biota Dose Rate Criteria and Mean Radionuclide Concentrations

Spatial and temporal variability relative to the distribution of contamination in the environment can be taken into account when evaluating doses to biota. This section provides guidance on spatial and temporal averaging regarding application of biota dose rate criteria and mean radionuclide concentrations. The rationale used to define an evaluation area is an important aspect of any spatial averaging of radionuclide concentrations that may be applied in the graded approach.

C.2.1. Use of Time Averaging in Applying Dose Rate Criteria for Aquatic and Terrestrial Biota

The daily dose rate criteria for aquatic and terrestrial biota are based on recommendations of the NCRP (1991), the IAEA (1992), and a DOE workshop (Barnthouse 1995). The guidance presented in this section on the use of time averaging in applying the daily dose rate criteria is based on the data on radiation effects in biota found in these reports and on the intended applicability of the recommended daily dose rate criteria. The guidance is supported by radioecological studies at highly contaminated sites in the former Soviet Union (Polikarpov 1994).

The dose rate criteria for radiation protection of biota at DOE sites are expressed in terms of daily criteria on absorbed dose. The dose rate criteria are intended to be compared against dose rate averages (e.g., monthly, seasonally or annually) to demonstrate adequate protection. It is not appropriate to compare the criteria to short term monitoring one-time events. However, the information in the reports identified above clearly indicates that the daily dose rate criteria for biota are not intended to be applied to each day of exposure. Rather, the daily dose rate criteria should be applied as averages over substantially longer time periods.

C.2.2. Guidance on Time Averaging in Applying Daily Dose Rate Criteria

The guidance on the use of time averaging in applying the daily dose rate criteria for biota assumes that compliance with the standards will be based in part on measurements of the concentrations of radionuclides in surface water, sediments, and surface soil. The following guidelines were offered:

- The estimated daily dose rates from exposure to contaminated surface water may be averaged over a period of approximately 1 month (30 days), and up to but not to exceed 1 year (365 days); and
- The estimated daily dose rates from exposure to contaminated sediments or soil may be averaged over a period substantially longer than 1 month, but not to exceed 1 year (365 days);

The above guidelines are generally consistent with the frequency of sampling of surface water, sediments and surface soil at DOE sites. The different time periods for averaging daily doses from exposure to surface water and exposure to sediments or soil are based on considerations of the times over which radionuclide concentrations in these environmental compartments are likely to change significantly in response to short-term fluctuations in radionuclide concentrations in effluents. Retention times of radionuclides in the water column often are relatively short, due to such processes as deposition on sediments and flushing by natural flow. Therefore, radionuclide concentrations in surface water can change relatively rapidly (e.g., with more rapid change in lotic systems, and generally less rapid change in lentic systems). However, radionuclide concentrations in sediments or surface soil

usually change more slowly because of sorption of radionuclides onto these media and the immobility of sediments or soils in most environments. Site-specific conditions (e.g., intermittent storm water flows; scour and transport of contaminated sediments resulting from seasonal occurrences such as high flow conditions) that may produce wide variations of exposure to receptors should also be considered in conjunction with the guidelines provided above when determining appropriate averaging periods.

C.2.3. Rationale for Guidance on Time Averaging

The guidance on the use of time averaging in applying the daily dose rate criteria for biota is based on reviews and evaluations of existing data and discussions of daily dose rate criteria in NCRP (1991), IAEA (1992), and Barnthouse (1995). The rationale for the guidance is summarized as follows:

The daily dose rate criteria for biota are intended to provide protection of whole populations of individual species, rather than individual members of the population. Furthermore, the primary health effect of concern in protecting whole populations of individual species is impairment of reproductive capability over the normal reproductive lifetime or death.

Daily Dose Rate Criteria

The daily dose rate criteria for biota are not intended to be applied to each day of exposure. Rather, the daily dose rate criteria should be applied as averages over substantially longer time periods.

The data on radiation effects in biota that provided the basis for the daily dose rate criteria were obtained primarily from studies involving *chronic* exposure, in which the average dose rate in the population varied substantially, often by an order of magnitude or more, over exposure times ranging from several months to several years. In the studies involving chronic exposure, the dose rate in individual organisms also varied substantially due to spatial in homogeneities in the dose rate and/or the movement and burrowing habits of organisms.

Based on studies involving short-term exposures, dose rates about 2-5 times higher than the daily criteria for biota appear to be tolerable for short periods of time (i.e., 30 days) if the daily dose rate averaged over the lifetime of the exposed population is limited in accordance with the standards.

Significant spatial variability in the doses to aquatic and terrestrial organisms may occur in environmental systems, due to two factors:

- *The spatial variability in the concentrations of radionuclides in different environmental media, due to dispersion and dilution during transport from localized sources and the spatial variability of processes that concentrate or immobilize radionuclides.*
- *Migration of organisms from or to areas of greater or lesser contamination.*

Single acute doses about 10-30 times higher than the daily dose limit appear to be tolerable (a) if the recovery time between such doses is sufficiently long (i.e., 30-60 days) and (b) if the daily dose rate averaged over the lifetime of the exposed population is limited in accordance with the standards.

The *average* doses in populations of study organisms were the primary basis for reporting dose-response relationships for deterministic effects, including early mortality and impairment of reproductive capability, and for developing standards for radiation exposure of biota. Thus, time averaging, as well as spatial averaging, of dose rates was inherent in the development of daily dose rate criteria. The dose rate criteria were not intended as limits for each day of exposure but, rather, as limits on the average daily dose rates encountered from conception through reproductive age. Therefore, averaging times as long as 1 year may be appropriate for reproducing members of populations of the most radiosensitive organisms (vertebrate animals and some higher plants).

Radioecological studies at highly contaminated sites in the former Soviet Union (Polikarpov 1994) suggest that radiation effects are observed at the population and community level only for annual doses greater than about 400 rad (4 Gy) or an average daily dose of about 1 rad (0.01 Gy). Thus, effects attributable to radiation exposure were observed only for average daily doses over 1 year equal to the dose limit for aquatic animals and terrestrial plants and 10 times the dose limit for terrestrial animals.

All of these factors taken together suggest that applying the daily dose rate criteria for biota as averages over a time period between 30 days and 1 year would provide adequate protection, especially when the time-dependence of most routine releases at DOE sites is taken into account.

C.3. Spatial Averaging Regarding Application of Biota Dose Rate Criteria and Mean Radionuclide Concentrations

This section discusses how spatial variability in doses could be taken into account when applying daily dose rate criteria for biota. General considerations and rationale regarding suitable approaches to selecting measured concentrations of radionuclides in environmental media (water, sediments, and soil) to be used when demonstrating compliance with the daily dose rate criteria based on the screening models is presented here. Guidance on selecting measured concentrations other than maximum values is also presented. The daily dose rate criteria for biota are intended to provide protection of whole populations of individual species rather than individual members of a population that might experience a greater dose. Thus, given that exposures of a population normally would occur over a considerable area, some type of an average value of the concentrations of radionuclides in environmental media over the area occupied by the population would be suitable for purposes of demonstrating compliance with the daily dose rate criteria. Most of the scientific data underlying the evolution of the dose rate criteria involves averaged responses to averaged dose rates, applying rational spatial averaging schemes for environmental media concentrations used in a biota dose evaluation would be appropriate.

The screening methods developed in this technical standard are intended to be conservative in their approach to estimating dose rates per unit concentration of radionuclides in water, sediments, or soil. Similarly, for judging compliance with the daily dose rate criteria for biota, some degree of conservatism also is warranted when initially selecting the values of measured concentrations of radionuclides in the environment to be used as input to the screening methods. For example, when protecting whole populations of individual species, it would be appropriately conservative to select initial radionuclide concentrations averaged values at a variety of locations close to any sources. Indeed, this is the rationale for first using maximum radionuclide concentrations in environmental media in the general

screening phase of the graded approach. In addition, because the area of habitation for many species will be considerably greater than the area of contamination, average values of radionuclide concentrations over the contaminated area should be conservative for purposes of complying with the dose rate criteria, albeit to a lesser extent.

It is typically labor-intensive and potentially difficult to completely characterize the distribution of radionuclide concentrations in the environment, particularly in sediments and soil. This is particularly true if such characterizations have not already been conducted. It may be resource- intensive and/or difficult to determine the ranges of concentrations of radionuclides in the exposure environment, and to provide reliable estimates of statistical measures of the distribution of concentrations with location, including, for example, the mean (average value).

As noted previously, many species are highly mobile. Therefore, when limited environmental data are available, an approach to applying the daily dose rate criteria for biota that relies on some form of statistical analysis may be unlikely to be more rigorous than a more qualitative and judgment-based approach to evaluating the data.

C.4. Guidance on Estimating Mean Values

For aquatic or terrestrial biota, compliance with applicable dose rate criteria should be demonstrated by first comparing the average measured values of radionuclide concentrations in environmental media (water, sediments, and soil), as obtained from existing networks for environmental monitoring, with the default BCGs in the general screening phase. However, if maximum measured concentrations do not comply with the biota dose rate criteria, then estimates of average concentrations over the evaluation area, determined as described in Section 6.1.1 can be compared with the default BCGs as the first step in the site-specific screening phase. Depending on the spatial coverage, quantity, or quality of the existing data, either judgment or statistical methods could be used to select average concentrations for comparison with the BCGs. In all cases, the approach to selecting the average values shall be documented. If average concentrations of radionuclides over the contaminated area exceed the default BCGs in the site-specific screening phase, then efforts to demonstrate compliance probably should focus on other aspects of the graded approach, such as reducing the degree of conservatism in the BCGs (e.g., generating more accurate and realistic site-specific BCGs, using site-representative parameters as described in site-specific screening and site-specific analysis, are all elements of the graded approach).

Appendix D: K_d Factors

Distribution coefficients describe the partitioning of a radionuclide between water and soil or sediment. Denoted by the variable K_d these parameters were used in the absence of water (or sediment) data to estimate the missing radionuclide concentration data.

Table D-1 Dose Factors and Common Parameters Spreadsheet

	Distribution Coefficients, K_d					
Nuclide	**Maximum Value L/kg (mL/g)**	**Reference $K_{d,max}$**	**Minimum Value L/kg (mL/g)**	**Reference $K_{d,min}$**	**Most Probable Value [1] L/kg (mL/g)**	**Reference $K_{d,mp}$**
Am-241	2.00E+06	Boyer	1.00E+03	Boyer	8.00E+04	Boyer
Ba-140	8.00E+04	Boyer	5.00E+01	Boyer	8.00E+03	Boyer
C-14	9.00E+03	TRS422	1.60E+02	TRS422	1.00E+01	RESRAD
Ce-141	1.50E+06	Boyer	8.00E+03	T&M	2.00E+05	Boyer
Ce-144	1.50E+06	Boyer	8.00E+03	T&M	2.00E+05	Boyer
Cf-252	2.00E+06	TRS422	1.00E+01	TRS472	1.00E+03	RESRAD
Cl-36	1.00E+00	DCH	4.00E-02	DCH	3.00E-01	DCH
Cm-242	2.00E+06	TRS422	1.00E+01	TRS472	1.00E+05	Boyer
Cm-244	2.00E+06	TRS422	1.00E+01	TRS472	1.00E+05	Boyer
Cs-134	3.00E+06	Boyer	1.00E+01	Boyer	7.00E+03 (DS), 1.00E+05 (SS)	Boyer
Cs-135	3.00E+06	Boyer	1.00E+01	Boyer	7.00E+03 (DS), 1.00E+05 (SS)	Boyer
Cs-137	3.00E+06	Boyer	1.00E+01	Boyer	7.00E+03 (DS), 1.00E+05 (SS)	Boyer
Co-58	2.00E+07	Boyer	2.00E+00	Boyer	9.00E+01 (DS), 4.00E+04 (SS)	Boyer
Co-60	2.00E+07	Boyer	2.00E+00	Boyer	9.00E+01 (DS), 4.00E+04 (SS)	Boyer
Cr-51	6.00E+05	Boyer	1.00E+00	DCH	2.00E+04 (DS), 7.00E+04 (SS)	Boyer
Eu-152	7.00E+05	Boyer	3.00E+04	Boyer	2.00E+05	Boyer
Eu-154	7.00E+05	Boyer	3.00E+04	Boyer	2.00E+05	Boyer
Eu-155	7.00E+05	Boyer	3.00E+04	Boyer	2.00E+05	Boyer
H-3	2.00E-01	RESRAD	5.00E-02	RESRAD	1.00E-01	RESRAD
I-129	1.00E+05	Boyer	7.00E-02	Boyer	3.00E+03	Boyer
I-131	1.00E+05	Boyer	7.00E-02	Boyer	3.00E+03	Boyer
Ir-192	3.00E+06	TRS422	3.50E+02	TRS422	2.00E+02	RESRAD
K-40	1.00E+04	Boyer	9.00E+02	Boyer	1.90E+03	Boyer
Np-237	1.30E+02	T&M	2.00E-01	T&M	4.00E+01	DCH
Pa-231	1.00E+07	TRS422	5.00E+02	DCH	2.00E+03	DCH
Pb-210	2.00E+07	Boyer	3.00E+01	Boyer	4.00E+04 (DS), 3.00E+05 (SS)	Boyer

	Distribution Coefficients, K_d					
Nuclide	**Maximum Value L/kg (mL/g)**	**Reference $K_{d,max}$**	**Minimum Value L/kg (mL/g)**	**Reference $K_{d,min}$**	**Most Probable Value [1] L/kg (mL/g)**	**Reference $K_{d,mp}$**
Po-210	3.00E+07	Boyer	1.00E+01	DCH	1.00E+05 (DS), 8.00E+05 (SS)	Boyer
Pu-238	2.00E+07	Boyer	2.00E+02	Boyer	1.00E+05	Boyer
Pu-239	2.00E+07	Boyer	2.00E+02	Boyer	1.00E+05	Boyer
Ra-226	2.00E+05	Boyer	8.00E+01	Boyer	1.00E+03 (DS), 5.00E+03 (SS)	Boyer
Ra-228	2.00E+05	Boyer	8.00E+01	Boyer	1.00E+03 (DS), 5.00E+03 (SS)	Boyer
Sb-125	1.00E+05	Boyer	6.00E-01	DCH	8.00E+03	Boyer
Se-75	7.00E+04	Boyer	5.00E+03	Boyer	7.00E+03 (DS), 2.00E+04 (SS)	Boyer
Sr-90	2.00E+04	Boyer	3.00E+00	Boyer	1.00E+02 (DS), 3.00E+03 (SS)	Boyer
Tc-99	1.00E+02	T&M	1.00E-02	DCH	5.00E+00	T&M
Th-228	3.00E+06	Boyer	1.00E+02	Boyer	7.00E+02 (DS), 2.00E+05 (SS)	Boyer
Th-229	3.00E+06	Boyer	1.00E+02	Boyer	7.00E+02 (DS), 2.00E+05 (SS)	Boyer
Th-230	3.00E+06	Boyer	1.00E+02	Boyer	7.00E+02 (DS), 2.00E+05 (SS)	Boyer
Th-232	3.00E+06	Boyer	1.00E+02	Boyer	7.00E+02 (DS), 2.00E+05 (SS)	Boyer
Th-234	3.00E+06	Boyer	1.00E+02	Boyer	7.00E+02 (DS), 2.00E+05 (SS)	Boyer
U-233	1.00E+05	Boyer	9.00E+01	Boyer	4.00E+03 (DS), 1.00E+04 (SS)	Boyer
U-234	1.00E+05	Boyer	9.00E+01	Boyer	4.00E+03 (DS), 1.00E+04 (SS)	Boyer
U-235	1.00E+05	Boyer	9.00E+01	Boyer	4.00E+03 (DS), 1.00E+04 (SS)	Boyer
U-238	1.00E+05	Boyer	9.00E+01	Boyer	4.00E+03 (DS), 1.00E+04 (SS)	Boyer
Zn-65	3.00E+07	Boyer	2.00E+00	Boyer	1.00E+02 (DS), 7.00E+04 (SS)	Boyer
Zr-95	1.00E+05	T&M	1.00E+02	RESRAD	1.00E+03	T&M

T&M = Table 3.2, Till and Meyer 1983; Boyer = Table 2, Boyer et al. 2018; RESRAD = Table 3.9-1, NUREG/CR-6697; DCH = Table 2.13.5, Data Collection Handbook (Yu et al. 2015).

Note: The $K_{d's}$ listed in this table from RESRAD and DCH are soil $K_{d's}$. These $K_{d's}$ should be considered as placeholders and, whenever available, sediment K_d values should be used. The K_d values from Boyer are mostly from the field measurements. For some radionuclides, the K_d values for both suspended sediment (SS) and deposited sediment (DS) are available.

(1) = "Most Probable" values shall be used to generate the generic BCGs for use in general screening in a case where only water or sediment data are available. In general, deposited sediment K_d values are lower than that of suspended sediment K_d values. To calculate water concentration from known sediment concentration, use DS K_d value; and to calculate sediment concentration from known water concentration, use SS K_d value.

Table D-2 Most Probable K_d values for use in calculating BCGs for sediment or water for an aquatic system evaluation in the absence of co-located water and sediment data

Radionuclide	Most Probable Value L/kg (mL/g)	Reference $K_{d,mp}$
Am-241	8.00E+04	Boyer
Ba-140	8.00E+03	Boyer
C-14	1.00E+01	RESRAD
Ce-141	2.00E+05	Boyer
Ce-144	2.00E+05	Boyer
Cf-252	1.00E+03	RESRAD
Cl-36	3.00E-01	DCH
Cm-242	1.00E+05	Boyer
Cm-244	1.00E+05	Boyer
Cs-134	7.00E+03 (DS), 1.00E+05 (SS)	Boyer
Cs-135	7.00E+03 (DS), 1.00E+05 (SS)	Boyer
Cs-137	7.00E+03 (DS), 1.00E+05 (SS)	Boyer
Co-58	9.00E+01 (DS), 4.00E+04 (SS)	Boyer
Co-60	9.00E+01 (DS), 4.00E+04 (SS)	Boyer
Cr-51	2.00E+04 (DS), 7.00E+04 (SS)	Boyer
Eu-152	2.00E+05	Boyer
Eu-154	2.00E+05	Boyer
Eu-155	2.00E+05	Boyer
H-3	1.00E-01	RESRAD
I-129	3.00E+03	Boyer
I-131	3.00E+03	Boyer
Ir-192	2.00E+02	RESRAD
K-40	1.90E+03	Boyer
Np-237	4.00E+01	DCH
Pa-231	2.00E+03	DCH
Pb-210	4.00E+04 (DS), 3.00E+05 (SS)	Boyer
Po-210	1.00E+05 (DS), 8.00E+05 (SS)	Boyer
Pu-238	1.00E+05	Boyer
Pu-239	1.00E+05	Boyer

Radionuclide	Most Probable Value L/kg (mL/g)	Reference $K_{d,mp}$
Ra-226	1.00E+03 (DS), 5.00E+03 (SS)	Boyer
Ra-228	1.00E+03 (DS), 5.00E+03 (SS)	Boyer
Sb-125	8.00E+03	Boyer
Se-75	7.00E+03 (DS), 2.00E+04 (SS)	Boyer
Sr-90	1.00E+02 (DS), 3.00E+03 (SS)	Boyer
Tc-99	5.00E+00	T&M
Th-228	7.00E+02 (DS), 2.00E+05 (SS)	Boyer
Th-229	7.00E+02 (DS), 2.00E+05 (SS)	Boyer
Th-230	7.00E+02 (DS), 2.00E+05 (SS)	Boyer
Th-232	7.00E+02 (DS), 2.00E+05 (SS)	Boyer
Th-234	7.00E+02 (DS), 2.00E+05 (SS)	Boyer
U-233	4.00E+03 (DS), 1.00E+04 (SS)	Boyer
U-234	4.00E+03 (DS), 1.00E+04 (SS)	Boyer
U-235	4.00E+03 (DS), 1.00E+04 (SS)	Boyer
U-238	4.00E+03 (DS), 1.00E+04 (SS)	Boyer
Zn-65	1.00E+02 (DS), 7.00E+04 (SS)	Boyer
Zr-95	1.00E+03	T&M
Boyer = Table 2, Boyer et al. 2018, Median value for fresh water systems		
RESRAD = NUREG/CR-6697, Table 3.9-1, Median value from default RESRAD distribution for soil.		
DCH = Table 2.13.5, Data Collection Handbook (Yu et al. 2015), Median value from the distribution for generic soil type.		
T&M = Table 3.2, Till & Meyer 1983, Median value for fresh water systems.		
Note: The K_{d}'s listed in this table from RESRAD and DCH are soil K_{d}'s. These K_{d}'s should be considered as placeholders and, whenever available, sediment K_d values should be used. The K_d values from Boyer are mostly from the field measurements. For some radionuclides, the K_d values for both suspended sediment (SS) and deposited sediment (DS) are available.		

Appendix D presents tables of updated K_d values (minimum, maximum and most likely). However, tables of default BCGs also presented in this updated Graded Approach are unchanged from the default BCGs presented in the 2002 Graded Approach. This means that the new K_d values (most likely) are not reflected in the default BCGs.

Appendix E: Dose Conversion Factors

E.1. Introduction

Dose conversion factors (DCFs) (also called dose conversion coefficients (DCCs) or simply dose coefficients) give dose rates from exposure per unit concentration of radionuclides in environmental media. DCFs are calculated separately for either internal or external exposures. Calculation examples and tables of screening-level DCFs are provided here for both exposure situations.

Screening-level DCFs for aquatic and terrestrial biota provide conservative overestimates of absorbed dose rates from exposure to given concentrations of radionuclides in the environment. These DCFs also provide a means of demonstrating compliance with specified criteria on absorbed dose rate for aquatic and terrestrial biota that can be used at any DOE site, without the need for a detailed exposure pathway analysis based on site-specific considerations of the important species at risk and the important exposure pathways.

Additionally, a comparison is provided between DCFs for non-human biota available from RESRAD-BIOTA, ICRP 108 (2008) and UNSCEAR 2008 Annex E (2011).

E.2. External DCFs

This section describes a simple approach to calculating external DCFs for aquatic and terrestrial biota that can be used for purposes of screening in demonstrating compliance with specified criteria on absorbed dose rates to biota, and it presents tables of screening-level external DCFs for exposure of aquatic and terrestrial biota to selected radionuclides in the environmental media of concern.

For external exposure to radionuclides in the environment, penetrating radiations (photons and electrons) are of primary concern, while non-penetrating radiations (i.e., alpha particles) are unlikely to result in significant doses. The environmental media of concern are contaminated water and sediments for exposure of aquatic/riparian animals and contaminated soil and water for exposure of terrestrial biota. Contaminated air (i.e., the active air pathway) is not an important source medium for terrestrial biota, because the limits on allowable concentrations of radionuclides in air based on requirements for protection of on-site workers and members of the public would result in absorbed dose rates to terrestrial biota that are far less than specified criteria (see Appendix H: Exposure Parameters).

E.2.1. Approach to Calculating External DCFs

The approach to calculating external DCFs for aquatic and terrestrial biota for use in general screening should be simple and transparent, so that it can be easily implemented and understood. Furthermore, the approach must clearly result in conservative estimates of external dose rates to aquatic and terrestrial biota for given concentrations of radionuclides in the environment. The following assumptions are made:

- The source medium (water, sediment, or soil) is assumed to be infinite in extent and to contain uniform concentrations of radionuclides. This assumption results in reasonably realistic estimates of dose rates for radionuclides which are dispersed in the source medium because the range of electrons emitted in radioactive decay is no more than a few cm, and the mean-free-path of emitted photons is no more than a few tens of centimeters (Shleien et al. 1998).

- The exposed organism is assumed to be very small (less than the mean free path of the electron emitted in decay). This assumption results in overestimates of external dose rates for any finite-sized organism, because the attenuation of photons and electrons in transport through an organism is ignored. In addition, the assumption of a very small organism combined with the assumption of an infinitely large and uniformly contaminated source medium leads to a particularly simple approach to calculating screening-level external DCFs developed in the following section. Specifically, because all of the energy emitted by radionuclides in a uniformly contaminated and infinite source medium is absorbed uniformly throughout the medium, the dose rate in the organism is essentially the same as the dose rate in the medium itself, and the absorbed dose rate can be calculated directly from the energy of photons and electrons emitted per disintegration of the radionuclides in the medium.
- Because the organism is assumed to be very small, the energies of all photons and electrons emitted by radionuclides are taken into account in calculating the screening-level external DCFs. This approach is particularly conservative for electrons when the irradiated tissues of concern lie below the body surface of an organism and lower-energy electrons could not penetrate to the location of these tissues. Taking into account the energies of all photons and electrons in radioactive decay is tantamount to assuming that the radiosensitive tissues of concern (i.e., the reproductive tissues) lie on the surface of a very small organism. This is very conservative for large animals.

Based on the foregoing discussions, the approach to calculating screening-level external DCFs is based only on the known energies and intensities of photons and electrons emitted in the decay of radionuclides. The approach is conservative in providing overestimates of external dose rates to the reproductive tissues of finite-sized organisms. Information on nuclear decay data for dosimetric calculations may be obtained from ICRP Publication 107 (2008b).

E.2.1.1. Screening-Level External DCFs for Aquatic and Riparian Animals

Screening-level external DCFs for exposure of aquatic and riparian animals to radionuclides in sediments and water are calculated based on the assumptions described in the previous section and the additional conservative assumption that the organism is located 100 percent of the time at the water-sediment interface. Thus, it is assumed that the organism is exposed at the boundary of two semi-infinite and uniformly contaminated media. The assumption of exposure at the boundary of a semi-infinite medium results in an absorbed dose rate in the organism that is one-half of the dose rate in an infinite source volume.

The total energies of all photons and electrons emitted in the decay of radionuclides are assumed to be given in units of MeV per disintegration. For exposure to contaminated sediments, the desired units for the external DCFs are rad/d per pCi/g. The emitted energy in MeV per disintegration (i.e., per Bq-s) is expressed in terms of the desired units for the external DCFs by multiplication of the known factors relating energy in MeV to ergs, absorbed energy in ergs/g to rads, time in seconds to days, and activity in Bq to pCi:

$$1\ \frac{\text{MeV}}{\text{Bq}\times\text{s}}\times 1.6\times 10^{-6}\frac{\text{ergs}}{\text{MeV}}\times 0.01\ \frac{\text{g}\times\text{rad}}{\text{erg}}\times 8.64\times 10^{4}\frac{\text{s}}{\text{d}}\times 0.037\frac{\text{Bq}}{\text{pCi}}=5.12\times 10^{-5}\ \frac{\text{rad/d}}{\text{pCi/g}} \qquad \text{(Eq.3)}$$

If SI units are used for absorbed dose (Gy), activity (Bq), and mass (kg), and the unit of time is taken to be the year, the factor for converting emitted energy to the external DCF is obtained by a similar calculation as:

$$1\ \frac{\text{MeV}}{\text{Bq}\times\text{s}}=5.04\times 10^{-6}\ \frac{\text{Gy/y}}{\text{Bq/kg}} \qquad \text{(Eq.4)}$$

As noted above, the external DCF at the sediment-water interface is one-half of the value for exposure in an infinite medium. Therefore, given the total energies (E) of photons and electrons in MeV per disintegration of a radionuclide, the external DCF (DCF_{ext}) for exposure to contaminated sediments is given by:

$$DCF_{ext,sediment}\ \left[\frac{\text{rad/d}}{\text{pCi/g}}\right]=2.56\times 10^{-5}\times E_{photons+electrons}\left[\frac{\text{MeV}}{\text{dis}}\right] \qquad \text{(Eq.5)}$$

Or:

$$DCF_{ext,sediment}\ \left[\frac{\text{Gy/y}}{\text{Bq/kg}}\right]=2.52\times 10^{-6}\times E_{photons+electrons}\left[\frac{\text{MeV}}{\text{dis}}\right] \qquad \text{(Eq.6)}$$

For exposure to contaminated water, the desired units for the external DCFs are rad/d per pCi/L. If the density of water is assumed to be 1 g/cm^3, the external DCF for exposure to contaminated water at the sediment-water interface is obtained from a calculation similar to that for contaminated sediments given above as:

$$DCF_{ext,water}\ \left[\frac{\text{rad/d}}{\text{pCi/L}}\right]=2.56\times 10^{-8}\times E_{photons+electrons}\left[\frac{\text{MeV}}{\text{dis}}\right] \qquad \text{(Eq.7)}$$

Or:

$$DCF_{ext,water}\ \left[\frac{\text{Gy/y}}{\text{Bq/m}^3}\right]=2.52\times 10^{-9}\times E_{photons+electrons}\left[\frac{\text{MeV}}{\text{dis}}\right] \qquad \text{(Eq.8)}$$

Screening-level external DCFs for exposure of aquatic and riparian animals to selected radionuclides in contaminated sediments and contaminated water calculated are given in Table E-1.

Note: For aquatic organisms, the screening-level concentrations of most radionuclides in aquatic environments should be based on considerations of external exposure to contaminated *sediments* and *internal* exposure, rather than external exposure to contaminated water.

For most radionuclides, the concentration in aquatic animals relative to the concentration in water should be considerably greater than unity (Kennedy and Strenge 1992). Therefore, the dose rate from internal exposure calculated for purposes of screening by assuming that all radiations emitted in the decay of radionuclides in an organism are absorbed in the organism, usually would be considerably higher than the screening-level dose rate from external exposure. In addition, for most radionuclides, the solid/solution distribution coefficient K_d in sediments should be considerably greater than unity (Onishi et al. 1981). Therefore, for the assumption of exposure at the sediment-water interface, the screening-level dose rate from external exposure to contaminated sediments should be higher in most

cases than the corresponding dose rate from external exposure to contaminated water. Based on these arguments, the screening-level external DCFs for exposure of aquatic animals to contaminated water in Table E-1 are unlikely to be important for most radionuclides in determining screening-level concentrations in water.

E.2.1.2. Screening-Level External DCFs for Terrestrial Animals

Screening-level external DCFs for exposure of terrestrial biota to radionuclides in soil are calculated based on the assumption that the organism is immersed 100% of the time in an infinite and uniformly contaminated source region (i.e. 4π geometry). This assumption takes into account that some terrestrial animals reside well below ground for a substantial fraction of the time, and it is appropriately conservative for purposes of screening.

For exposure to contaminated soil, the desired units for the external DCFs are rad/d per pCi/g. Therefore, based on the calculations for contaminated sediments discussed in the previous section, the external DCF for exposure to contaminated soil is given by:

$$DCF_{ext,soil}\left[\frac{\text{rad/d}}{\text{pCi/g}}\right] = 5.12 \times 10^{-5} \times E_{photons+electrons}\left[\frac{\text{MeV}}{\text{dis}}\right] \quad \text{(Eq.9)}$$

Or:

$$DCF_{ext,soil}\left[\frac{\text{Gy/y}}{\text{Bq/kg}}\right] = 5.05 \times 10^{-6} \times E_{photons+electrons}\left[\frac{\text{MeV}}{\text{dis}}\right] \quad \text{(Eq.10)}$$

The screening-level external DCFs for exposure of terrestrial biota to selected radionuclides in contaminated soil calculated as described above are given in Table E-1. Due to the assumption of 100% immersion, the values for contaminated soil are twice the values for contaminated sediments.

E.2.1.3. Discussion of Decay Chains for External DCFs

Several radionuclides – including Sr-90, Zr-95, Sb-125, Cs-137, Ce-144, Pb-210, Ra-226, Ra- 228, Ac-227, Th-228, Th-229, U-235, U-238, Np-237, and Am-243 – have radioactive decay products that are sufficiently short-lived that the decay products are assumed to be in secular equilibrium with the parent radionuclide in each environmental medium. For these radionuclides, the external DCFs are the sum of the values for the parent and it's indicated short-lived decay products, taking into account the branching fractions in the decay of the parent.

For several radionuclides, however, the external DCFs do not include possible contributions from decay products that are sufficiently long-lived that they may not be in activity equilibrium with the parent radionuclide, even though the contributions from the decay products may be significant. The radionuclides of concern (with the decay products in parentheses) include Ra-226 (Pb-210), Ra-228 (Th-228), Th-232 (Ra-228 and Th-228), Pa-231 (Ac-227), and U-232 (Th-228). If separate data on the concentrations of the shorter-lived decay products in sediments, water, or soil are not available, the decay products could be assumed to be in activity equilibrium with the parent, and the DCFs for the parent and the decay products should be added. This approach may be conservative, depending on differences in the environmental behavior of the parent and its decay products.

Table E-1 Screening-Level External Dose Conversion Factors

Radionuclide[a]	Decay Energy (MeV)[b]	External DCF for contaminated SEDIMENT (aquatic and riparian animals) (2π geometry)		External DCF for contaminated WATER (aquatic, riparian, and terrestrial animals) (2π geometry)		External DCF for contaminated SOIL (terrestrial animals) (4π geometry)	
		rad/d per pCi/g	Gy/y per Bq/kg	rad/d per pCi/L	Gy/y per Bq/m^3	rad/d per pCi/g	Gy/y per Bq/kg
H-3	0.0057	1.50E-07	1.40E-08	1.50E-10	1.40E-11	2.90E-07	2.90E-08
C-14	0.0495	1.30E-06	1.20E-07	1.30E-09	1.20E-10	2.50E-06	2.50E-07
P-32	0.6949	1.80E-05	1.80E-06	1.80E-08	1.80E-09	3.60E-05	3.50E-06
Co-60	2.6016	6.70E-05	6.60E-06	6.70E-08	6.60E-09	1.30E-04	1.30E-05
Ni-59	0.0067	1.70E-07	1.70E-08	1.70E-10	1.70E-11	3.40E-07	3.40E-08
Ni-63	0.0171	4.40E-07	4.30E-08	4.40E-10	4.30E-11	8.80E-07	8.60E-08
Zn-65	0.5904	1.50E-05	1.50E-06	1.50E-08	1.50E-09	3.00E-05	3.00E-06
Sr-90 + Y-90	1.1305	2.90E-05	2.80E-06	2.90E-08	2.80E-09	5.80E-05	5.70E-06
Zr-95 + Nb-95	1.6614	4.30E-05	4.20E-06	4.30E-08	4.20E-09	8.50E-05	8.40E-06
Nb-94	1.7027	4.40E-05	4.30E-06	4.40E-08	4.30E-09	8.70E-05	8.60E-06
Tc-99	0.0846	2.20E-06	2.10E-07	2.20E-09	2.10E-10	4.30E-06	4.30E-07
Sb-125 + Te-125m	0.5670	1.50E-05	1.40E-06	1.50E-08	1.40E-09	2.90E-05	2.90E-06
I-129	0.0789	2.00E-06	2.00E-07	2.00E-09	2.00E-10	4.00E-06	4.00E-07
I-131	0.5715	1.50E-05	1.40E-06	1.50E-08	1.40E-09	2.90E-05	2.90E-06
Cs-134	1.7171	4.40E-05	4.30E-06	4.40E-08	4.30E-09	8.80E-05	8.70E-06
Cs-135	0.0563	1.40E-06	1.40E-07	1.40E-09	1.40E-10	2.90E-06	2.80E-07
Cs-137 + Ba-137m	0.7966	2.00E-05	2.00E-06	2.00E-08	2.00E-09	4.10E-05	4.00E-06
Ce-144 + Pr-144	1.3517	3.50E-05	3.40E-06	3.50E-08	3.40E-09	6.90E-05	6.80E-06
Eu-154	1.5269	3.90E-05	3.80E-06	3.90E-08	3.80E-09	7.80E-05	7.70E-06
Eu-155	0.1224	3.10E-06	3.10E-07	3.10E-09	3.10E-10	6.30E-06	6.20E-07

Radionuclide[a]	Decay Energy (MeV)[b]	External DCF for contaminated SEDIMENT (aquatic and riparian animals) (2π geometry)		External DCF for contaminated WATER (aquatic, riparian, and terrestrial animals) (2π geometry)		External DCF for contaminated SOIL (terrestrial animals) (4π geometry)	
		rad/d per pCi/g	Gy/y per Bq/kg	rad/d per pCi/L	Gy/y per Bq/m^3	rad/d per pCi/g	Gy/y per Bq/kg
Pb-210 + Bi-210	0.4279	1.10E-05	1.10E-06	1.10E-08	1.10E-09	2.20E-05	2.20E-06
Ra-266 + P[c]	2.7023	6.90E-05	6.80E-06	6.90E-08	6.80E-09	1.40E-04	1.40E-05
Ra-228 + Ac-228[d]	1.3677	3.50E-05	3.40E-06	3.50E-08	3.40E-09	7.00E-05	6.90E-06
Ac-227 + P[e]	1.4916	3.80E-05	3.80E-06	3.80E-08	3.80E-09	7.60E-05	7.50E-06
Th-228 + P[f]	2.4310	6.20E-05	6.10E-06	6.20E-08	6.10E-09	1.20E-04	1.20E-05
Th-229 + P[g]	1.2282	3.10E-05	3.10E-06	3.10E-08	3.10E-09	6.30E-05	6.20E-06
Th-230	0.0143	3.70E-07	3.60E-08	3.70E-10	3.60E-11	7.30E-07	7.20E-08
Th-232[h]	0.0121	3.10E-07	3.00E-08	3.10E-10	3.00E-11	6.20E-07	6.10E-08
Pa-231[i]	0.0727	1.90E-06	1.80E-07	1.90E-09	1.80E-10	3.70E-06	3.70E-07
U-232[j]	0.0162	4.10E-07	4.10E-08	4.10E-10	4.10E-11	8.30E-07	8.20E-08
U-233	0.0037	9.50E-08	9.30E-09	9.50E-11	9.30E-12	1.90E-07	1.90E-08
U-234	0.0128	3.30E-07	3.20E-08	3.30E-10	3.20E-11	6.60E-07	6.50E-08
U-235 + Th-231	0.3729	9.50E-06	9.40E-07	9.50E-09	9.40E-10	1.90E-05	1.80E-06
U-238 + P[k]	0.9154	2.30E-05	2.30E-06	2.30E-08	2.30E-09	4.70E-05	4.60E-06
Np-237 + Pa-233	0.5049	1.30E-05	1.30E-06	1.30E-08	1.30E-09	2.60E-05	2.50E-06
Pu-238	0.0099	2.50E-07	2.50E-08	2.50E-10	2.50E-11	5.10E-07	5.00E-08
Pu-239	0.0056	1.40E-07	1.40E-08	1.40E-10	1.40E-11	2.90E-07	2.80E-08
Pu-240	0.0098	2.50E-07	2.50E-08	2.50E-10	2.50E-11	5.00E-07	4.90E-08
Pu-241	0.0052	1.30E-07	1.30E-08	1.30E-10	1.30E-11	2.70E-07	2.60E-08
Am-241	0.0575	1.50E-06	1.40E-07	1.50E-09	1.40E-10	2.90E-06	2.90E-07
Am-243 + Np-239	0.4990	1.30E-05	1.30E-06	1.30E-08	1.30E-09	2.60E-05	2.50E-06
Cm-242	0.0092	2.40E-07	2.30E-08	2.40E-10	2.30E-11	4.70E-07	4.60E-08

Radionuclide[a]	Decay Energy (MeV)[b]	External DCF for contaminated SEDIMENT (aquatic and riparian animals) (2π geometry)		External DCF for contaminated WATER (aquatic, riparian, and terrestrial animals) (2π geometry)		External DCF for contaminated SOIL (terrestrial animals) (4π geometry)	
		rad/d per pCi/g	Gy/y per Bq/kg	rad/d per pCi/L	Gy/y per Bq/m^3	rad/d per pCi/g	Gy/y per Bq/kg
Cm-243	0.2547	6.50E-06	6.40E-07	6.50E-09	6.40E-10	1.30E-05	1.30E-06
Cm-244	0.0079	2.00E-07	2.00E-08	2.00E-10	2.00E-11	4.00E-07	4.00E-08

(a) Short-lived decay products assumed to be in activity equilibrium are listed with parent radionuclide, and "P" (Progeny) denotes multiple decay products listed in separate footnote. Contributions to DCF from decay products take into account branching fractions in decay of parent radionuclide (Kocher 1981).

(b) Total energy of all photons and electrons emitted per decay of radionuclide from Kocher (1980).

(c) Short-lived decay products include Rn-222, Pb-214, Bi-214, and Po-214. Possible contributions to DCF from Pb-210 decay product are not included, but DCF for decay product is listed separately.

(d) Possible contributions to DCF from Th-228 decay product are not included, but DCF for decay product is listed separately.

(e) Short-lived decay products include Th-227, Fr-223, Ra-223, Rn-219, Po-215, Pb-211, Bi-211, and Tl-207.

(f) Short-lived decay products include Ra-224, Rn-220, Pb-212, Bi-212, and Tl-208.

(g) Short-lived decay products include Ra-225, Ac-225, Fr-221, At-217, Bi-213, Tl-209, and Pb-209.

(h) Possible contributions to DCF from Ra-228 and Th-228 decay products are not included, but DCFs for decay products are listed separately.

(i) Possible contributions to DCF from Ac-227 decay product are not included, but DCF for decay product is listed separately.

(j) Possible contributions to DCF from Th-228 decay product are not included, but DCF for decay product is listed separately.

(k) Short-lived decay products include Th-234, Pa-234m, and Pa-234.

E.3. Internal DCFs

This section presents the approach used to calculate internal DCFs that can be used in general screening for internal exposure of aquatic and terrestrial biota to selected radionuclides. A table of screening-level internal DCFs is provided.

E.3.1. Approach to Calculating Internal DCFs

Internal DCFs (Gy y-1 per Bq kg-1) were derived for unit concentrations of each of the target radionuclides in tissue. Reference decay energies and abundances were taken from ICRP 38 (1983) for each of the target radionuclides and its progeny. The default dose factor includes buildup of progeny with half-lives less than 100 y. The calculations assume all of the energies of radioactive decay were retained in the tissue of the organism (i.e., the organism was presumed to be very large in size). The radionuclides were presumed to be homogeneously distributed in the tissue. The default internal dose factors include a dose modifying factor of 20 (i.e., W_r 20) for alpha particles and the alpha-emitting progeny of chain-decaying nuclides as included in RESRAD-BIOTA.

The DCFs were calculated as the sum of all decay energies and multiplied by appropriate unit conversion factors. The equation used to calculate an internal DCF for a specific radionuclide is shown below. The resultant DCFs are presented in Table E-2.

For internal exposure to contaminants, the units for the DCFs were calculated as Gy/y per Bq/kg of wet tissue.

$$DCF_{internal,i} = 1\ \frac{\mathrm{dis/s}}{\mathrm{Bq}} \times \left[\sum_i \sum_j Y_j \times E_j \times Q_j\right] \times 1.602 \times 10^{-13}\ \frac{\mathrm{J}}{\mathrm{MeV}} \times 3.1536 \times 10^{7}\ \frac{\mathrm{s}}{\mathrm{y}} \times \frac{1\ \mathrm{Gy}}{\mathrm{J/kg}} \qquad \text{(Eq.11)}$$

where:

$DCF_{internal,i}$ = Gy/y per Bq/kg of wet tissue for radionuclide

Y_j = yield (abundance) of radiation j per disintegration of nuclide i

E_j = energy (MeV) of radiation j for nuclide i; and

Q_j = the radiation weighting factor (quality factor, also called w_R) for radiation j of nuclide i.

The DCFs can also be expressed in rad/d per pCi/g, where all other factors have been defined:

$$DCF_{internal,i} = 1\ \frac{\frac{\mathrm{dis}}{\mathrm{s}}}{\mathrm{Bq}} \times 0.037\ \frac{\mathrm{Bq}}{\mathrm{pCi}} \times \left[\sum_i \sum_j Y_j \times E_j \times Q_j\right] \times 1.602 \times 10^{-6}\ \frac{\mathrm{erg}}{\mathrm{MeV}} \times 8.64 \times 10^{4}\ \frac{\mathrm{s}}{\mathrm{d}} \times 0.01 \frac{\mathrm{g} \times \mathrm{rad}}{\mathrm{erg}} \qquad \text{(Eq.12)}$$

E.3.2. Screening-Level Internal DCFs

Table E-2 Screening Level Internal Dose Conversion Factors

Radionuclide	Internal dose with progeny[a]		Internal dose without progeny	
	Gy/y per Bq/kg (wet)	Rad/d per pCi/g (wet)	Gy/y per Bq/kg (wet)	Rad/d per pCi/g (wet)
Am-241	5.60E-04	5.70E-03	5.60E-04	5.70E-03
Ce-144	6.80E-06	6.90E-05	5.60E-07	5.70E-06
Cs-135	3.40E-07	3.40E-06	3.40E-07	3.40E-06
Cs-137	4.30E-06	4.30E-05	9.40E-07	9.60E-06
Co-60	1.30E-05	1.30E-04	1.30E-05	1.30E-04
Eu-154	7.60E-06	7.70E-05	7.60E-05	7.70E-05
Eu-155	6.20E-07	6.30E-06	6.20E-07	6.30E-06
H-3	2.90E-08	2.90E-07	2.90E-08	2.90E-07
I-129	4.50E-07	4.50E-06	4.50E-07	4.50E-06
I-131	2.90E-06	2.90E-05	2.90E-06	2.90E-05
Pu-239	5.30E-04	5.40E-03	5.30E-04	5.40E-03
Ra-226	3.00E-03	3.10E-02	4.90E-04	5.00E-03
Ra-228	3.60E-03	3.70E-02	8.50E-08	8.60E-07
Sb-125	2.70E-06	2.70E-05	2.70E-06	2.70E-05
Sr-90	5.70E-06	5.80E-05	9.90E-07	1.00E-05
Tc-99	5.10E-07	5.20E-06	5.10E-07	5.20E-06
Th-232	4.10E-03	4.10E-02	4.10E-04	4.20E-03
U-233	4.90E-04	5.00E-03	4.90E-04	5.00E-03
U-234	4.90E-04	5.00E-03	4.90E-04	5.00E-03
U-235	4.50E-04	4.60E-03	4.50E-04	4.60E-03
U-238	4.40E-04	4.50E-03	4.30E-04	4.40E-03
Zn-65	3.00E-06	3.00E-05	3.00E-06	3.00E-05
Zr-95	8.40E-06	8.50E-05	4.30E-06	4.40E-05

(a) Includes listed radiations (a b g, X) and an RBE of 20 (RESRAD-BIOTA default) for alpha particles. Progeny with half-lives less than 100 y are included at 100% abundance.

E.4. Reference Comparison

While screening-level DCFs are provided in this Appendix, the calculations described above use highly conservative assumptions. DCFs for biota are also available the ICRP (2008) and UNSCEAR 2008 Annex E (2011) as well as in RESRAD-BIOTA. RESRAD-BIOTA default DCFs are used to calculate biota doses in Level 1 and Level 2 analyses, but these parameters become adjustable for a user-defined organism in a Level 3 analysis. Therefore, the following comparison of references may be of interest for the final stages of the graded approach.

In general, the DCFs available in ICRP, UNSCEAR, and RESRAD-BIOTA are consistent. However, several notable differences are observed:

- In all three references, the DCFs for internal and external exposures vary based on organism geometry. For some nuclides, the DCF calculation is very sensitive to small differences in size. Therefore, the different geometry libraries used in each reference contribute to differences in the DCFs even for similar organism types.
- For internal exposures specifically, the tabulated DCFs vary significantly based on the choice of W_r (radiation weighting factor) value for alpha emitters. The ICRP reports DCFs in units of absorbed dose, and therefore does not modify its DCFs by a factor. UNSCEAR has adopted a modifying factor of 10 for alphas, and RESRAD-BIOTA uses a modifying factor of 20 for alphas in deriving its DCFs.
- For external exposures, differences between the references can arise due to the assumed exposure geometry. While RESRAD-BIOTA and this standard default to 100% immersion (4π) geometry for terrestrial organism exposure to soil, the ICRP and UNSCEAR assume only a semi-infinite (2π) geometry. Another consideration for external exposure differences is the inclusion or exclusion of shallow dose in addition to deep dose.
- Large differences can arise based on the inclusion or exclusion of decay chain progeny in the DCF calculations. Users planning to adjust the default parameters in their dose calculations should be aware of which progeny are accounted for.

Appendix F: Bioaccumulation Factors

F.1. Estimating Internal Tissue Concentrations for Use in Dose Equations: The Bioaccumulation Factor

For most radionuclides, the single most important predictor of biota dose is the method used to estimate internal tissue concentrations. For the general screening phase of the graded approach, bioaccumulation factors were used to provide estimates of organism tissue concentration, and ultimately derive the BCG corresponding to each radionuclide, media, and organism type. The technical literature contains reference to empirically-based parameters which measure concentrations of contaminants in an organism relative to the surrounding media. These ratios are called "concentration ratios," "concentration factors," or "wet-weight concentration ratios" (B_{iv}s) These B_{iv} values are available for many radionuclides for plant:soil and for aquatic species:water. In a few instances they are also available for animal:soil or sediment. The advantage of using one of these factors is that it allows the prediction of tissue concentration based on simple measurements of contamination in environmental media such as water, sediment and soil.

The selection of a value for this B_{iv} becomes problematic, however, when considering the range of organism types meant to be covered by the graded approach. For example, there is very limited data available for riparian and terrestrial animals (e.g., very limited animal:water, animal:soil, and animal:sediment concentration ratios). As the graded approach methodology evolved it became apparent that these data gaps (e.g., for selecting appropriate B_{iv} values needed to be addressed.) Two alternative approaches for deriving and selecting B_{iv}s were evaluated:

- **Calculating the B_{iv}s by multiplying related concentration ratios (product approach).** For example, the product of plant:soil and animal:plant concentration ratios yields an animal:soil ratio which may be used as the B_{iv} for a terrestrial animal. This approach must be used with caution, as the data used in the process are most likely from different sources. This approach is also hampered by the general lack of environmental data.
- **Calculating the B_{iv}s by using uncertainty analysis on the kinetic/allometric method.** The kinetic/allometric method, as used in the analysis phase of the graded approach, is based on mathematically modeling the exposure of an organism using simplistic, first-order kinetic reactions. There are several allometric equations which relate body size to many of the parameters contributing to internal dose (e.g., including ingestion rates, life span, and inhalation rate). Uncertainty analysis (i.e., using Monte Carlo techniques) on each of the allometric equations, and on their corresponding parameters varied over their known ranges of values, can provide an upper bound estimate (i.e., at the 95th percentile) of B_{iv}s for those organism types (riparian and terrestrial animals) for which there is limited empirical data.

Figure F-1 shows the logic flow for the derivation and selection of default B_{iv} values employed in the general screening phase for each of the four organism types addressed in the graded approach. Refer to RESRAD-BIOTA for most current default B_{iv} values.

	Aquatic Animal	Riparian Animal	Terrestrial Plant	Terrestrial Animal
(1) B_{iv}s/ lumped parameters compiled for each organism type (literature searches; models; empirical data)	Very good empirical data	Fair to limited	Very good empirical data	Fair to limited
(2) B_{iv}s/ lumped parameter data sets reviewed for quality, quantity, and range of values	Very good	Limited: RA: water RA: sediment Some: RA(fs) : sediment RA: RA(fs)	Very good	Limited: TA: water TA: soil Some: TA: soil TA: TP
(3) For Fair/ Limited Data:				
(3a) B_{iv}/ lumped parameters estimated using product approach (e.g. multiplying concentration ratios, CRs)	-	(RA(fs) : sediment) • (RA • RA(fs)) yields (RA: sediment)	-	(TP: soil) • (TA: TP) yields (TA: soil)
(3b) Lumped parameters estimated by using uncertainty analysis on the kinetic/allometric method (95th percentile of resulting distributions)	-	Uncertainty analysis on each allometric equation and their corresponding parameters varied over their known ranges of values.	-	Uncertainty analysis on each allometric equation and their corresponding parameters varied over their known ranges of values.
(3c) B_{iv}/ lumped parameter value comparison: product approach; uncertainty analysis (K/A method); available empirical data	-	B_{iv}/ lumped parameter comparison: product approach; uncertainty analysis (K/A method); empirical data	-	B_{iv}/ lumped parameter comparison: product approach; uncertainty analysis (K/A method); empirical data
(4) B_{iv}/ lumped parameter values selected as default values for general screening.	empirical values used	Preference for empirical values where available and of sufficient quality; otherwise uncertainty analysis (K/A method) values	empirical values used	Preference for empirical values where available and of sufficient quality; otherwise uncertainty analysis (K/A method) values

KEY	
AA	= Aquatic Animal
RA	= Riparian Animal
TP	= Terrestrial Plant
TA	= Terrestrial Animal
RA(fs)	= Food source to a Riparian Animal
Uncertainty Analysis (K/A Method)	= Uncertainty analysis on kinetic/allometric method

Figure F-1 Process for Selecting Default B_{iv} Values for Use in the General Screening Phase of the Graded Approach

F.2. Default Bioaccumulation Factors, B_{iv}

As mentioned earlier, bioaccumulation factors, B_{iv}s, are the ratio of the contaminant concentration in the organism relative to the contaminant concentration in an environmental medium resulting from the uptake of the contaminant from one or more routes of exposure. In technical literature this ratio may also be called "concentration ratios," "concentration factors," or "wet-weight concentration ratios" (B_{iv}s). In

RESRAD-Biota, the default bioaccumulation factors are conservative values. The B_{iv} default values are summarized in Tables F-1 through F-3.

BCGs are for use with radionuclide concentrations from co-located water and sediment. The default B_{iv}s listed in Table F-1 were used to derive the generic BCGs for the general screening phase. The B_{iv} values for aquatic animals were selected from across all sampled aquatic taxa and include predatory fin fish, crustaceans, and other organisms. Typically, the most limiting values come from crustaceans or molluscs. The specific source of default values used for the general screening phase of the graded approach for aquatic animal evaluations is shown in Table F-2. Table F-3 provides the values used for the general screening phase in the derivation of terrestrial plant BCGs.

F.3. Site-specific Bioaccumulation Factors B_{iv}s

The default bioaccumulation factor values (B_{iv}s) listed in Table F-1 may be replaced with site-representative values in the site-specific screening component of the analysis phase. In most cases, site-specific values are likely to be orders of magnitude smaller. The B_{iv} default values summarized in Tables F-1 through F-3 may be compared with the ranges of values listed in IAEA (2014). The IAEA upper limits are comparable with the default values, while the lower limits are up to 6 orders of magnitude smaller. Therefore, use of the default B_{iv} can substantially overestimate the biota dose and for this reason each site is encouraged to establish site-specific values.

There is not likely to be a single site-specific value that applies to all animals or all plants at all locations. For some elements such as carbon, plutonium, cesium, strontium, and radium site-specific studies can establish upper limits that may be orders of magnitude less than the default values. Summarized below in Table F-4 are examples of selected site-specific B_{iv} values. For some elements such as cesium, strontium, and radium site-specific studies can establish upper limits that may be orders of magnitude less than the default values. The following sections discuss the bioaccumulation of potassium-40, cesium-137, strontium-90, radium-226, and the uranium isotopes.

Table F-1 Aquatic Animal Biota Concentration Guide Spreadsheet

Nuclide	Derived Concentrations		Bioaccumulation Factor	
	BCG (sediment) Bq/kg	BCG (water) Bq/m^3	B_{iv}, Organism to Water (L/kg) Fresh Mass	Water B_{iv} Reference[(a)]
^{241}Am	3E+07	2E+04	400	CRITR
^{144}Ce	1E+06	6E+04	9000	T&M, Table 5.41
^{135}Cs	3E+07	5E+05	22000	T&M, Table 5.41
^{137}Cs	2E+06	4E+04	22000	T&M, Table 5.41
^{60}Co	6E+05	1E+05	2000	T&M, Table 5.41
^{154}Eu	1E+06	8E+05	600	GENII
^{155}Eu	1E+07	1E+07	600	GENII
^{3}H	3E+08	2E+11	0.2	CRITR
^{129}I	2E+07	4E+07	220	T&M, Table 5.41
^{131}I	3E+06	6E+06	220	T&M, Table 5.41
^{239}Pu	3E+08	7E+03	1000	T&M, Table 5.41
^{226}Ra	5E+05	4E+02	3200	T&M, Table 5.41
^{228}Ra	1E+06	3E+02	3200	Based on ^{226}Ra
^{125}Sb	3E+06	1E+07	100	T&M, Table 5.41
^{90}Sr	1E+06	2E+06	320	T&M, Table 5.41
^{99}Tc	2E+07	9E+07	78	T&M, Table 5.41
^{232}Th	1E+08	1E+04	80	T&M, Table 5.41
^{233}U	4E+08	7E+03	1000	T&M, Table 5.41
^{234}U	1E+08	7E+03	1000	T&M, Table 5.41
^{235}U	4E+06	8E+03	1000	T&M, Table 5.41
^{238}U	2E+06	8E+03	1000	T&M, Table 5.41
^{65}Zn	2E+06	7E+04	17000	T&M, Table 5.41
^{95}Zr	9E+05	3E+05	1600	T&M, Table 5.41

(a) T&M = Till and Meyer 1983; GENII = Napier et al. 1988; CRITR = Baker and Soldat 1992

Table F-2 Default bioaccumulation factors (B_{iv}s for aquatic animals)

Radionuclide	B_{iv},aa,i Organism to Water (L/kg) fresh mass	Water B_{iv},aa,i Reference	Comment
^{241}Am	400	CRITR	Value for fresh water molluscs taken from CRITbiog.dat (generic bioaccumulation: 2000) and converted to wet weight basis by multiplying by 5 (an arbitrary dry to wet weight conversion). Conversation with D Strenge and B Napier indicated the GENII and CRITR values are dry-weight basis.
^{144}Ce	9000	T&M T. 5.41	Maximum fresh weight value for molluscs.
^{135}Cs	22000	T&M T. 5.41	Maximum value for crustaceans, fresh weight, for ^{133}Cs, ^{134}Cs, ^{137}Cs.
^{137}Cs	22000	T&M T. 5.41	Maximum value for crustaceans, fresh weight, for ^{133}Cs, ^{134}Cs, ^{137}Cs.
^{60}Co	2000	T&M T. 5.41	Maximum fresh weight value for molluscs.
^{154}Eu	600	GENII	Value for fresh water molluscs taken from BIOAC1.dat (generic bioaccumulation: 3000) and converted to wet weight basis by multiplying by 5 (an arbitrary dry to wet weight conversion). Conversation with D Strenge and B Napier indicated the GENII and CRITR values are dry-weight basis.
^{155}Eu	600	GENII	Value for fresh water molluscs taken from BIOAC1.dat (generic bioaccumulation: 3000) and converted to wet weight basis by multiplying by 5 (an arbitrary dry to wet weight conversion). Conversation with D Strenge and B Napier indicated the GENII and CRITR values are dry-weight basis.
^{3}H	0.2	CRITR	Value for fresh water molluscs taken from CRITbiog.dat (generic bioaccumulation: 1) and converted to wet weight basis by multiplying by 5 (an arbitrary dry to wet weight conversion). Conversation with D Strenge and B Napier indicated the GENII and CRITR values are dry-weight basis.
^{129}I	220	T&M T. 5.41	Maximum fresh weight value for molluscs.
^{131}I	220	T&M T. 5.41	Maximum fresh weight value for molluscs.
^{239}Pu	1000	T&M T. 5.41	Maximum fresh weight value for crustaceans.
^{226}Ra	3200	T&M T. 5.41	Freshwater gammarus.
^{228}Ra	3200	Ra-226	Freshwater gammarus.
^{125}Sb	100	T&M T. 5.41	Maximum fresh weight value for fish.
^{90}Sr	320	T&M T. 5.41	Maximum fresh weight value for molluscs.
^{99}Tc	78	T&M T. 5.41	Maximum fresh weight value for fish.
^{232}Th	80	T&M T. 5.41	Maximum fresh weight value for fish.
^{233}U	1000	T&M T. 5.41	Maximum fresh weight value for molluscs.
^{234}U	1000	T&M T. 5.41	Maximum fresh weight value for molluscs.
^{235}U	1000	T&M T. 5.41	Maximum fresh weight value for molluscs.
^{238}U	1000	T&M T. 5.41	Maximum fresh weight value for molluscs.
^{65}Zn	17000	T&M T. 5.41	Maximum fresh weight values for snails.
^{95}Zr	1600	T&M T. 5.41	Maximum fresh weight values for snails.

Table F-3 Default bioaccumulation factors (B_{iv}s) for Terrestrial Plants

Radionuclide	$B_{iv,tp,i}$, Plant to Soil Bq/kg wet weight to Bq/kg soil (dry) mass	Plant $B_{iv,tp,i}$ Reference, Bq/kg plant (wet weight) per Bq/kg soil	Comment
^{241}Am	8.0E-03	T&M T5.16, T 5.18	Calculated from a CR value of 0.042 (dry wt/dry wt) for grasses. Converted to B_{iv} using wet/dry ratio of 5.5. Note this also includes aerial deposition.
^{144}Ce	4.0E-02	T&M T5.16, T 5.17	Converted from a CR value of 0.22 (dry wt/dry wt) for grasses in a soil with low pH content (<5.5). Converted to B_{iv} using wet/dry ratio of 5.5
^{135}Cs	1.0E+01	T&M T5.16, T 5.17	Calculated from a CR value of 42.6 (dry wt/dry wt) for legumes in Florida soils with low K content. Converted to B_{iv} using wet/dry ratio of 4.5
^{137}Cs	1.0E+01	T&M, T5.16, T 5.17	Calculated from a CR value of 42.6 (dry wt/dry wt) for legumes in Florida soils with low K content. Converted to B_{iv} using wet/dry ratio of 4.5
^{60}Co	2.0E-01	T&M T5.16, T 5.17	Calculated from a CR value of 1 (dry wt/dry wt) for grasses in histosol soils. Converted to B_{iv} using wet/dry ratio of 4.5
^{154}Eu	4.0E-02	Estimated from Ce value by KAH	
^{155}Eu	4.0E-02	Estimated from Ce value by KAH	
^{3}H	1.0E+00	NUREG 1.109	NUREG 1.109 and divided by a wet to dry conversion value of 4.5
^{129}I	4.0E-01	T&M T5.16, T 5.17	Calculated from a CR value of 1.84 (dry wt/dry wt) for legumes. Converted to B_{iv} using wet/dry ratio of 4.5. Note this also includes aerial deposition.
^{131}I	4.0E-01	T&M T5.16, T 5.17	Calculated from a CR value of 1.84 (dry wt/dry wt) for legumes. Converted to B_{iv} using wet/dry ratio of 4.5. Note this also includes aerial deposition.
^{239}Pu	1.0E-02	T&M T5.16, T 5.18	Calculated from a CR value of 0.066 (dry wt/dry wt) for legumes. Converted to B_{iv} using wet/dry ratio of 4.5. Note this also includes aerial deposition.
^{226}Ra	1.0E-01	T&M T5.16, T 5.18	Calculated from a CR value of 0.49 (dry wt/dry wt) for legumes. Converted to B_{iv} using wet/dry ratio of 4.5. Note this also includes aerial deposition.
^{228}Ra	1.0E-01	T&M, T5.16, T 5.18	Calculated from a CR value of 0.49 (dry wt/dry wt) for legumes. Converted to B_{iv} using wet/dry ratio of 4.5. Note this also includes aerial deposition.
^{125}Sb	1.0E-02	GENII	Taken from GENII and converted to wet weight basis by multiplying by 5 (an arbitrary wet to dry weight conversion). Conversation with D Strenge and B Napier indicated the GENII and CRITR ftrans values are on a dry-weight basis.
^{90}Sr	4.0E+00	T&M T5.16, T 5.17	Converted from a CR value of 17.3 (dry wt/dry wt) for legumes in a soil with low Ca content. Converted to B_{iv} using wet/dry ratio of 4.5
^{99}Tc	8.0E+00	GENII	Taken from GENII and converted to wet weight basis by multiplying by 5 (an arbitrary wet to dry weight conversion). Conversation with D Strenge and B Napier indicated the GENII and CRITR ftrans values are on a dry-weight basis.
^{232}Th	1.0E-03	T&M T5.16, T 5.18	Calculated from a CR value of 0.0046 (dry wt/dry wt) for legumes. Converted to B_{iv} using wet/dry ratio of 4.5. Note this also includes aerial deposition.
^{233}U	4.0E-03	T&M T5.16 T 5.18	Calculated from a CR value of 0.017 (dry wt/dry wt) for legumes. Converted to B_{iv} using wet/dry ratio of 4.5. Note this also includes aerial deposition.
^{234}U	4.0E-03	T&M T5.16, T 5.18	Calculated from a CR value of 0.017 (dry wt/dry wt) for legumes. Converted to B_{iv} using wet/dry ratio of 4.5. Note this also includes aerial deposition.
^{235}U	4.0E-03	T&M T5.16, T 5.18	Calculated from a CR value of 0.017 (dry wt/dry wt) for legumes. Converted to B_{iv} using wet/dry ratio of 4.5. Note this also includes aerial deposition.
^{238}U	4.0E-03	T&M T5.16, T 5.18	Calculated from a CR value of 0.017 (dry wt/dry wt) for legumes. Converted to B_{iv} using wet/dry ratio of 4.5. Note this also includes aerial deposition.

Radionuclide	$B_{iv,tp,i}$, Plant to Soil Bq/kg wet weight to Bq/kg soil (dry) mass	Plant $B_{iv,tp,i}$ Reference, Bq/kg plant (wet weight) per Bq/kg soil	Comment
^{65}Zn	3.0E-01	T&M T5.16, T 5.17	Calculated from a CR value of 1.5 (dry wt/dry wt) for legumes. Converted to B_{iv} using wet/dry ratio of 4.5. This value includes external (aerial) deposition in the value.
^{95}Zr	3.0E-02	T&M T5.16, T 5.17	Calculated from a CR value of 0.13 (dry wt/dry wt) for legumes. Converted to B_{iv} using wet/dry ratio of 4.5.

Table F-4 Site-Specific B_{iv} Values

Element	Site	Biota	Site-Specific B_{iv} Values (L/kg)
Carbon	SRS	Aquatic animal	Carbon water to aquatic animal B_{iv} =3
Cesium	LANL	Terrestrial animal	Cs-137 soil to terrestrial animal: B_{iv} = 0.06
	LANL	Terrestrial plant	Cs-137 soil to terrestrial plant: B_{iv} = 0.06
	LANL	Riparian animal	Cs-137 water to riparian animal: B_{iv} = 200
	LANL	Aquatic animal	Cs-137 water to aquatic animal: B_{iv} = 200
	ORNL	Aquatic animal	Cs-137 water to aquatic animal: B_{iv} = 1150
	SRS	Aquatic animal	Cs-137 water to aquatic animal: B_{iv} =3000
Strontium	LANL	Terrestrial animal	Sr-90 soil to terrestrial animal: B_{iv} = 4
	LANL	Riparian animal	Sr-90 water to riparian animal: B_{iv} = 400
	LANL	Aquatic animal	Sr-90 water to aquatic animal: B_{iv} = 100
	ORNL	Aquatic animal	Sr-90 water to aquatic animal: B_{iv} = 110
Plutonium	SRS	Aquatic animal	Pu-238 water to aquatic animal: B_{iv} =30

F.3.1.Potassium-40

Potassium-40 (K-40) was not included in the original DOE Standard because it is naturally occurring and is unlikely to contribute a significant dose. Tissue concentrations are controlled by biological homeostasis, therefore the internal dose is constant and for K-40 B_{IV} is not a meaningful quantity.

However, it is useful to consider this radionuclide and its relevance to biota dose, especially because cesium concentrations are related to potassium concentrations, as described in Section F.3.2.

Isotopically-enriched potassium-40 is unlikely to be released to the environment in sufficient quantities to cause a significant dose. Essentially all potassium in the environment contains 0.0117% K-40 and has a specific activity of 32 Bq/g. Although the external dose rate is detectable in the laboratory, it is unlikely to be significant in the environment.

Technologically enhanced concentrations of potassium are possible, for example in wood ash, fertilizer, dietary “salt substitute” or “sodium-free salt”, and some types of snow-melt materials. These are as likely to cause dose to humans as to biota, though in neither case is the dose likely to be harmful.

Potassium is essential to life. All living organisms contain potassium, and in every case the internal concentrations are precisely controlled by biological homeostasis. All plants and animals are made of eukaryotes and so share the same basic biology for which potassium is essential. Some animals and plants contain more water than others, and this water content is the main factor that determines the concentration in eukaryotes of essential elements such as potassium.

The highest concentrations, about 0.6% by weight, are found in dry materials such as nuts. Lower concentrations, about 0.2%, are found in wet tissues such as lettuce. In most cases, the concentrations are somewhere between these two extremes. For example, the concentration in most animal tissue and

some fruits such as bananas is about 0.36%. Therefore, typical potassium-40 concentrations in living organisms are within about a factor of two of 0.1 Bq/g.

Potassium does not bioaccumulate. Where potassium in the soil or water is scarce, the concentration ratio is large because the organism will extract the potassium it needs from the low concentrations available. On the other hand, when potassium is abundant, the organism adapts and the ratio becomes small. Because this homeostasis is tightly controlled, the bioaccumulation factor is not a useful parameter in RESRAD-BIOTA. The internal dose is fixed. Therefore, either potassium-40 data should be omitted from RESRAD-BIOTA, or if the external dose is of interest the value of B_{IV} should be set to zero so that the internal dose from potassium-40 will not be included.

Nevertheless, potassium-40 data are useful for several reasons. The results provide a useful reality check on other data. Also, the concentrations may be used to predict the uptake of chemically similar elements such as cesium because the biological processes used to control the uptake of potassium also serve to regulate the uptake of cesium. When potassium is scarce, living organisms adjust to maximize the uptake of potassium, with the unintended result that the uptake of cesium also increases (NCRP Report #154, 2008).

In summary, potassium-40 data need not be entered into RESRAD-BIOTA except in very unusual circumstances, in which case the B_{iv} should be set to zero.

F.3.2.Cesium-137

The cesium-137 BCGs are listed in Tables I-1 to I-4 and in some cases are comparable to the concentrations used to protect human health. For example, the BCG in Table I-2 is 40 pCi/L, whereas the allowed concentration in drinking water is 120 pCi/L. Drinking water is unlikely to be hazardous to biota. This low value for the BCG is a result of the default B_{iv} values; the BCGs are small because the B_{iv} values are large.

For example, for terrestrial animals and soil, B_{iv} is 110, and for riparian animals and water it is 54,000. These high values occur where potassium is scarce. In these cases, the organism adapts to absorb as much as possible, and cesium, which is chemically similar, is also absorbed.

NCRP Report #154 (2008) provides useful equations to predict cesium uptake based on the potassium concentrations.

For non-piscivore fish, the concentration ratio, C_r, is estimated from the potassium concentration, *K*, (micro-mol/L) and the sediment load, *SL*, (mg/L) using the equation 6.9 on page 244 of NCRP Report #154 (with *TL* = 0 for non-piscivore fish).

$$\log(Cr) = 4.332 - 0.718\log(K) - 0.233\log(SL).$$

For example, *K* and *SL* were measured and used to calculate C_r as follows.

K = 200 ± 40 micro-mol/L

SL = 3 ± 1 mg/L

∴ C_r = 370

This result may be compared with Fig. 3.9 on page 140 of NCRP Report No. 76 (1984), which provides upper bounds for B_{iv}s as a function of *K* for piscivorous and non-piscivorous fish. Till and Meyer (1983) (Table 5.41 page 5-101) provides the equations for these upper bounds as a function of *K* in units of mg/L. For piscivorous fish, $C_r = 1500/K$ and for non-piscivorous fish, $C_r = 500/K$.

Till and Meyer (1983) adds the note "Divide by 5 for waters of turbidities greater than 50 ppm suspended solids." This note reflects the discussion in NCRP Report No. 76 (1984) at the top of page 140. Biota readily absorb dissolved cesium but have difficulty absorbing suspended solids.

For freshwater, estuarine and marine invertebrates, use the equation 6.8 on page 243 of NCRP Report #154.

$\log C_r = 3.628 - 0.583 \log(K)$

For example, if $K = 200$ micro-mol/L the equation yields the result: $C_r = 193$.

F.3.3.Strontium-90

Strontium-90 shares some similarities with cesium-137: the B_{iv} value depends on the calcium concentrations in the soil or water (Fig. 3.10 NCRP Report No. 76).

For strontium-90, Till and Meyer (1983) (page 5-99) provide equations as a function of calcium concentration [*Ca*] in units of mg/L. These equations are based on Fig. 3.10 of NCRP Report No. 76 (page 142).

For fish flesh, $C_r = 178/[Ca]$

For fish bone, $C_r = 15{,}000/[Ca]$

At most DOE sites, the calculated and measured results are likely to be orders of magnitude less than the default values.

F.3.4.Radium

For radium, the situation is similar to that for strontium: the BCG is low because the default B_{iv} is high. The BCGs for water in aquatic systems are 4 and 3 pCi/L for Ra-226 and Ra-228, whereas the national drinking water standard is 5 pCi/L for total radium. It is unlikely that drinking water is hazardous to biota.

High radium concentrations in surface water are often a result of suspended sediment containing natural uranium, thorium, and their decay products. For example, if the concentration of uranium and each of its decay products is 1 pCi/g in sediment, and the concentration of sediment in water is 10 g/L, the concentration of radium-226 is 10 pCi/L, which is greater than the default BCG. Furthermore, in this case the gross-alpha data may be more than 80 pCi/L, which is far above the human drinking-water standard of 15 pCi/L. This situation is common in unfiltered storm water containing only natural material and is unlikely to present a hazard to biota.

In the case of radium, it is helpful to measure the tissue concentration and establish a site-specific B_{iv}. Measurements of similar species and of the food chain will also provide valuable data. As discussed in Section 4.3.3, the tissue concentration that corresponds to 1 rad/d is the reciprocal of the value in

Table G-3. In the case of Ra-226 it is 27 pCi/g (on a wet weight basis). Ra-226 is accompanied by its decay products, Pb-214 and Bi-214, which may be measured with a portable gamma spectrometer.

At most DOE sites, radium-226 is not a significant source of contamination and the radium that is detected is naturally occurring. Depleted and enriched uranium and their precursor, refined uranium, do not produce detectable amounts of radium. This is because the radium and thorium that were in the ore remain with the mill tailings and it takes thousands of years for new radium to grow in to detectable concentrations. Naturally-occurring radium can normally be identified by observing the decay chain and determining whether the chain is in secular equilibrium. In contrast, DOE operations disturb the secular equilibrium and it takes millions of years to restore it.

F.3.5. Uranium

Establishing B_{iv} for the uranium isotopes is complicated by the presence of natural uranium and its decay chain, both in solution and in suspended sediment.

Naturally-occurring uranium is accompanied by a decay chain that begins with U-238 and ends with Pb-206. However, many DOE sites use one or more forms of refined uranium such as uranium metal, depleted uranium, and enriched uranium; in these cases, the decay products have been chemically separated and remain with the mill tailings so decay products such as Ra-226, Bi-214 and Pb-214 are not found in refined uranium.

Naturally occurring uranium can be identified by the presence of the decay chain in secular equilibrium with the uranium-238 parent. In some cases, the analytical process may include dissolution or heating, which disturb the secular equilibrium. However, analytical laboratories have well-established protocols to allow the original equilibrium to re-establish before the sample is counted. For example, the protocol may include waiting for 3 or 4 weeks to allow the radium decay products to grow in. If these protocols are followed, naturally occurring uranium may be identified by the presence of Bi-214 and Pb-214. In contrast, Bi-214 and Pb-214 are not detectable in refined uranium, depleted uranium, or enriched uranium.

In water, the activity-concentration for U-234 is usually greater than for U-238 because the decay process dislodges the atom from the lattice allowing U-234 to go into solution more easily. In tissue, a similar ratio of U-234 to U-238 shows that uptake is mostly from uranium in solution and in general it is more appropriate to use the concentrations in filtered water.

In solution, the uranium and radium concentrations may be different, depending on the local conditions (Arndt and West 2004, DOE 2015), whereas in suspended sediment the decay chain is more likely to be in secular equilibrium. These variables, combined with varying amounts of suspended sediment and the movement of fish, all make it difficult to assess the dose unless water data are combined with tissue data.

Gross-alpha data are especially difficult to interpret because the detector is usually calibrated with low-energy alpha particles, so it over-responds to the higher-energy alpha particles emitted by the polonium isotopes.

In summary, refined uranium, enriched uranium, and depleted uranium do not produce measurable radium contamination. At most DOE sites, the radium in the environment is natural, and can be identified by the secular equilibrium of the decay chain.

Appendix G: Biota Concentration Guides (BCGs) in Water, Sediment, and Soil

The pathways of exposure evaluated for each of the four organism types were developed based on consideration of the likelihood of dose occurring through a specific route, or "pathway." Based on the potential pathways of exposure, BCGs were derived for surface water, sediment, and soil. Calculated using conservative assumptions, the BCGs are intended to preclude the relevant biota from being exposed to radiation levels in excess of the relevant existing or recommended biota dose rate criteria.

G.1. Selection of Target Radionuclides

Biota Concentration Guides (BCGs) that are considered to be conservatively protective of non- human biota were derived for twenty-three radionuclides. These BCGs are provided for radionuclide concentrations in water, sediment, and soil. They have been calculated based on limiting the potential radiological dose rate to the most sensitive receptors: aquatic, terrestrial, and riparian animals, and terrestrial plants. These radionuclides (see Tables G-1-G-3) were selected because they are relatively common constituents in past radionuclide releases to the environment from DOE facilities. This list is not meant to imply particular concern for biotic impact from these twenty-three specific radionuclides. Rather, it is a starting point for application of the methodology.

Table G-1 General Dose Equation and Approach Used to Derive BCGs

$\text{Limiting Concentration} = \frac{\text{Dose Rate Criteria}}{(\text{Internal Dose Rate}) + (\text{External Dose Rate}_{\text{soil,sediment}}) + (\text{External Dose Rate}_{\text{water}})}$	
Limiting Concentration	• The limiting concentration in an environmental medium was calculated by first setting a target total dose (e.g., 1 rad/d for aquatic organisms and terrestrial plants, or 0.1 rad/d for riparian and terrestrial animals) and then back-calculating to the medium concentration (i.e., the BCG) necessary to produce the applicable dose from radionuclides in the organism (internal dose), plus the external dose components from radionuclides in the environment (external dose). • The denominator of the generic equation represents the dose per unit media concentration and may be broken down into the base components of internal and external dose. • Internal doses originate from radionuclides inside the organism's body. The internal dose is calculated as the product of the internal radionuclide concentration and internal dose conversion factor. External doses originate from radionuclides external to the organism and are calculated as the product of the radionuclide concentration in the environmental medium in which the organism resides and an appropriate dose conversion factor.

Table G-2 Biota Concentration Guides (BCGs) for Water and Sediment for Use in Aquatic System Evaluations. For use with radionuclide concentrations from co-located water and sediment.

Nuclide	BCG_{water} Bq/m^3	BCG_{water} pCi/L	Organism Responsible for Limiting Dose in Water	$BCG_{sediment}$ Bq/kg	$BCG_{sediment}$ pCi/g	Organism Responsible for Limiting Dose in Sediment
Am-241	2E+04	4E+02	Aquatic Animal	2E+05	5E+03	Riparian Animal
Ce-144	6E+04	2E+03	Aquatic Animal	1E+05	3E+03	Riparian Animal
Cs-135	2E+04	5E+02	Riparian Animal	2E+06	4E+04	Riparian Animal
Cs-137	2E+03	4E+01	Riparian Animal	1E+05	3E+03	Riparian Animal
Co-60	1E+05	4E+03	Aquatic Animal	5E+04	1E+03	Riparian Animal
Eu-154	8E+05	2E+04	Aquatic Animal	1E+05	3E+03	Riparian Animal
Eu-155	1E+07	3E+05	Aquatic Animal	1E+06	3E+04	Riparian Animal
H-3	1E+10	3E+08	Riparian Animal	1E+07	4E+05	Riparian Animal
I-129	1E+06	4E+04	Riparian Animal	1E+06	3E+04	Riparian Animal
I-131	5E+05	1E+04	Riparian Animal	2E+05	5E+03	Riparian Animal
Pu-239	7E+03	2E+02	Aquatic Animal	2E+05	6E+03	Riparian Animal
Ra-226	2E+02	4E+00	Riparian Animal	4E+03	1E+02	Riparian Animal
Ra-228	1E+02	3E+00	Riparian Animal	3E+03	9E+01	Riparian Animal
Sb-125	1E+07	4E+05	Aquatic Animal	3E+05	7E+03	Riparian Animal
Sr-90	1E+04	3E+02	Riparian Animal	2E+04	6E+02	Riparian Animal
Tc-99	2E+07	7E+05	Riparian Animal	2E+06	4E+04	Riparian Animal
Th-232	1E+04	3E+02	Aquatic Animal	5E+04	1E+03	Riparian Animal
U-233	7E+03	2E+02	Aquatic Animal	2E+05	5E+03	Riparian Animal
U-234	7E+03	2E+02	Aquatic Animal	2E+05	5E+03	Riparian Animal
U-235	8E+03	2E+02	Aquatic Animal	1E+05	4E+03	Riparian Animal
U-238	8E+03	2E+02	Aquatic Animal	9E+04	2E+03	Riparian Animal
Zn-65	5E+02	1E+01	Riparian Animal	5E+04	1E+03	Riparian Animal
Zr-95	3E+05	7E+03	Aquatic Animal	9E+04	2E+03	Riparian Animal

Table G-3 BCGs for Water and Soil for Use in Terrestrial System Evaluations.

Nuclide	BCG_{water} Bq/m^3	BCG_{water} pCi/L	Organism Responsible for Limiting Dose in Water	BCG_{soil} Bq/kg	BCG_{soil} pCi/g	Organism Responsible for Limiting Dose in Soil
Am-241	7E+06	2E+05	Terrestrial Animal	4E+03	1E+05	Terrestrial Animal
Ce-144	1E+08	3E+06	Terrestrial Animal	1E+03	5E+04	Terrestrial Animal
Cs-135	3E+08	8E+06	Terrestrial Animal	3E+02	1E+04	Terrestrial Animal
Cs-137	2E+07	6E+05	Terrestrial Animal	2E+01	8E+02	Terrestrial Animal
Co-60	4E+07	1E+06	Terrestrial Animal	7E+02	3E+04	Terrestrial Animal
Eu-154	8E+07	2E+06	Terrestrial Animal	1E+03	5E+04	Terrestrial Animal
Eu-155	1E+09	3E+07	Terrestrial Animal	2E+04	6E+05	Terrestrial Animal
H-3	9E+09	2E+08	Terrestrial Animal	2E+05	6E+06	Terrestrial Animal
I-129	2E+08	6E+06	Terrestrial Animal	6E+03	2E+05	Terrestrial Animal
I-131	7E+07	2E+06	Terrestrial Animal	9E+02	3E+04	Terrestrial Animal
Pu-239	7E+06	2E+05	Terrestrial Animal	6E+03	2E+05	Terrestrial Animal
Ra-226	3E+05	8E+03	Terrestrial Animal	5E+01	2E+03	Terrestrial Animal
Ra-228	3E+05	7E+03	Terrestrial Animal	4E+01	2E+03	Terrestrial Animal
Sb-125	3E+08	7E+06	Terrestrial Animal	3E+03	1E+05	Terrestrial Animal
Sr-90	2E+06	5E+04	Terrestrial Animal	2E+01	8E+02	Terrestrial Animal
Tc-99	6E+08	2E+07	Terrestrial Animal	4E+03	2E+05	Terrestrial Animal
Th-232	2E+06	5E+04	Terrestrial Animal	2E+03	6E+04	Terrestrial Animal
U-233	1E+07	4E+05	Terrestrial Animal	5E+03	2E+05	Terrestrial Animal
U-234	1E+07	4E+05	Terrestrial Animal	5E+03	2E+05	Terrestrial Animal
U-235	2E+07	4E+05	Terrestrial Animal	3E+03	1E+05	Terrestrial Animal
U-238	2E+07	4E+05	Terrestrial Animal	2E+03	6E+04	Terrestrial Animal
Zn-65	6E+06	2E+05	Terrestrial Animal	4E+02	2E+04	Terrestrial Animal
Zr-95	8E+07	2E+06	Terrestrial Animal	1E+03	4E+04	Terrestrial Animal

G.2. Overview of the Technical Approach for Deriving the BCGs

The derivation of BCGs used to demonstrate compliance with the biota dose rate criteria is based on the fact that biota dose is a function of the contaminant concentration in the environment, and is the sum of internal and external contributions. It is possible, given a unit concentration (i.e., 1 Bq kg^{-1}) of a contaminant in a single media (i.e., soil) to estimate the potential dose rate to a receptor from both internal and external exposures (admittedly, several assumptions must be made to do so, and these are described in the following sections). Once the dose rate has been calculated, it can be ratioed to the dose rate limit, and used to back-calculate a concentration of the contaminant in the media that could generate a dose rate at the specified biota dose limit. If multiple contaminated media are present then the dose evaluation can be performed for each, and the results individually ratioed to the standard. This "sum of fractions" approach is commonly used in evaluating compliance for humans exposed to radionuclides discharged to air, soil and water.

Once the target radionuclides had been selected, external dose coefficients (also called dose conversion factors, DCFs) were developed which relate environmental concentrations of the contaminants in water, sediment and soil to projected organism dose rate. Internal dose coefficients (DCFs) were also developed to estimate dose rate from internally deposited radionuclides.

G.3. Selection of the Most Limiting BCGs for Use in General Screening

As discussed, BCGs were derived for a matrix of radionuclides and media types for each of four organism types. That is, BCGs were derived for twenty-three radionuclides within water, sediment, and soil media for aquatic animal, riparian animal, terrestrial plant, and terrestrial animal organism types. The resulting BCGs from this matrix of radionuclides, media types, and organism types were then reviewed to determine the most limiting (i.e., most conservative or protective) values that could be summarized in two tables for the general screening phase of the graded approach: one for aquatic systems and one for terrestrial systems. The logic flow for selecting the BCG values for use in the general screening phase of the graded approach is illustrated in Figure G-1 Selection of Biota Concentration Guides (BCGs) for Use in Aquatic and Terrestrial System Evaluations.

Based on the potential pathways of exposure, BCGs were derived for surface water, sediment, and soil. Calculated using conservative assumptions, the BCGs are intended to preclude the relevant biota from being exposed to radiation levels in excess of established or recommended biota dose rate criteria. Determination of compliance with the dose rate criteria requires that all organism-relevant environmental media be evaluated at the same time. This is done by using the “sum of fractions” approach commonly used in evaluating radionuclide discharges to the environment.

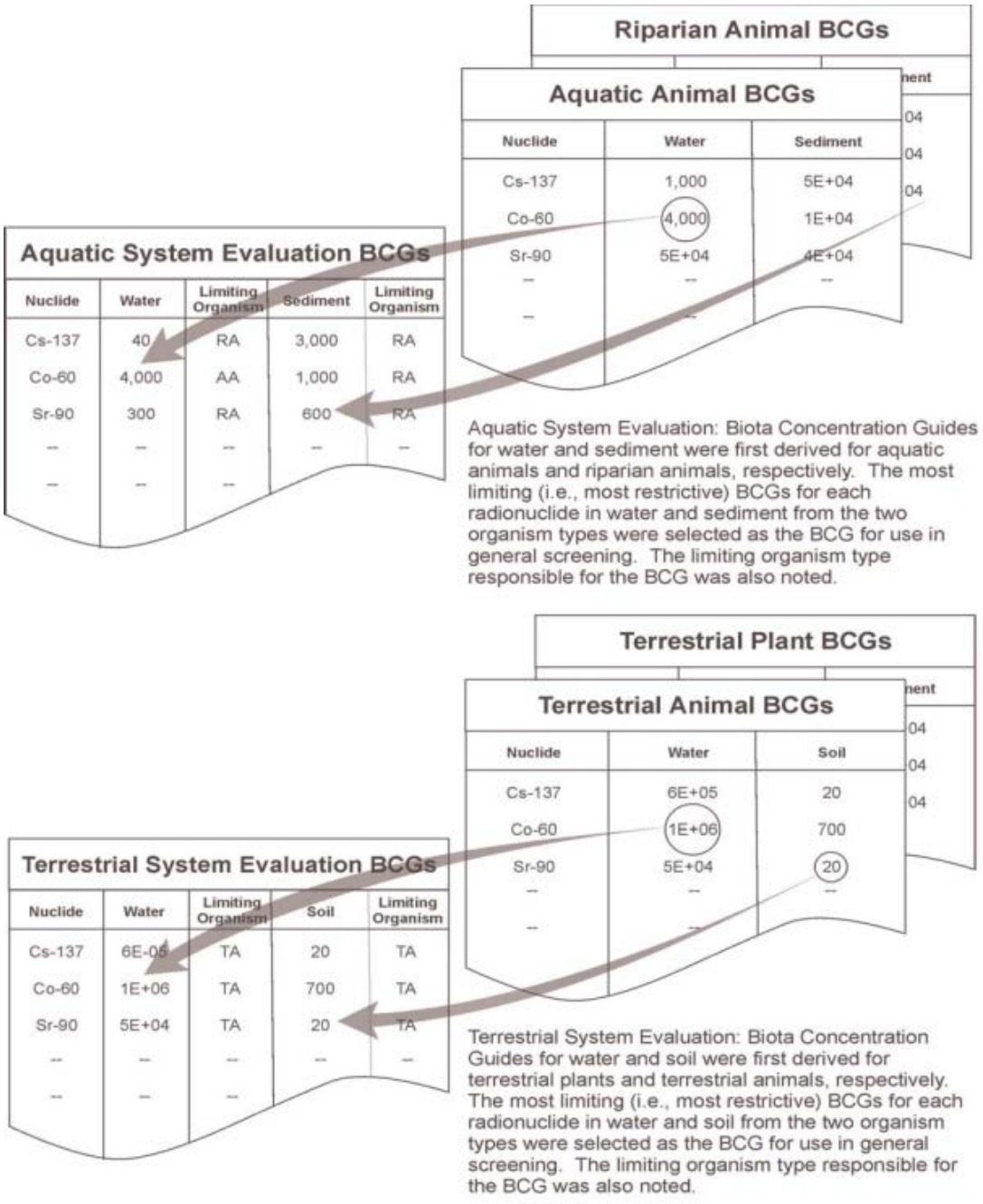


Figure G-1 Selection of Biota Concentration Guides (BCGs) for Use in Aquatic and Terrestrial System Evaluations

G.4. Equations and Models for Aquatic Systems

G.4.1. Aquatic Animals

G.4.1.1. Sediment BCGs for Aquatic Animals

The conceptual model for aquatic animals places the organism at the sediment-water interface. In this screening model, sediment presents an external dose hazard to the aquatic animal, with the BCG therefore based on a semi-infinite exposure model. Uptake of contaminants from the sediment to the

organism is implicitly addressed via the empirical organism to water B_{iv} discussed in following sections. The method used to derive the aquatic animal BCGs for exposure to a single nuclide in contaminated sediment is:

$$BCG_{sediment,aquatic\ animal,i} = \frac{365.25 \times DL_{aa}}{CF_{aa} \times DCF_{ext,sediment,i}} \quad \text{(Eq.13)}$$

Where:

- $BCG_{sediment,aquatic\ animal,i}$ $\left[\frac{\text{Bq}}{\text{kg}}\right]$ is the concentration of nuclide i in sediment which, based on the screening level assumptions, numerically equates to a dose rate of DL_{aa} (0.01 Gy d^{-1}) to the aquatic animal;
- 365.25 (days per year) is a conversion factor;
- DL_{aa} (0.01 Gy d^{-1}) is the dose limit for aquatic animals. This limit can be adjusted by the user through use of the RESRAD BIOTA tool;
- $DCF_{ext,sediment,i}$ $\left[\frac{\text{Gy/y}}{\text{Bq/kg}}\right]$ is the external dose conversion factor used to estimate the dose rate to the tissues of the aquatic animal from nuclide i in the sediment; and
- CF_{aa} (dimensionless) is the correction factor for area or organism residence time. This correction factor is set at a default of 1.

It should be noted that Eq. 13 can also be used to evaluate compliance for aquatic plants. Both the dose factor and dose limit are the same.

G.4.1.2. Water BCGs for Aquatic Animals

The conceptual model for aquatic animals places the organism at the sediment-water interface. In this screening model, water presents both an internal and external dose hazard to the aquatic animal. B_{iv}s are used to estimate the extent of internal contamination (and by extension, the dose), and external exposure is assessed with a semi-infinite source term. The method used to derive the screening-level aquatic animal BCGs for exposure to a single nuclide in contaminated water is:

$$BCG_{water,aquatic\ animal,i} = \frac{365.25 \times DL_{aa}}{CF_{aa} \times \left[\left(0.001 \times B_{iv,aa} \times DCF_{int,i}\right) + DCF_{ext,water,i}\right]} \quad \text{(Eq.14)}$$

Where:

- $BCG_{water,aquatic\ animal,i}$ $\left[\frac{\text{Bq}}{\text{m}^3}\right]$ is the concentration of nuclide i in sediment which, based on the screening level assumptions, numerically equates to a dose rate of DL_{aa} (0.01 Gy d^{-1}) to the aquatic animal;
- DL_{aa} (0.01 Gy d^{-1}) is the dose limit for aquatic animals. This limit can be adjusted by the user through use of the tools available in RESRAD Biota tool;
- 0.001 is a conversion factor for L to m^3;
- $B_{iv,aa}$ $\left[\frac{L}{kg}\right]$ is the fresh mass aquatic animal to water concentration factor for nuclide i;

- $DCF_{int,i}$ $\left[\frac{\text{Gy/y}}{\text{Bq/kg}}\right]$ is the dose conversion factor used to estimate the dose rate to the tissues from nuclide i in tissues;
- $DCF_{ext,water,i}$ $\left[\frac{\text{Gy/y}}{\text{Bq/m}^3}\right]$ is the dose coefficient used to estimate the dose rate to the aquatic animal from submersion in contaminated water; and
- All other terms have been defined.

It should be noted that Equation 1 (see Section 5.1) can also be used to evaluate compliance for aquatic plants. Both the dose factor and the dose limit are the same. In lieu of an aquatic animal B_{iv}s simply substitute an aquatic plant concentration factor.

G.4.2. Riparian Animals

Sediment BCGs for Riparian Animals.

The conceptual model for riparian animals also places the organism at the sediment-water interface (as does the aquatic animal model). However, in this screening model, sediment presents both an internal and external dose hazard to the riparian animal. B_{iv}s are used to estimate the extent of internal contamination (and by extension, the dose), and external exposure is assessed with a semi-infinite source term. The method used to derive the riparian animal BCGs for exposure to a single nuclide in contaminated sediment is:

$$BCG_{sediment,riparian\ animal,i} = \frac{365.25 \times DL_{ra}}{CF_{ra} \times \left[\left(B_{iv_{ra,sed,i}} \times DCF_{int,i}\right) + DCF_{ext,sed,i}\right]} \qquad \text{(Eq.15)}$$

Where:

- $BCG_{sediment,riparian\ animal,i}$ $\left[\frac{\text{Bq}}{\text{kg}}\right]$ is the concentration of nuclide i in sediment, based on the screening level assumptions, numerically equates to a dose rate of DL_{ra} (0.001 Gy d-1) to the riparian animal;
- DL_{ra} (0.001 Gy d-1) is the recommended dose limit for riparian animals. This limit can be adjusted by the user if so directed by an appropriate agency;
- $B_{iv_{ra,sed,i}}$ (dimensionless) is the fresh mass riparian animal to sediment concentration factor of nuclide i;
- CF_{ra} (dimensionless) is the correction factor for area or organism residence time for the riparian organism. This correction factor is set at a default of 1; and
- all other terms have been defined.

G.4.2.1. Water BCGs for Riparian Animals

As noted previously, the conceptual model for riparian animals has the animal situated at the sediment-water interface. In assessing potential contributors to dose, water presents both an internal and external dose hazard. As before, B_{iv}s are used to estimate the extent of internal contamination. External exposure is assessed with a semi-infinite source term. The method used to derive the

screening-level riparian animal BCGs for exposure to a single nuclide in contaminated water is as follows:

$$BCG_{water,riparian\ animal,i} = \frac{365.25 \times DL_{ra}}{CF_{ra} \times \left[\left(0.001 \times B_{iv_{ra,water,i}} \times DCF_{int,i}\right) + DCF_{ext,water,i}\right]} \quad \text{(Eq.16)}$$

Where:

- $BCG_{water,riparian\ animal,i}\ \left[\frac{Bq}{m^3}\right]$ is the concentration of nuclide i in water, which based on the screening level assumptions, numerically equates to a dose rate of DL_{aa} (0.001 Gy d-1) to the riparian animal;
- $B_{iv_{ra,water,i}}\ \left[\frac{L}{kg}\right]$ is the fresh mass riparian animal to water concentration factor of nuclide i; and all other terms have been defined.

G.4.3. Important Considerations When Implementing Equations and Models in an Aquatic System Evaluation

For the aquatic environment, compliance with the dose limit is determined by comparison of the projected dose from both water and sediment. This is achieved by using a sum of fractions approach. The measured concentrations of radionuclides for the water and sediment pathways are each ratioed to their respective BCGs and the resultant values summed. If the total is less than one, then compliance (for that nuclide) is achieved. For multiple nuclides the process is repeated, with the sum of all fractions (the grand total) required to be less than one for compliance.

G.4.3.1. Co-located water and sediment samples

The preferred method of determining compliance is to use co-located water and sediment data. If such data are available, then compliance is determined in the manner described in the preceding paragraph.

G.4.3.2. Water and sediment samples not co-located

In situations where co-located water and sediment data are not available, the user estimates the missing data through use of the radionuclide-specific "most probable" distribution coefficient. If water data are present, but sediment data are unavailable, the missing sediment data are estimated through use of the following calculation:

$$C_{sediment} = 0.001 \times C_{water} \times K_{d,most\ probable} \quad \text{(Eq.17)}$$

Where:

- $C_{sediment}\ \left[\frac{\mathrm{Bq}}{\mathrm{kg}}\right]$ is the concentration of nuclide i in the sediment;
- $0.001\ \left[\frac{\mathrm{m^3}}{\mathrm{L}}\right]$ is the conversion factor for L to m^3;
- $C_{water}\ \left[\frac{\mathrm{Bq}}{\mathrm{m^3}}\right]$ is the concentration of nuclide i in water; and

- $K_{d,most\ probable}$ (expressed as $\left[\frac{\mathrm{L}}{\mathrm{kg}}\right]$ but also equates to $\left[\frac{\mathrm{mL}}{\mathrm{g}}\right]$) is the distribution coefficient used to relate the water concentration to the sediment concentration. In doing this calculation, median values of distribution coefficients were selected, rather than extreme values. For many nuclides, distribution coefficients range over several orders of magnitude. Selection of extreme values would result in unrealistic projections of water (or sediment) concentrations of radionuclides.

Conversely, if water data are unavailable, estimate the missing water data through use of the following calculation:

$$C_{water} = \frac{C_{sediment}}{0.001 \times K_{d,most\ probable}} \quad \text{(Eq.18)}$$

where all terms have been previously defined.

If the user has water data from one location, and sediment data from another (for the same radionuclide), he/she should use both approaches outlined above, and select the method which results in the highest (,i.e., most conservative) partial fraction.

G.5. Equations and Models for Terrestrial Systems

G.5.1. Terrestrial Plants

G.5.1.1. Soil BCGs for Terrestrial Plants

In this screening model, soil provides both an internal and external dose hazard to plants. The conceptual model for terrestrial plants is based on the entire plant being surrounded by soil. While many plants may have a substantial portion of their mass above ground, the BCG thus derived, will be conservative. B_{iv}s are used to estimate the extent of internal contamination (and by extension, the dose), and external exposure is assessed using an infinite source term. The B_{iv}s used in the model account for aerial deposition onto plant surfaces with subsequent uptake. The method used to derive the BCGs for terrestrial plant exposure to a single nuclide in contaminated soil is:

$$BCG_{soil,terrestrial\ plant,i} = \frac{365.25 \times DL_{tp}}{CF_{tp} \times \left[\left(B_{iv,tp,i} \times DCF_{int,i}\right) + DCF_{ext,soil,i}\right]} \quad \text{(Eq.19)}$$

Where:

- $BCG_{soil,terrestrial\ plant,i}\ \left[\frac{\mathrm{Bq}}{\mathrm{kg}}\right]$ is the concentration of nuclide i in soil which, based on the screening level assumptions, numerically equates to a dose rate of DL_{tp} (0.01 Gy d-1) to the terrestrial plant;
- DL_{tp}(0.01 Gy d-1) is the recommended dose limit for terrestrial plants. This limit can be adjusted by the user if so directed by an appropriate agency;
- $B_{iv,tp,i}$ (dimensionless) is the fresh mass terrestrial plant to soil concentration factor;
- CF_{tp} (dimensionless) is the correction factor for area or time. This correction factor is set at a default of 1;

- $DCF_{ext,soil,i}$ $[\frac{\text{Gy/y}}{\text{Bq/kg}}]$ is the dose conversion factor used to estimate the dose rate to the plant tissues from nuclide *i* in surrounding soils; and
- all other terms are as previously defined.

It should be noted that the derivation of the water BCG for terrestrial plants only considers external exposure of plants from submersion in water. Although this may seem to ignore uptake of contaminants from pore water into the plant, there is very limited data available to support this type of calculation. The best estimator of internal deposition is the plant to soil concentration factor, utilized in Equation 19. If only water data is available, and no soil data (for example, measurements in irrigation water), you can use the relationship outlined in Equation 17 to predict the soil concentration and substitute this value into Equation 19.

G.5.1.2. Water BCGs for Terrestrial Plants

The conceptual model for terrestrial plants is based on the entire plant being surrounded by soil. However, the potential for exposure to contaminated water – from soil pore water or from irrigation exists. As a compromise to the methodology, external exposure from water was added. In this screening model, the BCG for water is based on a semi-infinite exposure model. The method used to derive the BCGs for terrestrial plant exposure to a single nuclide in contaminated water is:

$$BCG_{water,terrestrial\ plant,i} = \frac{365.25 \times DL_{tp}}{CF_{tp} \times DCF_{ext,water,i}} \quad \text{(Eq.20)}$$

Where:

- $BCG_{water,terrestrial\ plant,i}$ $\left[\frac{\text{Bq}}{\text{m}^3}\right]$ is the concentration of nuclide i in soil which, based on the screening level assumptions, numerically equates to a dose rate of DL_{tp} (0.01 Gy/d) to the terrestrial plant; and
- all other terms are as previously defined.

G.5.2. Terrestrial Animals

G.5.2.1. Soil BCGs for Terrestrial Animals

The screening conceptual model for terrestrial animals has the animal surrounded by soil. In assessing potential contributors to dose, soil presents both an internal and external dose pathway. As before, B_{iv}s are used to estimate the extent of internal contamination (e.g., as might occur from ingestion or inhalation). External exposure is assessed with an infinite source term. The method used to derive the terrestrial animal BCGs for exposure to a single nuclide in contaminated soil is:

$$BCG_{soil,terrestrial\ animal,i} = \frac{365.25 \times DL_{ta}}{CF_{ta} \times \left[\left(B_{iv_{ta,soil,i}} \times DCF_{int,i}\right) + DCF_{ext,soil,i}\right]} \quad \text{(Eq.21)}$$

Where:

- $BCG_{soil,terrestrial\ animal,i}\ \left[\frac{Bq}{kg}\right]$ is the concentration of nuclide i in soil which, based on the screening level assumptions, numerically equates to a dose rate of DL_{ta} (0.001 Gy/d) to the terrestrial animal;
- DL_{ta} (0.001 Gy/d) is the recommended dose limit for terrestrial animals. This limit can be adjusted by the user if so directed by an appropriate agency;
- $B_{iv_{ta,soil,i}}$ (dimensionless) is the fresh mass terrestrial animal to soil concentration factor of nuclide *I*; and
- CF_{ta} (dimensionless) is the correction factor for area or organism residence time for the terrestrial organism. This correction factor is set at 1 for the general screening phase of the calculations; and all other terms have been defined.

G.5.2.2. Water BCGs for Terrestrial Animals

The conceptual model for terrestrial animals is based on the entire animal being surrounded by soil. However, the potential for exposure to contaminated water from soil pore water or by drinking from contaminated ponds or rivers exists. Water presents both an internal and external dose hazard. As before, B_{iv}s are used to estimate the extent of internal contamination (i.e.., as might occur from ingestion). A semi-infinite exposure model is used for the external exposure. The method used to derive the terrestrial animal BCGs for exposure to a single nuclide in contaminated water is:

$$BCG_{water,terrestrial\ animal,i} = \frac{365.25 \times DL_{ta}}{CF_{ta} \times \left[\left(0.001 \times \left(B_{iv_{ta,soil,i}} \times DCF_{int,i}\right) + DCF_{ext,soil,i}\right)\right]} \qquad \text{(Eq.22)}$$

Where:

- $BCG_{water,terrestrial\ animal,i}\ \left[\frac{Bq}{m^3}\right]$ is the concentration of nuclide, *i*, in water, which based on the screening level assumptions, numerically equates to a dose rate of DL_{ta} (0.001 Gy d-1) to the terrestrial animal;
- $Biv\ \left[\frac{L}{kg}\right]$ is the fresh mass terrestrial animal to water concentration factor of nuclide i; and all other terms have been defined.

How are these Dose Equations and their Parameters Used in Implementing the Graded Approach?

General Screening. *The initial value of the B_{iv} used in the general screening phase is specifically chosen to produce conservative default BCGs. This quickly removes from further consideration contamination levels that would not cause biota to receive doses above acceptable limits. However, some sites may fail the general screen. This does not mean that they are causing biota to receive doses above the acceptable limit, but suggests that further analysis is warranted for specific radionuclides and media. It is recognized that actual B_{iv} values range over several orders of magnitude, depending upon biotic and abiotic features of the environment.*

Site-Specific Screening. *The next step is to examine the B_{iv}, and using data either directly from the site, or from the technical literature, select a value which is more representative for the specific-site conditions. In doing so, the screening calculation is repeated and a new site- specific BCG is provided. The process for each organism-type is as follows:*

- **Aquatic Animals**. The user is allowed to modify the $B_{iv,aa,i}$ (the wet weight bioaccumulation factor) to a more site-representative value. All other aspects of the calculations remain the same.
- **Riparian Animals**. The user is allowed to modify the $B_{iv\ ra,\ water,\ i}$ and $B_{iv\ ra,\ sed,\ i}$ (the wet weight bioaccumulation factor for animal to water or animal to sediment) to a more site-representative value. All other aspects of the calculations remain the same.
- **Terrestrial Plants**. The user is allowed to modify the $B_{iv,tp,i}$ (the wet weight bioaccumulation factor) to a more site-representative value. All other aspects of the calculations remain the same.
- **Terrestrial Animals**. The user is allowed to modify the $B_{iv\ ra,\ water,}$ and $B_{iv\ ra,\ soil,\ i}$ the wet weight bioaccumulation factor for terrestrial animal to water or terrestrial animal to soil) to a more site-

G.6. Alternatives to Bivs for Riparian and Terrestrial Animals: The Kinetic/Allometric Method

As discussed in Section 6.2.1, for most radionuclides, the single-most important predictor of biota dose is the method used to estimate internal tissue concentrations. The technical literature contains reference to these empirically based parameters that measure concentrations of contaminants in an organism relative to the surrounding media. These ratios are called "concentration ratios," "concentration factors," or "wet-weight concentration ratios" B_{iv}s. These B_{iv}s are available for many nuclides for plant:soil and for aquatic species:water. In a few instances they are also available for animals:soil or animals:sediment. The advantage of using one of these factors is that it allows the prediction of tissue concentration based on simple measurements of contamination in environmental media such as soil, water, or sediment. The use of B_{iv}s is an integral feature of the screening approach. However, as the methodology evolved it became apparent that there were gaps in the data that needed to be addressed, particularly for riparian and terrestrial animal lumped parameters. An alternative approach, called the kinetic/allometric method, was developed. This method had two objectives: first, to fill in data gaps in the literature on lumped parameters; and second, to provide users with an alternative, more sophisticated method for evaluating dose to specific riparian and terrestrial animal receptors.

The kinetic/allometric method may be applied in the site-specific analysis component of the graded approach. In site-specific analysis, the internal pathways of exposure are examined in greater detail.

This evaluation relies upon mathematically modeling the exposure of the organism using simplistic, first-order kinetic reactions of the form:

$$q = \frac{R}{k}\left(1 - e^{-kt}\right) \quad \text{(Eq.23)}$$

Where:

- q is the total activity [Bq] in the organism of concern at time t;
- R is the intake rate of activity $\left[\frac{\text{Bq}}{\text{d}}\right]$ into the organism;
- k is the effective loss rate of activity [d^{-1}] from the organism; and
- t is the total length of exposure to the contaminant [days].

The activity concentration in the animal is calculated as q divided by the mass; in SI units the mass would be expressed in kg. While this calculation method is simple, it still requires information on the intake rate of the organism, the total body mass, the loss rate of the radionuclide and the exposure period.

G.6.1. A Scaling Approach to Predicting Tissue Concentrations

The key to estimating body burdens in biota is an expression for intake that can account for potential change with size of the organism. There are several allometric equations which relate body size to many parameters, including ingestion rate, life span, inhalation rate, home range and more (West et al. 1997). These equations take the form of:

$$Y = \alpha X^{\beta} \quad \text{(Eq.24)}$$

Where Y and X are size-related measures and α and β are constants.

While these equations were originally derived from empirical observations, there is a growing body of evidence that these relationships have their origins in the dynamics of energy transport mechanisms. An example of one use of this type of equation is illustrated in deriving soil BCGs for terrestrial animals.

G.6.1.1. Estimating Intake (Soil Pathway)

The intake of radioactivity into a terrestrial animal is presumed to come from three routes of exposure: ingestion of contaminated foodstuffs, ingestion of contaminated soil, and inhalation of re-suspended soil.

Ingestion of Food

Metabolic rate is known to scale to body mass to the ¾ power (Calder 1984, Reiss 1989, and West et al. 1997). The food intake rate can also be calculated if allowances are made for several factors (Whicker and Shultz 1982):

$$r = \frac{a}{d \times c} \times 70M^{0.75} \quad \text{(Eq.25)}$$

Where:

- r is food intake in $\left[\frac{g}{d}\right]$;

- a is the ratio of active or maintenance metabolic rate to the basal metabolic rate;
- d is the fraction of the energy ingested that is assimilated and oxidized;
- c is the caloric value of food in $\left[\frac{\text{kcal}}{\text{g}}\right]$; and
- M is the live body weight in kg

The rate of radionuclide intake into the animal is a product of the food intake rate and the activity concentration of the foodstuff. The concentration of radionuclides in food is a product of the soil concentration (C_s, Bq/kg) and the food-to-soil uptake factor $B_{iv,tp,i}$ (dimensionless). The radionuclide intake rate via ingestion is expressed in Bq/d:

$$I_{ingestion,food,i} = C_{s,i} B_{iv,tp,i} \left[10^{-3} \times \frac{a}{d \times c} \times 70 M^{0.75}\right] \quad \text{(Eq.26)}$$

Where:

- $I_{ingestion,food,i}$ is the intake rate $\left[\frac{Bq}{d}\right]$of a radionuclide into the animal via consumption of contaminated food, the concentration of radionuclides in the contaminated food is calculated as a product of the soil concentration and the food-to-soil (wet-weight) uptake factor (B_{iv}), and the factor of 10^{-3} converts the ingestion rate of equation 25 from $\left[\frac{\text{g}}{\text{d}}\right]$ to $\left[\frac{\text{kg}}{\text{d}}\right]$; and
- all other terms have been defined.

Ingestion of Soil

Studies on soil ingestion by wildlife indicate that it scales as a percentage of the mass of the daily diet (US EPA 1993). The rate of radionuclide intake into the animal via soil ingestion (Bq d^{-1}) would therefore be the soil concentration times the daily mass of food ingested times the fraction of the daily diet that comes from soil ingestion (f).

$$I_{ingestion,soil,i} = C_{si} \times f \left[10^{-3} \times \frac{a}{d \times c} \times 70 M^{0.75}\right] \quad \text{(Eq.27)}$$

Where:

- f is the fraction of the mass of daily diet that comes from soil ingestion.

Inhalation of Soil

The rate of intake of soil into the lungs of the animal can be calculated as the product of the inhalation rate ($m^3\ d^{-1}$) and the air concentration (in Bq m^{-3}) of the nuclide.

The air concentration can be estimated using the mass loading approach. The activity in air is calculated as the product of X, the dust loading in air (in kg m^{-3}) and C_{soil}. The lung ventilation rate also scales as a function of body mass (Pedley 1975 and West et al. 1997). Because of differences in solubility in body fluids, material taken into the body via inhalation may (or may not) be more readily absorbed than those taken in via ingestion. In his paper assessing the contribution of inhalation to dose, Zach (1985) derived a series of correction factors (PT/IT) which provided an adjustment for inhalation relative to ingestion. These factors are used to correct the inhalation rate to that of an equivalent amount of ingested soil:

$$I_{inhalation,soil,i} = \frac{PT}{IT} \times C_{si} \times 0.481M^{0.76} \quad \text{(Eq.28)}$$

Calculating Total Intake

The total intake to the body can be calculated as the sum of inputs from inhalation given in equation 28, food ingestion in equation 26, and soil ingestion in equation 27. This is accomplished by direct substitution and rearrangement into the relationship: $R = I_{inhalation} + I_{soil\,ingestion} + I_{food}$, as follows:

$$R = C_{soil} \times \left[(B_{iv} + f) \times \left(10^{-3} \times \frac{a}{d \times c} \times 70M^{0.75}\right) + \left(\frac{PT}{IT} \times 0.481M^{0.76}\right)\right] \quad \text{(Eq.29)}$$

Estimating the Fraction Assimilated into the Body

Because only a fraction of the material ingested actually enters into the blood, the total intake rate must be modified by a factor, f_1, to account for this difference:

$$R^* = f_1 R = f_1 C_{soil} \times \left[(B_{iv} + f) \times \left(10^{-3} \times \frac{a}{d \times c} \times 70M^{0.75}\right) + \left(\frac{PT}{IT} \times 0.481M^{0.76}\right)\right] \quad \text{(Eq.30)}$$

Where R^* is the species-independent estimate of radionuclide uptake to blood (Bq d^{-1}) from exposure to contaminated soil, and f_1 is the fraction of intake assimilated to the body.

G.6.1.2. Estimating the Total Loss Rate from the Organism

The loss of radioactive material from the organism is due to radiological decay as well as biological elimination. There is substantial evidence that biological half-time of material in the body is related to metabolism, and therefore should be a function of body mass with the following relationship:

$$T_{\frac{1}{2},biological,i} = \alpha W^{\beta} \quad \text{(Eq.31)}$$

Where α and β are scaling constants related to the biological elimination of a particular element and W is the body mass (in g). In their book, Whicker and Schultz (1982) identified empirical relationships for Sr, Cs, I, Co, and tritium. Three of these elements exhibited scaling to the ¼ power (Cs, Sr, Co). Iodine scaled at $W^{0.13}$ and ^3H scaled at $W^{0.55}$. The biological decay time is then used to calculate the biological decay constant (i.e., k in Equation 23). The effective decay constant, k_{eff} is calculated as the sum of the radiological and biological decay constants.

Scaling constants for other radionuclides were estimated from data provided in the literature on the biological elimination rates for various species of animals.

G.6.1.3. Calculating the Fractional Buildup to Equilibrium Tissue Concentrations

The activity in an organism continuously exposed to a constant source of contaminated material will, potentially, continue to increase until either a maximum value, or equilibrium, is attained.

The degree of equilibrium that is attained is dictated by the lifespan of the organism, and the length of exposure, in conjunction with the effective loss-rate constant. For the purposes of radiological protection we need to know the maximum potential body burden in the organism. If exposure is constant throughout the life of the organism, then the time of maximum body burden will definitely occur when the exposure time equals maximum lifespan of the organism (for radionuclides with a short

half-life or biological elimination rate, the time to reach maximum body burden will be substantially shorter). Using the lifespan of the organism to calculate tissue concentrations is the simplest approach.

In a manner similar to metabolic rate and inhalation rate, the maximum lifespan of an organism has been found to scale as a function of body mass. Calder (1984) analyzed the lifespan of 35 species of wild mammals to estimate their life expectancy (in the wild):

$$T_{expected,wild} = 1.02M^{0.30\pm0.026} \quad \text{(Eq.32)}$$

Where $T_{expected,wild}$ is in years and $M$is the live weight in kg.

G.6.1.4. Calculating Species-Independent Tissue Concentrations from Soil Exposure

The activity in an organism continuously exposed to a constant source of contaminated material will, potentially, continue to increase until either a maximum value, or equilibrium, is attained.

The degree of equilibrium that is attained is dictated by the lifespan of the organism, and the length of exposure, in conjunction with the effective loss-rate constant. If exposure is constant throughout the life of the organism, then the time of maximum body burden will occur when the exposure time equals the maximum lifespan of the organism (for radionuclides with a short half- life or biological elimination rate, the time to reach maximum body burden will be substantially shorter). Equations 23, 25, 30, and 32 can be combined (with appropriate unit conversions) to provide an estimate of the maximal tissue concentration for the organism consuming contaminated plants, soil, and breathing contaminated air:

$$C_{animal,soil} = \frac{f_1 C_{soil} \times \left[(B_{iv} + f) \times \left(10^{-3} \times \frac{a}{d \times c} \times 70M^{0.75}\right) + \left(\frac{PT}{IT} \times 0.481M^{0.76}\right)\right] \times \left(1 - e^{-(k_{rad}+k_{bio})(365.25)(1.02M^{0.3})}\right)}{(k_{rad} + k_{bio}) \times M} \quad \text{(Eq.33)}$$

G.6.1.5. Calculating Limiting Soil Concentrations (BCGs) Using the Kinetic/Allometric Method: An Example

Although predicting tissue concentrations of species exposed to contaminants is important, the overall purpose of this effort is to derive media concentrations that will be protective of biota at a site. The methodology can be demonstrated using the soil-terrestrial animal pathway. Equation 33 estimates the maximum potential tissue concentration in an animal from prolonged exposure to soil contaminated with radionuclide *i* at a unit concentration (i.e., 1 Bq/kg). If a particular dose limit is chosen (D_{ta} for example, in Gy/y), the limiting soil concentration to achieve that dose limit (LS_i) can be calculated as:

$$LS_i = \frac{D_{ta}}{C_{animal,i}\left(DCF_{int,i}\right)} \quad \text{(Eq.34)}$$

Where:

- LS_i is the limiting soil concentration in Bq/kg;
- D_{ta} is the chosen dose limit in Gy/y;
- $C_{animal,i}$ is the predicted tissue concentration of an animal from exposure to 1 Bq/kg contamination in soil; and
- $DCF_{int,i}$ is the internal dose coefficient $\left[\frac{Gy/y}{Bq/kg}\right]$ of soil.

The equation can be further modified to account for external exposure of the organism:

$$LS_i = \frac{D_{ta}}{C_{animal,i}\left(DCF_{int,i}\right) + DCF_{ext,i}} \quad \text{(Eq.35)}$$

Where $DCF_{ext,i}$ is the external dose coefficient $\left[\frac{Gy/y}{Bq/kg}\right]$ of soil; and all other factors have been defined.

Substitution of the tissue concentrations (Equation 21) into the equation for calculating limiting media concentrations results in the following equation:

$$LS_{terrestrial\ animal,i} = \frac{0.001\ \left[\frac{Gy}{d}\right]}{\frac{f_1(\alpha+\beta)\delta DCF_{int,i}}{K_{eff} \times M} + DCF_{ext,soil,i}} \quad \text{(Eq.36)}$$

Where:

- α provides an estimate of the daily intake rate of contaminated food and soil into the terrestrial animal;

$$\alpha = \frac{a}{d \times c} 70M^{0.75}\left(B_{iv,sp,i} + f\right) \quad \text{(Eq.37)}$$

- β provides the estimate of the daily intake that occurs through inhalation (and adjusts uptake relative to ingestion);

$$\beta = \frac{PT}{IT} \times 0.481M^{0.76} \quad \text{(Eq.38)}$$

- and δ provides an estimate of the exposure period, expressed as a function of the maximal life span of the target organism;

$$\delta = (1 - e^{-k_{eff}1.02M^{0.30}}) \quad \text{(Eq.39)}$$

- and all other terms have been previously defined.

G.6.2. Application of the Kinetic/Allometric Method in the Derivation of BCGs for Riparian Animals

In the analysis phase of the graded approach, a user may not have access to site-specific B_{iv}s, or use of them results in exceeding site-specific screening. If that is the case, the user should conduct a more in-depth analysis of potential dose using the kinetic/allometric method. Equations have been developed for riparian animals using the methodology and equations discussed in Section 6.2.1.5. Two equations were developed, one for exposure to contaminated sediment, and a second for exposure to contaminated water.

Sediment. Riparian animal exposure to sediment considers external exposure as well as the inadvertent ingestion of sediment. The derivation of the sediment BCG for riparian animals is based on predicting maximal tissue concentrations after a lifetime of exposure. The equation used to derive the riparian BCGs for exposure to a single nuclide in contaminated sediment is:

$$BCG_{sediment,riparian\ animal,i} = \frac{365.25 \times DL_{ra}}{CF_{ra}\left(\left[\frac{f_1 f\left[10^{-3}\frac{a}{d \times c}70M^{0.75}\right]\left[1 - e^{-((k_{rad}+k_{bio})(365.25)(1.02M^{0.3}))}\right]DCF_{int,i}}{(k_{rad}+k_{bio})M}\right] + \left[DCF_{ext,soil,i}\right]\right)} \quad \text{(Eq.40)}$$

Water. The equation used to derive the riparian BCGs for exposure to a single nuclide in contaminated water is similar but includes ingestion of contaminated foodstuff and water, as well as external exposure, and is based on predicting maximal tissue concentrations after a lifetime of exposure. Water consumption scales as a function of body mass (EPA 1993) in a manner similar to ingestion:

$$r_{water} = 0.099M^{0.90} \quad \text{(Eq.41)}$$

The BCG is calculated as:

$$BCG_{water,riparian\ animal,i} = \frac{365.25 \times DL_{ra}}{CF_{ra}\left(\left[\frac{f_1\left[B_{iv,af}(10^{-3}\frac{a}{d \times c}70M^{0.75}) + 0.099M^{0.9}\right]\left[1 - e^{-((k_{rad}+k_{bio})(365.25)(1.02M^{0.3}))}\right]DCF_{int,i}}{(k_{rad}+k_{bio})M}\right] + \left[DCF_{ext,water,i}\right]\right)} \quad \text{(Eq.42)}$$

Where $B_{iv,af}$ = aquatic foods bioaccumulation factor and all other terms have been defined.

It should be noted that Equations 40 and 42 can be condensed to the simpler form of Equations 15 and 16, respectively, by substitution of a single constant for the organism-specific variables. Also, it is possible to use Equation 42 to assess impacts to either carnivorous or herbivorous riparian animals by substituting appropriate values of $B_{iv,aa}$ into this equation. This method is applicable to carnivores because the B_{iv}s selected for the default case represent the upper-end values from the technical literature. These literature values encompass carnivores as well as herbivores. The bioaccumulation factor ($B_{iv,aa}$) in Equation 42, when multiplied by the water concentration, provides a prediction of radionuclide concentration in the riparian animal's food. For herbivorous riparian animals, one can substitute B_{iv}values appropriate for aquatic plant: water in lieu of $B_{iv,aa}$values for aquatic animals.

G.6.3. Application of the Kinetic/Allometric Method in the Derivation of BCGs for Terrestrial Animals

In a manner similar to that used for riparian animals, equations have been developed for terrestrial animals using the methodology and equations discussed in section 6.2.1.5.

Soil. The derivation of the soil BCG considers ingestion of contaminated foodstuff, and soil, inhalation of soil, and external exposure. It is based on predicting maximal tissue concentrations after a lifetime of exposure.

$$BCG_{soil,terrestrial\ animal,i} = \frac{365.25 \times DL_{ta}}{CF_{ta}\left(\left[\frac{f_1\left[(B_{iv}+f)(10^{-3}\frac{a}{d \times c}70M^{0.75}) + \left(\frac{PT}{IT} \times 0.481M^{0.76}\right)\right]\left[1 - e^{-((k_{rad}+k_{bio})(365.25)(1.02M^{0.3}))}\right]DCF_{int,i}}{(k_{rad}+k_{bio})M}\right] + \left[DCF_{ext,sed,i}\right]\right)} \quad \text{(Eq.43)}$$

Where all terms have been defined.

Water. The equation used to derive the terrestrial animal BCGs for exposure to a single nuclide in contaminated water is similar to that used for soil, but includes ingestion of contaminated water, as well as external exposure, and is based on predicting maximal tissue concentrations after a lifetime of exposure.

$$BCG_{water,terrestrial\ animal,i} = \frac{365.25 \times DL_{ta}}{CF_{ta}\left(0.001\left[\frac{f_1 0.099 M^{0.9}\left[1 - e^{-((k_{rad}+k_{bio})(365.25)(1.02M^{0.3}))}\right]DCF_{int,i}}{(k_{rad}+k_{bio})M}\right] + \left[DCF_{ext,water,i}\right]\right)} \quad \text{(Eq.44)}$$

Where all terms have been defined.

It should be noted that Equations 43 and 44 could be condensed to the simpler form of Equations 21 and 22, respectively, by substitution of a single lumped parameter constant for the organism- specific variables. Also, it is possible to use Equation 43 to assess impacts to either carnivorous or herbivorous animals by substituting appropriate values of B_{iv} into this equation. The bioaccumulation factor ($B_{iv,tp}$) in Equation 43, when multiplied by the soil concentration, provides a prediction of radionuclide concentration in the terrestrial animal's food. While B_{iv} values for animal:soil could be substituted, a more conservative approach is to use the existing ($B_{iv,tp}$) values provided for terrestrial plants. In this manner, biomagnification through higher trophic levels can be assessed.

G.7. Selection of B_{iv}s for Riparian and Terrestrial Animals

Recall that the general screening phase of the graded approach utilizes B_{iv}s to provide estimates of organism tissue concentration, and ultimately derive the nuclide, media, and organism–specific BCGs. While there is a relative abundance of data for aquatic animals and terrestrial plants, less information is found for terrestrial and riparian animals.

As noted in Sections 6.2.1.5, the kinetic/allometric equations can be condensed to a simpler form by substitution of a single lumped parameter in place of the organism-specific variables. The choice of a value for this lumped parameter becomes problematic, however, when considering the range of organism types meant to be covered by the method. Also, there is very limited data available in the literature on animal: water, animal: soil, and animal: sediment ratios. Two alternative approaches were evaluated:

Calculating Lumped Parameters by Multiplying Related Concentration Ratios (Product Approach). It is possible to calculate the lumped parameters by multiplying related concentration ratios; for example, the product of plant: soil and animal: plant concentration ratios yields an animal:soil ratio which may be substituted for the lumped parameter used in Equation 21. This approach must be used with caution, as the data used in the process are most likely from different sources. This approach also is hampered by the lack of environmental data.

Calculating B_{iv}s by Using Uncertainty Analysis on the Kinetic/Allometric Method. An alternative method to developing B_{iv}s for riparian and terrestrial animals was addressed by using uncertainty analysis on the kinetic/allometric method. A Monte-Carlo simulation was used to determine the effect of parameter variability on the calculation of maximal animal tissue concentrations relative to environmental media concentrations. The allometric equations shown for riparian and terrestrial animals in Section 6.2.1.5 was rearranged to predict lumped parameters resulting from exposure to a

unit concentration of contaminant in water, sediment, or soil. The rearranged equations are shown below. Each of the variables has been previously defined.

$$LP_{sed,riparian\ animal,i} = \frac{C_{sed,riparian\ animal}}{C_{sed}} = \frac{f_1 f\left[10^{-3}\frac{a}{d\times c}70M^{0.75}\right]\left[1-e^{-\left((k_{rad}+k_{bio})(365.25)(1.02M^{0.3})\right)}\right]}{(k_{rad}+k_{bio})M} \quad \text{(Eq.45)}$$

$$LP_{water,riparian\ animal,i} = \frac{C_{riparian\ animal,i}}{C_{water}} = \left[\frac{f_1\left[B_{iv,af}(10^{-3}\frac{a}{d\times c}70M^{0.75}) + 0.099M^{0.9}\right]\left[1-e^{-\left((k_{rad}+k_{bio})(365.25)(1.02M^{0.3})\right)}\right]}{(k_{rad}+k_{bio})M}\right] \quad \text{(Eq.46)}$$

$$LP_{soil,terrestrial\ animal,i} = \frac{C_{animal\ soil}}{C_{soil}} = \frac{f_1\left[(B_{iv}+f)(10^{-3}\frac{a}{d\times c}70M^{0.75}) + \left(\frac{PT}{IT}\times 0.481M^{0.76}\right)\right]\left[1-e^{-\left((k_{rad}+k_{bio})(365.25)(1.02M^{0.3})\right)}\right]}{(k_{rad}+k_{bio})M} \quad \text{(Eq.47)}$$

$$LP_{water,terrestrial\ animal,i} = \frac{C_{animal,water}}{C_{water}} = \left[\frac{f_1 0.099M^{0.9}\left[1-e^{-\left((k_{rad}+k_{bio})(365.25)(1.02M^{0.3})\right)}\right]}{(k_{rad}+k_{bio})M}\right] \quad \text{(Eq.48)}$$

A Monte Carlo uncertainty analysis was conducted on each equation, with parameters varied over their known ranges. The range of values assigned each variable used in the uncertainty analysis was taken from the technical literature. These values, and their accompanying distributions, are shown in Table D-1

Ten thousand simulations were run for each equation and nuclide. Results were generated for twenty-three radionuclides, and the 95th percentile value for each was compared with data (where it existed) from the technical literature. The results are tabulated in Table G-5-G-8.

Based on analysis, the model predictions tracked reasonably well with the values observed in the scientific literature. The B_{iv} value selected (from a choice of available empirical data, product approach, and uncertainty analysis on the kinetic/allometric method) for use as the default Biv for use in general screening is highlighted in each table. The preference was to use empirical data where available and of good quality, as was the case for many terrestrial animal:soil values. However, as previously discussed, data for riparian and terrestrial animals was generally limited. In most instances, the kinetic/allometric result was chosen over values taken from the technical literature. Generally, the kinetic/allometric calculation resulted in a higher estimate of the B_{iv}. This is expected, owing to the generally conservative nature of parameter values used in the kinetic/allometric method.

Table G-4 Parameters Used in Kinetic/Allometric Method Uncertainty Analysis for Riparian and Terrestrial Animals

Equation and Parameter	Mean	Range (and distribution)[a]
Riparian animal: sediment and water lumped parameter assessment		
$R_{ra} = \frac{a}{dc} 70M^{b}$ R_{ra} = food intake rate in g/day		
$R_{rad,sediment} = \frac{a}{dc} 70M^{b} f$ $R_{ra,sediment}$ = sediment intake rate in g/day;		
a, ratio of active to maintenance metabolic rate (see equation 25)	2	0.5-3.0 (normal)
d, fraction of energy ingested that is assimilated (see equation 25)	0.65	0.3-0.9 (normal)
c, caloric value of food intake (see equation 25)	5	4 – 9 (normal)
b, exponent in allometric relationship detailing consumption as a function of body mass (see equation 25)	0.75	0.68-0.8 (normal)
f, fraction of diet that is soil (see equation 27)	0.1	0.01-0.55 (normal)
M, body mass in kilograms	1 kg	0.02 – 6000 (log normal)
$T_{ls} = 1.02\ M^{0.30}$ T_{ls} = maximum lifespan of the organism, years		
exponent (0.30), allometric relationship detailing lifespan as a function of body mass (see equation 32)	0.3	0.25 – 0.33 (normal)
constant (1.02), allometric relationship, detailing lifespan as a function of body mass (equation 32)	1.02	0.9 – 2.00 (normal)
$\lambda_{bio,i} = \frac{0.69315}{aM^{b}}$ $\lambda_{bio,i}$ = biological decay constant of material in organism, per day		
b, exponent, allometric relationship detailing biological half- time as a function of body mass (equation 31)	Varies by nuclide 0.24 for Cs	0.15 – 0.3 (normal)
a, constant, allometric relationship, detailing biological half- time as a function of body mass (equation 31)	Varies by nuclide 3.5 for Cs	2 - 5 (normal)
$I_w = 0.099\ M^{0.9}$ I_w =water intake, L/d		
constant, allometric relationship, detailing water intake rate I (l/d) as a function of body mass, where $I = 0.099W^{0.90}_{w}$ $_{w}$	0.099	0.07 - 0.13 (normal)
exponent, allometric relationship, detailing water intake rate as a function of body mass where $I = 0.099W^{0.90}$	0.9	0.63 - 1.17 (normal)
Terrestrial animal: soil and water lumped parameter assessment		
$R_{inhale,i} = 0.481\ M^{0.76}$ $r_{iinhale,\ i}$ = inhalation rate of soil		
exponent (0.76), allometric relationship detailing inhalation rate as a function of body mass (equation 28)	0.76	0.64-0.86 (normal)
X Dust loading (equation 28)	0.001	0.0001 – 0.01 (log normal)
constant (0.481), allometric relationship, detailing inhalation rate as a function of body mass (equation 28)	0.481	0.001 – 0.66 (normal)
$r_{ta,soil} = r_{ra,sed}$ $r_{ta} = r_{ra}$ all other factors have been defined.	Varies	Varies

[a]The distributions used in this assessment were created by examination of the range of values of the input variables and, where possible, by testing using the forecasting and risk analysis software, Crystal Ball®.

Table G-5 A Comparison of B_{iv}s Determined by Uncertainty Analysis on the Kinetic/Allometric Method, Product Approach, and Empirical Data (Literature Values): Riparian Animal to Sediment

Element	Calculated as Product of Concentration Ratios (CR)	Animal to Sediment Value Kinetic/Allometric Method		Empirically Measured B_{iv}
		50th percentile	95th percentile[a]	
Am	5.4E-05	3.6E-04	3.1E-03	1.4E-04
Ce	3.9E-02	1.5E-04	4.8E-04	
Cs	4.4E-01	1.2E-01	2.7E-01	
Co	4.0E-02	4.3E-03	1.0E-02	4.5E-01
Eu		5.9E-04	3.9E-03	
H	6.0E-01	1.2E-01	4.3E-01	
I	1.1E+00	1.3E-01	3.2E-01	
Pu	3.0E-06	3.6E-04	3.2E-03	5.0E-05
Ra	3.0E-02	1.4E-02	3.0E-02	
Sb	1.8E-03	1.8E-04	4.1E-04	
Sr	3.6E-01	1.1E+00	2.0E+00	
Tc	1.2E-02	1.7E-02	4.6E-02	
Th	2.4E-07	2.9E-04	1.9E-03	
U	1.0E-01	1.6E-03	3.8E-03	1.0E-03
Zn		7.2E-01	1.8E+00	
Zr	6.4E-03	1.1E-03	3.0E-03	

[a]The shaded cell indicates this value is used as the default lumped parameter in the general screening phase of the graded approach. Blank cells indicate data was unavailable.

Table G-6 A Comparison of $B_{iv}s$ Determined by Uncertainty Analysis on the Kinetic/Allometric Method, Product Approach, and Empirical Data (Literature Values): Riparian Animal to Water

Element	Calculated as Product of Concentration Ratios (CR)	Animal to Water Value Kinetic/Allometric Method		Empirically Measured B_{iv}
		50th Percentile	95th Percentile[a]	
Am	2.2E-02	1.4E+00	1.2E+01	
Ce	3.9E+01	1.4E+01	3.5E+01	
Cs	1.5E+05	2.6E+04	4.7E+04	2.5E+05
Co	1.0E+03	8.6E+01	1.6E+02	9.0E+02[b]
Eu		3.6E+00	2.0E+01	
H	1.2E-01	2.4E-01	8.1E-01	
I	1.1E+02	2.9E+02	5.7E+02	2.1E+02
Pu	1.5E-02	3.6E+00	3.0E+01	6.7E+00
Ra	3.2E+01	4.6E+02	8.0E+02	
Sb	1.8E+00	1.7E-01	3.1E-01	
Sr	1.4E+03	3.5E+03	6.2E+03	9.0E+03[b]
Tc	1.0E+01	1.4E+01	2.9E+01	
Th	2.4E-01	2.4E-01	1.5E+00	
U	5.1E+00	1.6E+01	3.0E+01	
Zn		1.2E+05	2.5E+05	
Zr	5.0E+02	1.8E+01	4.0E+01	

[a] The shaded cell indicates this value is used as the default lumped parameter in the general screening phase of the graded approach. Blank cells indicate data was unavailable.

[b] These values are not directly measured lumped parameters but were derived from other parameters.

Table G-7 A Comparison of B_{iv}s Determined by Uncertainty Analysis on the Kinetic/Allometric Method, Product Approach, and Empirical Data (Literature Values): Terrestrial Animal to Soil

Element	Calculated as Product of Concentration Ratios (CR)	Animal to Soil Value Kinetic/Allometric Method		Empirically Measured B_{iv}
		50th Percentile	95th Percentile[a]	
Am	4.1E-07	3.7E-04	4.0E-03	1.0E-04
Ce	1.7E-04	2.0E-04	5.5E-04	5.5E-03
Cs	6.7E+01	1.1E+01	2.0E+01	1.0E+02
Co	1.1E-01	1.0E-02	3.0E-02	8.0E-02
Eu		7.9E-04	4.6E-03	
H	6.6E-01	1.3E+00	4.3E+00[b]	
I	2.0E-01	6.8E-01	1.4E+00	3.0E+00
Pu	2.2E-07	4.1E-04	3.0E-03	3.0E-03
Ra	1.1E-03	3.0E-02	6.0E-02	2.1E-01
Sb	1.8E-04	1.9E-04	4.3E-04	
Sr	1.7E+01	4.2E+01	7.6E+01	6.1E-01
Tc	1.0E+00	1.4E+00	3.1E+00	
Th	3.1E-06	2.9E-04	1.6E-03	1.0E-03
U	1.9E-05	1.7E-03	4.1E-03	1.0E-03
Zn		3.3E+00	7.0E+00	1.0E-02
Zr	9.1E-03	1.4E-03	3.5E-03	

[a] The shaded cell indicates this value is used as the default B_{iv} in the general screening phase of the graded approach. Blank cells indicate data was unavailable.

[b] The H B_{iv} value was set at a default of 1.0 for calculation of the generic BCG.

Table G-8 A Comparison of B_{iv}s Determined by Uncertainty Analysis on the Kinetic/Allometric Method, Product Approach, and Empirical Data (Literature Values): Terrestrial Animal to Water

Element	Calculated as Product of Concentration Ratios (CR)	Animal to Water Value Kinetic/Allometric Method		Empirically Measured B_{iv}
		50th Percentile	95th Percentile[a]	
Am		5.6E-03	8.6E-02	
Ce		2.4E-03	8.2E-03	
Cs	1.1E+01	2.0E+00	3.4E+00	
Co	7.9E-01	7.5E-02	1.3E-01	
Eu		9.2E-03	9.7E-02	
H		1.9E+00	1.7E+01[b]	
I		2.2E+00	3.4E+00	5.4E+00
Pu	1.5E-05	5.6E-03	9.3E-02	
Ra	1.8E+01	2.4E-01	4.0E-01	
Sb		3.0E-03	5.2E-03	
Sr	6.4E+02	1.8E+01	3.1E+01	
Tc		2.7E-01	8.4E-01	
Th		4.6E-03	4.5E-02	
U	1.9E-04	3.0E-02	5.0E-02	1.0E-03
Zn		3.7E+00	2.0E+01	1.0E-02
Zr	9.1E-03	1.8E-02	3.1E-02	

[a]The shaded cell indicates this value is used as the default B_{iv} in the general screening phase of the graded approach. Blank cells indicate data was unavailable.

[b]The H B_{iv} was set at a default of 1.0 for calculation of the generic BCG.

G.8. Coefficients Used in the Kinetic/Allometric Method

The following tables list the values of kinetic/allometric coefficients used in the derivation of lumped parameters using the kinetic/allometric method.

Table G-9 Source of Default f_1 Values Used for Riparian and Terrestrial Animals

Radionuclide	f_1, (unitless)	Comment
^{241}Am	1.0E-03	ICRP 30 part 4 values for human and animal studies.
^{140}Ba	1.0E-01	ICRP 30 part 2 values for human and animal studies.
^{14}C	6.9E+03	ICRP 30 part 3 values for humans and animal studies.
^{141}Ce	3.0E-04	ICRP 30 part 1 values for human and animal studies.
^{144}Ce	3.0E-04	ICRP 30 part 1 values for human and animal studies.
^{252}Cf	1.0E-03	ICRP 30 part 4 values for human and animal studies.
^{36}Cl	1.0E+00	ICRP 30 part 2 values for human and animal studies.
^{242}Cm	1.0E-03	ICRP 30 part 4 values for human and animal studies.
^{244}Cm	1.0E-03	ICRP 30 part 4 values for human and animal studies.
^{134}Cs	1.0E+00	ICRP 30 part 1 values for human and animal studies.
^{135}Cs	1.0E+00	ICRP 30 part 1 values for human and animal studies.
^{137}Cs	1.0E+00	ICRP 30 part 1 values for human and animal studies.
^{58}Co	5.0E-02	ICRP 30 part 1 values for human and animal studies.
^{60}Co	5.0E-02	ICRP 30 part 1 values for human and animal studies.
^{51}Cr	1.0E-01	ICRP 30 part 2 values for human and animal studies.
^{152}Eu	1.0E-03	ICRP 30 Part 3 values for human and animal studies.
^{154}Eu	1.0E-03	ICRP 30 Part 3 values for human and animal studies.
^{155}Eu	1.0E-03	ICRP 30 Part 3 values for human and animal studies.
^{3}H	1.0E+00	ICRP 30 part 1 values for human and animal studies.
^{129}I	1.0E+00	ICRP 30 Part 1 values for human and animal studies.
^{131}I	1.0E+00	ICRP 30 Part 1 values for human and animal studies.
^{192}Ir	1.0E-02	ICRP 30 part 1 values for human and animal studies.
^{40}K	1.0E+00	ICRP 30 part 1 values for human and animal studies.
^{237}Np	1.0E-03	ICRP 30 part 4 values for human and animal studies.
^{231}Pa	1.0E-03	ICRP 30 part 3 values for human and animal studies.
^{210}Pb	2.0E-01	ICRP 30 part 2 values for human and animal studies.
^{210}Po	1.0E-01	ICRP 30 part 1 values for human and animal studies.
^{239}Pu	1.0E-03	ICRP 30 part 4 values for human and animal studies.
^{226}Ra	2.0E-01	ICRP 30 part 1 values for human and animal studies.
^{228}Ra	2.0E-01	ICRP 30 part 1 values for human and animal studies.
^{125}Sb	1.0E-02	ICRP 30 part 3 values for human and animal studies.
^{75}Se	8.0E-01	ICRP 30 part 3 values for human and animal studies.
^{90}Sr	3.0E-01	ICRP 30 part 1 values for human and animal studies.
^{99}Tc	8.0E-01	ICRP 30 part 2 values for human and animal studies.
^{228}Th	2.0E-04	ICRP 30 part 1 values for human and animal studies.

Radionuclide	f_1, (unitless)	Comment
^{229}Th	2.0E-04	ICRP 30 part 1 values for human and animal studies.
^{230}Th	2.0E-04	ICRP 30 part 1 values for human and animal studies.
^{232}Th-	2.0E-04	ICRP 30 part 1 values for human and animal studies.
^{234}Th	2.0E-04	ICRP 30 part 1 values for human and animal studies.
^{233}U	5.0E-02	ICRP 30 part 1 values for human and animal studies.
^{234}U	5.0E-02	ICRP 30 part 1 values for human and animal studies.
^{235}U	5.0E-02	ICRP 30 part 1 values for human and animal studies.
^{238}U	5.0E-02	ICRP 30 part 1 values for human and animal studies.
^{65}Zn	5.0E-01	ICRP 30 part 2 values for human and animal studies.
^{95}Zr	2.0E-03	ICRP 30 part 1 values for human and animal studies.

Table G-10 Source of Data Used in Estimating Biological Half-Times for Riparian and Terrestrial Animals

Radionuclide	α (constant)	β (exponent)	Reference
^{241}Am	0.8	0.81	ICRP 30 Part 4
^{140}Ba	107	0.26	RESRAD BIOTA
^{14}C	2	0.25	RESRAD BIOTA
^{141}Ce	1.4	0.8	ICRP 30 Part1
^{144}Ce	1.4	0.8	ICRP 30 Part 1
^{252}Cf	0.8	0.81	RESRAD BIOTA
^{36}Cl	3	0.013	RESRAD BIOTA
^{242}Cm	0.8	0.81	RESRAD BIOTA
^{244}Cm	0.8	0.81	RESRAD BIOTA
^{134}Cs	3.5	0.24	RESRAD BIOTA
^{135}Cs	3.5	0.24	Whicker & Schultz
^{137}Cs	3.5	0.24	Whicker & Schultz
^{58}Co	2.6	0.24	RESRAD BIOTA
^{60}Co	2.6	0.24	Whicker & Schultz
^{51}Cr	2.6	0.24	RESRAD BIOTA
^{152}Eu	1.4	0.8	RESRAD BIOTA
^{154}Eu	1.4	0.8	ICRP 30 Part 3
^{155}Eu	1.4	0.8	ICRP 30 Part 3
^{3}H	0.82	0.55	Whicker & Schultz
^{129}I	6.8	0.13	Whicker & Schultz
^{131}I	6.8	0.13	Whicker & Schultz
^{192}Ir	2	0.24	RESRAD BIOTA
^{40}K	3	0.13	RESRAD BIOTA
^{237}Np	0.8	0.28	RESRAD BIOTA
^{231}Pa	0.8	1.28	RESRAD BIOTA
^{210}Pb	0.5	0.25	RESRAD BIOTA
^{210}Po	0.5	0.25	RESRAD BIOTA
^{239}Pu	0.8	0.81	ICRP 30 Part 4
^{226}Ra	2	0.25	Estimated by KAH
^{228}Ra	2	0.25	Estimated by KAH
^{125}Sb	0.5	0.25	ICRP 30 Part 3
^{75}Se	0.5	0.25	RESRAD BIOTA
^{90}Sr	107	0.26	Whicker & Schultz

Radionuclide	α (constant)	β (exponent)	Reference
^{99}Tc	0.3	0.4	ICRP 30 Part 2
^{228}Th	3.3	0.81	RESRAD BIOTA
^{229}Th	3.3	0.81	RESRAD BIOTA
^{230}Th	3.3	0.81	RESRAD BIOTA
^{232}Th	3.3	0.81	ICRP 30 Part 1
^{234}Th	3.3	0.81	RESRAD BIOTA
^{233}U	0.8	0.28	ICRP 30 Part 1
^{234}U	0.8	0.28	ICRP 30 Part 1
^{235}U	0.8	0.28	ICRP 30 Part 1
^{238}U	0.8	0.28	ICRP 30 Part 1
^{65}Zn	100	0.25	ICRP 30 Part 2
^{95}Zr	100	0.25	ICRP 30 Part 1

Table G-11 Factors Used in Assessing the Relative Contribution to Internal Dose from Animal Inhalation versus Ingestion

Radionuclide	PT/IT[a] (Correction Factor)
^{241}Am	250
^{140}Ba	12
^{14}C	1
^{141}Ce	13
^{144}Ce	16
^{252}Cf	250
^{36}Cl	1
^{242}Cm	16
^{244}Cm	17
^{134}Cs	14
^{135}Cs	0.8
^{137}Cs	0.8
^{58}Co	18
^{60}Co	7
^{51}Cr	11
^{152}Eu	19
^{154}Eu	30
^{155}Eu	30
^{3}H	1
^{129}I	0.7
^{131}I	0.7
^{192}Ir	85
^{40}K	1
^{237}Np	4000
^{231}Pa	1000
^{210}Pb	20
^{210}Po	4
^{239}Pu	4000
^{226}Ra	3
^{228}Ra	3
^{125}Sb	3.5
^{75}Se	15

Radionuclide	PT/IT[a] (Correction Factor)
^{90}Sr	200
^{99}Tc	5
^{228}Th	750
^{229}Th	750
^{230}Th	750
^{232}Th	750
^{234}Th	750
^{233}U	7000
^{234}U	7000
^{235}U	3500
^{238}U	4000
^{65}Zn	1
^{95}Zr	10

[a] Based on ICRP 30, parts 1-3 and Zach's (1985) analysis of the relative contribution of inhalation to an equivalent amount of soil ingestion dose for animals. RESRAD BIOTA Calculations.

Table G-12 Allometric Equations and Parameter Values Used in Estimating Intake of Riparian Animal Organisms

Parameter	Equation	Descriptions	Value(s)	Reference
W		Body mass(g)	8800	default for raccoon or river
r	$r = \frac{a}{dc} 70\, M^{0.75}$	Food intake rate (g/d)	325.1377223	W&S, Vol. II, p. 43, equation 78
		a: ratio of active to basal metabolic rate	2	
		70: constant	70	
		d: fraction of energy ingested that is assimilated or	0.44	
		c: caloric value of food, kcal/g	5	
		M: body mass in kg	8.8	
		0.75: exponent in calculation	0.75	
$r_{sediment}$	$r_{sediment} = 0.1\, r$	Sediment Intake Rate (g/d)	32.51377223	EPA Wildlife Exposure Factor Handbook, Vol. 1, p. 4-22
		r: food intake rate, g/d	325.1377223	
		0.1: fraction of sediment in diet, expressed as % of food diet, dry	0.1	
T_{Is}	$T_{Is\,max}\ 1.02M^{0.30}$	Maximum Lifespan	1.958	Calder, p. 316, Table 11-5
		1.02: constant in equation	1.02	
		See above equation, M: body mass in kg	8.8	
		0.30: exponent in calculation	0.30	
R_b	$R_b = 0.481M^{0.76}$	Inhalation rate (m^3/d)	2.511608286	Pedley, p. 15, Table V., adjusted to provide units of m^3/d
		0.481: constant in calculation to give m^3/d	0.481	
		See above equation, M: body mass in kg	8.8	
		0.76: exponent in equation	0.76	
$r_{inhalation}$	$r_{inhalation} = xR_b$	Sediment inhalation rate (g/d)	0.000251161	derived
		x: airborne dust loading, g/m^3	0.0001	
		R_b: inhalation rate (see above)	2.511608286	
I_w	$I_w = 0.099\, M^{0.90}$	Water consumption rate (L/d)	0.700921852	EPA Wildlife Exposure Factor Handbook, Vol. 1, p. 3-10, equation3-17
		0.099: constant in equation	0.099	
		See above equation, M: body mass in kg	8.8	
		0.9: exponent in calculation	0.9	

Table G-13 Allometric Equations and Parameter Values used in Estimating Intake of Terrestrial Animal Organisms

Parameter	Equation	Descriptions	Value(s)	Reference
W		Body mass (g)	22	default for deer mouse
r	$r = \frac{a}{dc}\ 70\ M^{0.75}$	Food intake rate (g/d)	3.635150245	W&S, Vol. II, p. 43, equation78
		a: ratio of active to basal metabolic rate	2	
		70: constant	70	
		d: fraction of energy ingested that is assimilated or	0.44	
		c: caloric value of food, kcal/g	5	
		M: body mass in kg (=W*0.001)	0.022	
		0.75: exponent in calculation	0.75	
r_{soil}	$r_{soil} = 0.1\ r$	Soil Intake Rate (g/d)	0.363515025	EPA Wildlife Exposure Factor Handbook, Vol. 1, p. 4-22
		r: food intake rate, g/d	3.635150245	
		0.1: fraction of sediment in diet, expressed as % of	0.1	
T_{Is}	$T_{Is,max} = 1.02M^{0.3}$	Maximum Lifespan	.32	Calder, p. 316, Table 11-5
		1.02: constant in equation	1.02	
		See above equation, M: body mass in kg	0.022	
		0.30: exponent in calculation	0.30	
R_b	$R_b = 0.481M^{0.76}$	Inhalation rate (m^3/d)	0.026447603	Pedley, p. 15, Table V., adjusted to provide units of m^3/d
		0.481: constant in calculation to give m^3/d	0.481	
		See above equation, M: body mass in kg	0.022	
		0.76: exponent in equation	0.76	
$r_{inhalation}$	$r_{inhalation} = xR_b$	Soil inhalation rate (g/d)	2.64476E-06	derived
		x: airborne dust loading, g/m^3	0.0001	
		R_b: inhalation rate (see above)	0.026447603	
I_w	$I_w = 0.099\ M^{0.90}$	Water consumption rate (L/d)	0.003190183	EPA Wildlife Exposure Factor Handbook, Vol. 1, p. 3-10, equation3-17
		0.099: constant in equation	0.099	
		See above equation, M: body mass in kg	0.022	
		0.9: exponent in calculation	0.9	

Appendix H: Exposure Parameters Considered in the Graded Approach

H.1. Introduction

For non-human biota, the exposure conditions may vary significantly from organism to organism and from one ecosystem to another. Factors such as exposure geometry and route of exposure should be considered when evaluating doses to biota. The flexibility to address such differences is incorporated into the graded approach, and RESRAD-BIOTA has the capacity to be equally flexible. This Appendix provides a brief summary of the exposure conditions for RESRAD-BIOTA default animals and plants and offers options for adapting these defaults. Additionally, special considerations for the air pathway dose and exposure to radiation fields are discussed.

H.2. Default Parameters

Internal and external sources of dose (and their contributing exposure pathways) are incorporated in the derivation of the graded approach methodology. Sufficient prudence has been exercised in the development of each of the assumptions and default parameter values to ensure that the resulting BCGs are appropriately conservative. In the event that an individual default parameter value is subsequently found to be an upper-end value but not the "most limiting" value for a unique site-specific exposure scenario, the other prudent assumptions and default parameter values will ensure that the BCGs (and resultant doses to biota) should continue to carry the appropriate degree of conservatism for screening purposes. Key assumptions used in deriving the BCGs that highlight the conservatism applied in the general screening phase are presented in Table H-1. Exposure pathways for each of the reference organism types considered in the graded approach are presented in this Appendices.

Table H-1 Assumptions regarding sources, receptors, and routes of exposure applied in the general screening phase of the graded approach

Dose Rate Criteria	• BCGs were derived for aquatic animal, riparian animal, terrestrial plant, and terrestrial animal reference organisms. The dose rate criteria used to derive the BCGs for each organism type are 1 rad/d, 0.1 rad/d, 1 rad/d, and 0.1 rad/d respectively. • While existing effects data support the application of these dose rate criteria to representative individuals within populations of plants and animals, the assumptions and parameters applied in the derivation of the BCGs are based on a maximally exposed individual, representing a conservative approach for screening purposes.
External Sources of Radiation Exposure	• Estimates of the contribution to dose from external radioactive material were made assuming that all of the ionizing radiation was deposited in the organism (i.e., no pass-through and no self-shielding). This is conservative, and is tantamount to assuming that the radiosensitive tissues of concern (the reproductive tissues) lie on the surface of a very small organism. • For external exposure to contaminated soil, the source was presumed to be infinite in extent. In the case of external exposure to contaminated sediment and water, the source was presumed to be semi-infinite in extent. • The source medium to which the organisms are continuously exposed is assumed to contain uniform concentrations of radionuclides. • These assumptions provide for appropriately conservative estimates of energy deposition in the organism from external sources of radiation exposure.

Internal Sources of Radiation Exposure	• Estimates of the contribution to dose from internal radioactive material were conservatively made assuming that all of the decay energy is retained in the tissue of the organism, (i.e., 100% absorption). • Progeny of radionuclides and their decay chains are also included. This provides an over-estimate of internal exposure, as the lifetime of many of the biota of interest is generally short compared to the time for the build-up of progeny for certain radionuclides. • The radionuclides are presumed to be homogeneously distributed in the tissues of the receptor organism. This is unlikely to under-estimate the actual dose to the tissues of concern (i.e., reproductive organs). • A radiation weighting factor of 20 for alpha particles is used in calculating the BCGs for all organism types. This is conservative, especially if non- stochastic effects are most important in determining harm to biota. The true value may be a factor of 3 to 4 lower.

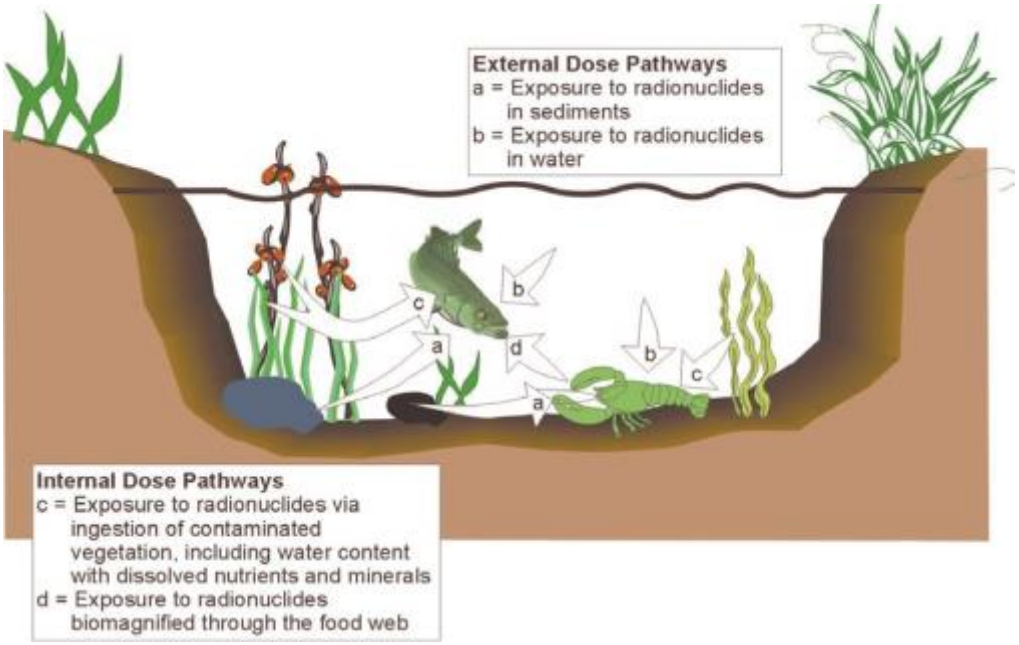


Figure H-1 Exposure Pathways for Aquatic Animals

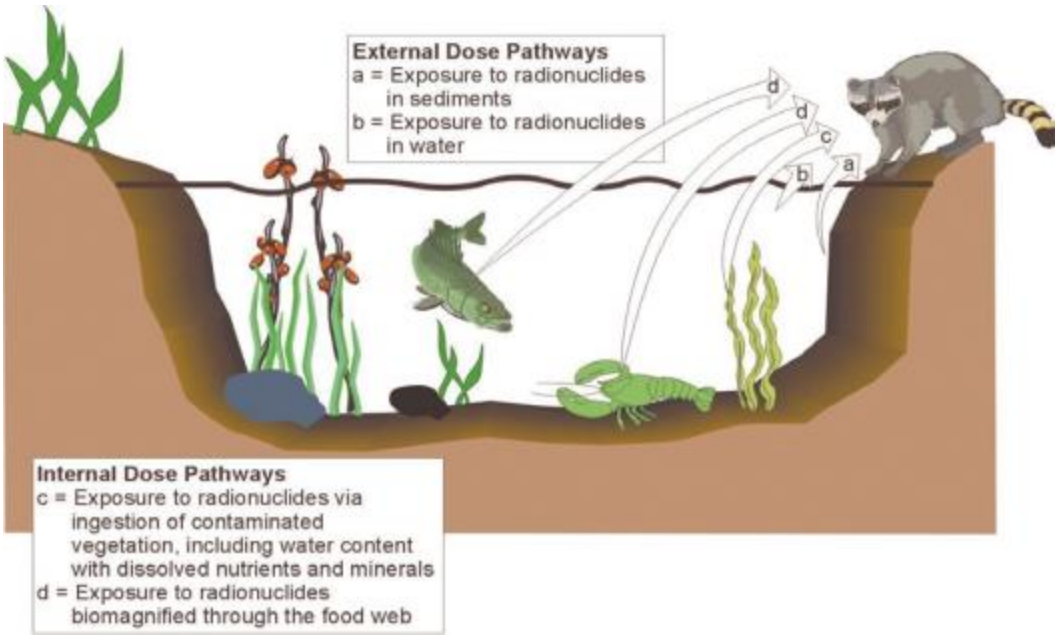


Figure H-2 Exposure Pathways for Riparian Animals

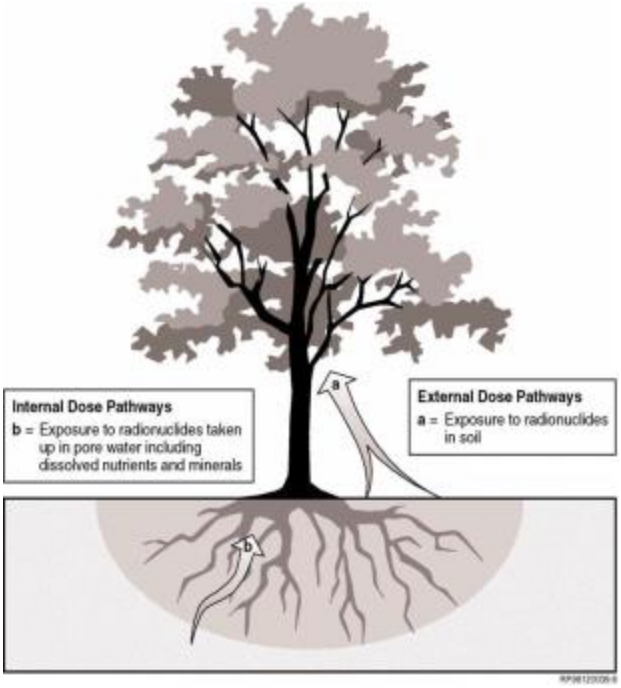


Figure H-3 Exposure Pathways for Terrestrial Plants

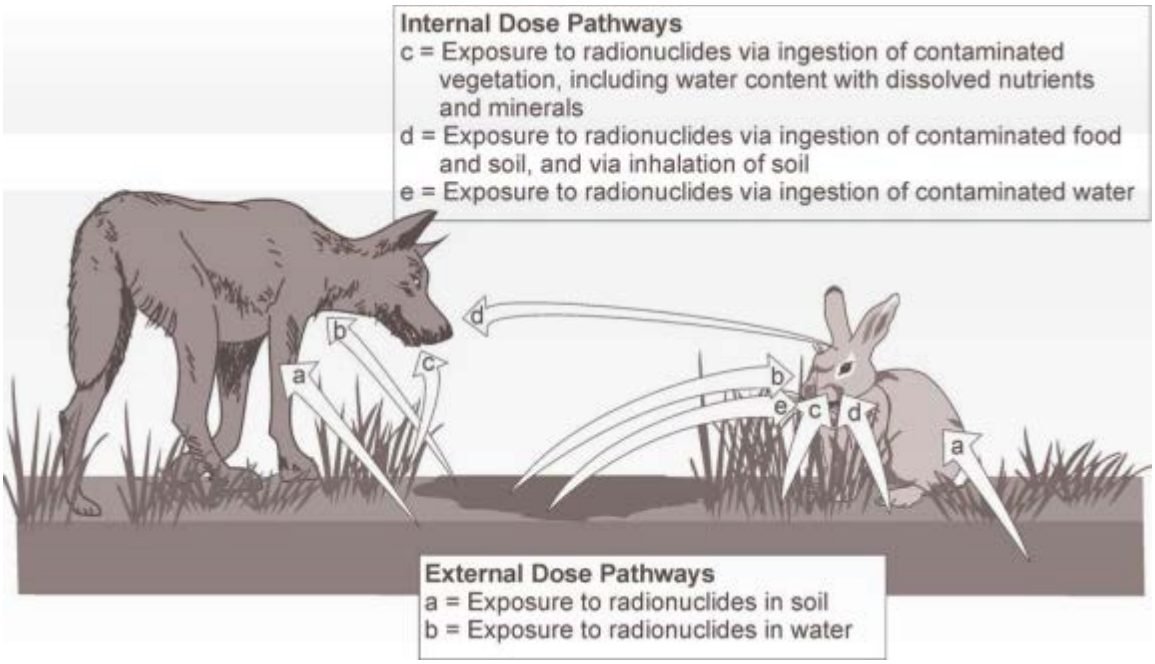


Figure H-4 Exposure Pathways for Terrestrial Animals

H.3. Adjustments to Defaults using the Graded Approach

The RESRAD-BIOTA default for organism geometry is a paradoxical condition intended to conservatively incorporate the full value of dose from both internal and external radiation sources. Similarly, the external exposure geometry factors have the potential to conservatively overestimate dose by assuming that the organism is irradiated by multiple media 100% of the time. For example, in RESRAD-BIOTA, the default terrestrial animal is irradiated in 4π geometry by the soil and at the same time is irradiated in 2π geometry by the water.

Any new organism defined by the user will be adjustable with respect to these geometry parameters. Selection of the organism geometry removes the conservative assumptions described in Table H-1 and Table H-2, resulting in an organism which is treated as the same size for both internal and external exposures. Table H-2 provides suggested geometries for reference animals discussed in ICRP Publication 108 (2008b), and RESRAD-BIOTA offers size selections for newly defined organisms with alternative references. The external exposure geometry factors in RESRAD-BIOTA may only be adjusted for a *new* organism. After the new organism has been defined, the external factors may be edited and ingestion of each type of media can be selected or deselected.

Table H-2 Reference organism geometries

Reference	Mass [kg]	Dimensions [cm]		
Deer	2.45E+02	130	60	60
Duck	1.26E+00	30	10	8
Frog	3.14E-02	8	3	2.5
Trout	1.26E+00	50	8	6
Flatfish	1.31E+00	40	25	2.5
Bee	5.89E-04	2	0.75	0.75
Crab	7.54E-01	20	12	6
Earthworm	5.24E-03	10	1	1
Pine Tree	4.71E+02	1000	30	30
Wild Grass	2.62E-03	5	1	1
Brown Seaweed	6.52E-01	50	50	0.5

H.4. Considerations for Aquatic Plants

There are no DOE dose rate criteria or internationally-recommended dose limits established for aquatic plants, primarily due to lack of data on radiation effects to these organisms. Indirect means can be used to provide a general indication of the effects on aquatic plants relative to effects on other organisms. Consider the following:

- Few investigations have been conducted on the impact of ionizing radiation on aquatic plants (Woodhead 1998). There is a paucity of data in the literature regarding the radiosensitivity of aquatic plants, even though site-specific $B_{iv}s$ (i.e., bioaccumulation factors) for accumulation of several radionuclides are available (Whicker et al. 1990, Cummins 1994, and Whicker et al. 1999).
- In general, one would expect higher plants to be less radiosensitive than the most sensitive birds, fishes and mammals (Whicker and Schultz 1982, and Whicker 1997). For these reasons, an evaluation that demonstrates protection of aquatic and riparian animals would provide an indication that aquatic plants are also likely protected.
- Alternatively, the aquatic animal spreadsheet can be used to calculate BCGs for aquatic plants. This is done by replacing the default $B_{iv}s$ in the aquatic animal spreadsheet within the RAD-BCG Calculator with appropriate bioaccumulation factors ($B_{iv}s$) for aquatic plant species. The remaining default parameters and assumptions are unchanged. Calculating BCGs for aquatic plants in this manner, if needed, should be done in consultation with EH-412 and the BDAC Core Team.

H.5. Air Pathway Dose

H.5.1. Rationale for the Active Air Pathway as a Minor Source of Exposure

The active air (i.e., continuous air emission) release pathway was not included in the derivation of the BCGs because biota inhalation and immersion in air were estimated to be relatively insignificant contributors to biota dose. Controls established to protect the public from air emissions also protect biota.

H.5.2. Behavior of Radionuclides Discharged to the Atmosphere

Unlike releases of radionuclides to water or soil, atmospheric discharges almost always rapidly disperse. For example, along the centerline of a Gaussian plume resulting from a ground-level point source, and assuming neutral stability (Pasquill-Gifford Stability Category D) to represent an average plume, the concentration at a distance of 100 m is reduced by a factor of about 500 compared with the concentration close to the source (DOE 1984). Reductions in concentrations are much greater at locations away from the plume centerline or at greater distances from a source. The rapid dispersal of airborne radionuclides is an important consideration in evaluating doses to biota.

H.5.3. Exposure Pathways Resulting from Atmospheric Releases

Within the context of the graded approach methodology, in considering radiation doses to biota resulting from atmospheric releases, there are three exposure pathways of concern. These are:

- External exposure of terrestrial plants and animals to airborne radionuclides (cloudshine);
- Inhalation of airborne radionuclides by terrestrial animals; and
- Absorption of airborne radionuclides by terrestrial plants.

All other potential exposure pathways are a consequence of deposition of airborne radionuclides onto the land surface or surface waters (including, for example, inhalation of resuspended radionuclides by terrestrial animals). It is important to note that these other pathways are already taken into account in the graded approach methodology.

H.5.4. Compliance with Human Radiation Dose Limits at DOE Sites Relative to Biota Dose CriteriaCriteria: A Perspective

First, airborne emissions of radionuclides at DOE sites are limited to very small quantities to protect human health. Current DOE (and EPA and NRC) policies restrict radioactive air emissions so that radiation exposures of the general public will be less than 10 mrem/y (0.1 mSv/y). Non-radiation workers at DOE sites and members of the public visiting a DOE site are protected to 100 mrem/y (1mSv/y) from all sources (USDOE 1984). These policies are significant in the original decision to not include the active air pathway in the graded approach methodology. Second, unlike exposures to radionuclides in soil, water, and sediment, the exposure pathways from active air releases are the same for biota as for humans. Terrestrial biota are exposed to approximately the same airborne concentrations and for approximately the same lengths of time. Several points are highlighted below which support these exposure-dose relationships:

H.5.4.1. Terrestrial animals

- Terrestrial animals typically receive external and internal (i.e., inhaled) doses of ionizing radiation from air at rates similar to those experienced by humans. No major differences have been documented either in external doses due to submersion in air, or in internal doses due to intake and biological retention rates as a result of inhalation. Thus, if a DOE facility or site is in compliance with the dose limits for humans given above, total doses to terrestrial animals should be far below the much higher recommended limit of 0.1 rad/d.

- Inhalation doses were calculated for terrestrial animals over a range of body mass and metabolic rates (e.g., a marsh wren; a heron; a large elk) at allowable air concentrations at DOE sites. It was found that the air concentrations to which populations of these terrestrial animals would need to be exposed in order to reach the dose limit for terrestrial animals at DOE sites would need to be two to three orders of magnitude greater than the allowable air concentrations for humans. In general, internal dose to terrestrial animals is largely a function of ingestion rather than inhalation. Doses due to inhalation of airborne activity were taken into account in the graded approach.
- The BCGs derived in the graded approach use appropriately measured B_{iv}s (e.g., animal:food or animal:soil values) which implicitly include both ingestion and inhalation pathways to an organism. In cases where B_{iv} values were limited or unavailable, allometric relationships, to include those for inhalation, were used to derive the BCGs for riparian and terrestrial organism types. In cases where a user believes that inhalation could be a relatively important contributor to internal dose, the inhalation parameter can be appropriately modified in the analysis phase (i.e., site-specific analysis component) of the graded approach.

H.5.4.2. Terrestrial plants

- Terrestrial plants also typically receive external doses of ionizing radiation from air at rates similar to those experienced by humans. Hence, the above rationale for external exposure of terrestrial animals applies equally to external exposure of terrestrial plants, especially given the higher recommended limit of 1.0 rad/d for plants.
- In regard to absorption of airborne radionuclides by plants, there is no known mechanism for significant absorption of radionuclides in particulate form. Some radionuclides in gaseous form are absorbed, especially ^{3}H as tritiated water and ^{14}C as carbon dioxide.
- In both cases, however, the specific activity in the water and carbon of plants would approach those in the atmosphere, so there would be no magnification of the dose compared with that in humans. Moreover, for terrestrial plants, soils serve as the ultimate integrator of radionuclides originating and transported via the air pathway. Therefore, it is highly unlikely that populations of terrestrial plants could receive a significant dose due to absorption of airborne radionuclides. The much lower maximum doses from airborne emissions that are specified for humans would provide an adequate level of protection for terrestrial plants.

H.5.5. Derivation of Biota Concentration Guides for Active Air Releases

Although active air releases are unlikely to result in significant doses to terrestrial biota, the BDAC derived BCGs for air to further evaluate the potential contribution of the active air pathway to biota dose. Active air BCGs were derived using ecologically-based modeling approaches consistent with those used for the other media types in this technical standard. Inhalation and external exposure pathways were included. Allometric equations were used to assess exposure via inhalation, and do not consider other pathways of exposure (i.e., consumption of foodstuffs contaminated by deposition of radionuclides) – as these pathways are addressed and accounted for in the derivation of the water and soil BCGs. The magnitude of the active air BCGs were then compared relative to other media BCGs, and with derived concentration guides (DCG (air)) given in DOE O 458.1 and DOE-STD-1196, *Derived*

Concentration Technical Standard, for members of the general public. The human DCG values were decreased by a factor of 10 to represent the 10 mrem/y dose limit to the public required under NESHAPS for air emissions from DOE facilities. This comparison indicated that - for exposure to radionuclides from the active air pathway - the dose limits and derived concentration guides for radiation protection of humans are more restrictive than the BCGs derived for radiation protection of biota. This analysis is consistent with and supports the assumptions and findings presented above in section H.5.1.

H.5.6. Summary

Based on the foregoing discussions:

- It is difficult to conceive of any credible circumstances under which populations of terrestrial animals and plants could receive a dose from exposure to radionuclides released through the active air pathway at DOE sites that would be more than a small fraction of applicable biota dose rate criteria referenced in this technical standard; and
- Compliance with the biota dose rate criteria for populations of terrestrial plants and animals can be evaluated without the explicit need to consider external and internal exposures from the active air pathway.

H.6. Direct Measurement of Radiation Fields

It is first important to distinguish between ionizing radiation and radioactive material/radionuclides. Ionizing radiation is defined as radiated energy that is energetic enough to eject one or more orbital electrons from the target atom or molecule (i.e., the radiation ionizes the target). Ionization can produce free radicals, which are chemically unstable atoms or molecules that have an odd number of electrons. These highly reactive products scavenge electrons by breaking chemical bonds, including those in cell membranes and DNA molecules. Thus, ionizing radiation can cause cell death (i.e., oocyte death) and mutations (i.e, cancer). However, ionizing radiation generally does not cause ambient media or biological tissues to become radioactive, which only occurs via the transfer and accumulation of radionuclides. That is, exposing an organism to a radiation field does not result in the transfer of radionuclides and does not make the organism radioactive. It follows that an organism that simply passes through a radiation field does not then become a source of radionuclides or radiation to other organisms.

H.6.1. Considerations for Evaluating Doses to Biota around Accelerators or other Sources of Direct Radiation

Accelerator facilities pose little risk regarding environmental contamination. Emissions are mainly short-lived gases which do not accumulate in the environment. Therefore, compliance with the dose rate criteria referenced in this technical standard is most efficiently accomplished by direct measurement and mapping of the radiation dose rate field outside the facility. This can be accomplished during routine radiation monitoring using the techniques normally employed by the facility. If the greatest dose rate in the field does not exceed 0.1 rad/d (1 mGy/d), the facility has demonstrated protection and no further action is required.

If the greatest dose rate in the field does exceed 0.1 rad/d (1 mGy/d), it does not immediately imply non-compliance. The dose limit is based on continuous exposure and radiation from accelerators is rarely continuous. The primary radiation field exists only when the accelerator is operating. In this case, dose assessors may wish to employ dose reduction factors accounting for the fraction of the day during which the dose rate field exists. If this technique is employed, it may also be important to ensure that maximum dose rates do not exceed 10 rad/d (100 mGy/d). According to the IAEA (1992), acute dose rates below this limit are very unlikely to produce persistent and measurable deleterious changes in populations or communities of terrestrial plants or animals.

Other considerations for direct measurement of radiation fields include:

- **Measurement technique.** The technique employed to measure the dose rate field should be appropriate for the type of radiation and sufficiently sensitive to demonstrate compliance with the criteria.
- **Dimensions of the field.** For most accelerators, the greatest dose rate may be observed in line with the beam. However, if the beam is potentially scattered, it may be important to obtain a 3-dimensional map of the dose rate field, which is typically a small fraction of the aerial extent of the habitat for the population.
- **Activation products.** If there is a potential for the creation of activation products in soil or water outside the accelerator building, assessors should consider applying the graded approach (i.e., using the BCGs) for contaminated media.
- **Biota intrusion.** Biota intrusion may be a problem in high-dose areas such as earthen beam stops, and this possibility should be investigated.

Appendix I: Example Applications of Graded Approach

I.1. Aquatic System Cases (Levels 1-3)

This example was prepared using actual measured radionuclide concentration data from a DOE site. However, the data is used within a hypothetical context for a generic site (i.e., Poplar Springs Site, a hypothetical site). Two cases are provided, drawing from the same data set of measured radionuclide concentrations from surface water samples. The first case considers the entire Poplar Springs Site as the evaluation area, and options for proceeding when the Site fails a general screening evaluation. The second case begins with the goal of assessing several evaluation areas independently within the boundary of the Poplar Springs Site. The cases are intended only to highlight key steps and concepts of the graded approach.

The purpose of the evaluation was to demonstrate that the aquatic doses associated with the Poplar Springs Site (PSS) are less than either 1 rad/d (10 mGy/d) aquatic biota or less than 0.1 rad/day (1 mGy/d) terrestrial biota (riparian organisms).

I.1.1. Data Assembly (Phase 1 of the Graded Approach)

I.1.1.1. Verify Data is Appropriate for a Biota Dose Evaluation

Surface water samples are collected and analyzed to assess the impact of past and current DOE operations on the quality of local surface water. Sampling locations include streams within the main plant area and at downstream locations from Poplar Springs Site (PSS) facilities; all are within the PSS boundary. These sampling stations are located within the Blue Falls Creek Watershed (main plant and downstream locations) and within other smaller watersheds, all of which flow into the Darlington River. Surface water data (via the surface water surveillance program) are collected throughout the year. The sampling frequency is dependent on historical data and the processes or legacy activities nearby or upstream from these locations. Therefore, sampling occurs at different locations monthly, bimonthly, quarterly, or semiannually. The sampling locations are presented in Table I-1.

Table I-1 Surface water sampling locations for the Poplar Springs Site

Watershed	Sampling Locations
Blue Falls Creek	
Main Plant–On-site Stream Locations:	Two Falls Creek TFCK 0.5
	Broad Creek BRCK
	Northwest Tributary NWTK 0.5
Downstream Locations:	Muddy Branch MB 0.6
	Blue Falls Creek BFCK 3.0
	Blue Falls Creek at Blue Falls Dam BFCK 1.4
Other Watersheds Entering the Darlington River	Taylor's Creek TCK 1.0
	Beaver Creek BVCK 2.3

I.1.1.2. Request Sampling Data, to Include Maximum and Mean Water and Sediment Radionuclide Concentrations (co-located if possible) Collected for the Environmental Monitoring and Surveillance Program at Poplar Springs Site

Table I-2 includes the sampling data. Maximum, minimum, and average values are summarized. The maximum measured radionuclide concentrations observed for the Poplar Springs Site (i.e., across all sampling locations) are indicated by an (*).

Table I-2 Measured radionuclide concentrations (pCi/L) in surface water collected from the Poplar Springs Site

Sampling Location	Radionuclide	Maximum	Minimum	Average
Main Plant: On-site station locations:				
Two Falls Creek (TFCK 0.5)	H-3	530	430	480
	Sr	15	15	15
Broad Creek (BRCK)	H-3	360	110	240
	Sr	290	59	170
	*U-234	36	7.7	22
	U-235	0.048	0	0.024
	U-238	0.52	0.28	0.40
Northwest Tributary (NWTK 0.5)	H-3	160	110	140
	Sr	71	1.8	36
Downstream Locations:				
Muddy Branch (MB 0.6)	*Co-60	4.6	-2.8	2.0
	Cs-137	3.0	0.0050	1.5
	*H-3	760,000	39,000	460,000
	*Sr	460	84	250
	U-234	0.52	0.15	0.33
	U-238	0.50	0.15	0.37
Blue Falls Creek (BFCK 3.0)	Co-60	1.5	0.034	0.79
	*Cs-137	67	12	37
	H-3	36,000	3,300	17,000
	Sr	330	28	100
	U-234	4.8	1.2	3.5
	*U-235	0.075	0	0.024
	*U-238	2.1	0.24	0.98
Blue Falls Creek at Blue Falls Dam (BFCK 1.4)	Co-60	3.9	0.58	2.5
	Cs-137	40	8.5	12
	H-3	140,000	32,000	71,000
	Sr	140	54	100
	U-234	8.2	1.6	5.0
	U-235	0.065	0	0.029
	U-238	1.6	0.41	0.95
Other watersheds entering the Darlington River:				
Taylor's Creek (TCK 1.0)	Co-60	3.2	0.64	1.9
Beaver Creek (BVCK 2.3)	Co-60	1.8	1.6	1.7
	H-3	330	180	260
	Sr	43	4.8	24

I.1.2. CASE 1: Use of Maximum Measured Radionuclide Concentrations for the Entire Poplar Springs Site

I.1.2.1. General Screening Evaluation (Phase 2 of the Graded Approach)

Enter Data into RESRAD-BIOTA

Maximum measured radionuclide concentration data for surface water detected for the entire Poplar Springs Site (i.e., the radionuclide-specific maximum values detected across the entire Site) were entered into the Level 1 Aquatic System Data Entry Worksheet within the RESRAD-BIOTA. RESRAD-BIOTA automatically calculates the missing sediment radionuclide concentration data (i.e., by using the "most probable" radionuclide-specific K_d values) and entered the calculated radionuclide concentrations into the appropriate fields.

Compare Measured Radionuclide Concentrations in Environmental Media with BCGs

RESRAD-BIOTA automatically calculates the radionuclide-specific partial sum of fractions for water and sediment, then calculates the total sum of fractions. A summary of the comparisons for each medium and radionuclide is provided in Table I-3. Note that this comparison could also be done manually by using Appendix H. The results indicated that the Poplar Springs Site failed the general screening evaluation using maximum radionuclide concentration data. Results also indicated that the water medium appears to be limiting (see partial sum of fractions for water and sediment, respectively, in Table I-3). In addition, Cs-137 and Sr-90 were the radionuclides that provided the greatest contribution to the total sum of fractions (e.g., they were the most limiting radionuclides, providing the greatest contribution to potential dose). A riparian animal was indicated as the limiting organism type for these radionuclides.

Table I-3 Aquatic System Evaluation: General screening results for Poplar Springs Site using maximum measured radionuclide concentrations in surface water across the entire site

Radionuclide	Maximum Measured Radionuclide Concentrations (pCi/L)	Water Sum of Fractions Ratio	Sediment Sum of Fractions
H-3	760,000	2.87E-3	2.03E-6
Sr-90	460	1.65	2.37E-02
U-234	36	1.78E-01	3.42E-04
U-235	0.075	3.45E-04	1.01E-06
U-238	2.1	9.4E-03	4.22E-05
Co-60	4.6	1.22E-03	3.14E-03
Cs-137	67	1.57	1.07E-02
Total of partial sum of fractions for each medium		3.41	3.80E-02
Total sum of fractions for all radionuclides and media			3.45

I.1.2.2. Site-Specific Screening using Mean Radionuclide Concentrations in Place of Maximum Values (Phase 3 of the Graded Approach)

It was determined through consultation with site environmental surveillance program personnel that the quality and quantity of data allowed for averaging of measured radionuclide concentration data by individual sampling location for the Poplar Springs Site, but not across the entire Site. It was determined that - although the habitats and presence of the limiting organism type (in this case a riparian animal) were similar across all sampling locations, radionuclide data could not be averaged across the entire Poplar Springs Site because: (1) the site was too large for such an averaging scheme to be sensible, and (2) the contamination profiles (e.g., the radionuclides detected and their levels) for Main Plant - on-site locations, downstream locations, and other streams that enter the Darlington River were too different from one another (see Table I-2).

However, it was determined that within the downstream locations, data from Blue Falls Creek (BFCK 3.0) and Blue Falls Creek at Blue Falls Dam (BFCK 1.4) station locations could be averaged over space and time, because of their proximity to each other (i.e., both stations are in the same water system), and because the contamination profiles, habitats, and limiting organism type (riparian animal) were determined to be similar across the areas represented by these sampling locations. Therefore, measured radionuclide concentrations for these two locations were averaged for subsequent use in site-specific screening. Measured radionuclide concentrations for each of the remaining sampling locations were averaged by location, consistent with advice from the Site environmental surveillance program personnel.

Enter Data into RESRAD-BIOTA

The averaging scheme presented above resulted in the need for seven separate evaluations: one for each of the six individual sampling locations, and one for the combined Blue Falls Creek / Blue Falls Creek at Blue Falls Dam locations. For each evaluation, mean measured radionuclide concentration data for surface water were entered into Level 2 Biota Case Menu page. RESRAD-BIOTA automatically calculated the missing sediment radionuclide concentration data (i.e., by using the "most probable" radionuclide- specific K_d values) and entered the calculated radionuclide concentrations into the appropriate fields.

Compare Measured Radionuclide Concentrations in Environmental Media with BCGs

RESRAD-BIOTA automatically calculated the radionuclide-specific partial sum of fractions for water and sediment, and then calculated the total sum of fractions. A summary of the comparisons for each location is provided in Table I-4. The results indicated that all of the sampling locations, each representing an individual evaluation area, passed the site-specific screening.

Table I-4 Aquatic System Evaluation: Site-specific screening results using mean radionuclide concentrations in surface water for each evaluation area

Sampling Location	Average Concentrations Sum of Fractions < 1.0 (Pass/Fail)?	Water Sum of Fractions	Sediment Sum of Fractions	Total Sum of Fractions
Main Plant - On-site Locations:				
Two Falls Creek (TFCK 0.5)	passed	5.38E-02	7.72E-04	0.055
Broad Creek (BRCK)	passed	7.21E-01	8.97E-03	0.73
Northwest Tributary (NWTK 0.5)	passed	1.29E-01	1.85E-03	0.13
Downstream Locations:				
Muddy Branch (MB 0.6)	passed	9.38E-01	1.45E-02	0.95
Blue Falls Creek (BFCK 3.0) and Blue Falls Creek at Blue Falls Dam Station (BFCK 1.4) (combined)*	passed	9.6E-1	1.02E-02	0.97
Other Streams that enter Darlington River:				
Taylor's Creek (TCK 1.0)	passed	5.05E-04	1.3E-03	0.002
Beaver Creek (BVCK 2.3)	passed	8.65E-02	2.4E-03	0.089

**For example, averaged the average values (original data not available); however, the average the full data set when estimating average concentrations from both locations.*

I.1.2.3. Documentation of Results

The results of the biota dose evaluation were summarized. A summary report which contains RESRAD Aquatic Biota results were retained on file for future reference. The rationale for using average radionuclide concentration values in place of maximum values was documented. As required by DOE Order 458.1, a summary of the evaluation was included in the Poplar Springs Site's Annual Site Environmental Report.

I.1.2.4. Lessons Learned

- All of the downstream station locations corresponding to individual evaluation areas resulted in total sums of fractions near one. These are good indicator locations for future biota dose evaluations.
- All of the evaluation areas passed the site specific screening with mean concentrations (Level 2). However, because the total sum of fractions for each of the downstream locations was very near 1.0, it may be useful to consider conducting additional analysis on these evaluation areas using the analysis phase of the graded approach (refer to the example provided in CASE 2).
- Possible future activities could include:
    - assessing the need for additional sampling locations;
    - collecting co-located sediment and water samples for these and other locations;
    - collecting representative receptors and analyzing tissue data to permit a direct and more realistic dose evaluation.

I.1.3. CASE 2: Evaluation of Several Evaluation Areas Using Maximum Measured Radionuclide Concentration Data

I.1.3.1. General Screening Evaluation (Phase 2 of the Graded Approach)

Enter Data into RESRAD-BIOTA

Maximum measured radionuclide concentration data for surface water for each sampling location (each representative of individual evaluation areas) were entered into Biota Aquatic Case Level 1 menu page. (e.g, in this case, eight individual evaluations, one for each sampling location representative of an evaluation area, were conducted). RESRAD-BIOTA automatically calculates the missing sediment radionuclide concentration data (i.e., by using the "most probable" radionuclide-specific K_d values) and entered the calculated radionuclide concentrations into the appropriate fields.

Compare Measured Radionuclide Concentrations in Environmental Media with BCGs

RESRAD-BIOTA automatically calculated the radionuclide-specific partial sum of fractions for water and sediment, and then calculates the total sum of fractions. A summary of the comparisons for each location is provided in Table I-5. The results indicated that four of the locations evaluated (Broad Creek, Muddy Branch, Blue Falls Creek, and Blue Falls Creek at Blue Falls Dam) failed the general screening evaluation using maximum radionuclide concentration data. Results also indicated that the water medium is limiting (see partial sum of fractions for water and sediment, respectively, in Table I-5). It was also determined that Cs-137 and Sr-90 were the radionuclides that provided the greatest contribution to the total sum of fractions (i.e., they were the most limiting radionuclides, providing the greatest contribution to potential dose). A riparian animal was the limiting organism type for these radionuclides.

Table I-5 Aquatic System Evaluation: General screening results for Poplar Springs Site using maximum measured radionuclide concentrations in surface water

Sampling Locations	Sum of Fractions < 1.0 (Pass/Fail?) Using Maximum Concentrations	Water Sum of Fractions	Sediment Sum of Fractions	Total Sum of Fractions
Main Plant--On-site Locations:				
Two Falls Creek (TFCK 0.5)	passed	5.39E-02	7.7E-04	0.05
Broad Creek (BRCK)	failed	1.22	1.53E-02	1.24
Northwest Tributary (NWTK 0.1)	passed	2.55E-01	3.66E-03	0.26
Downstream Locations:				
Muddy Branch (MB 0.6)	failed	1.73	2.73E-02	1.76
Blue Falls Creek (BFCK 3.0)	failed	2.79	3.1E-02	2.82
Blue Falls Creek at Blue Falls Dam (BFCK 1.4)	failed	1.49	1.64E-02	1.51
Other Streams that enter Darlington River:				
Taylor's Creek (TCK 1.0)	passed	8.51E-04	2.19E-03	0.003
Beaver Creek (BVCK 2.3)	passed	1.55E-01	3.45E-03	0.16

I.1.3.2. Site-Specific Screening using Mean Radionuclide Concentrations in Place of Maximum Values (Phase 3 of the Graded Approach)

It was determined, through consultation with Site environmental surveillance program personnel that the quality and quantity of data available allowed for time averaging of measured radionuclide concentration data for each individual evaluation area.

Enter Data into RESRAD-BIOTA

Mean radionuclide concentration data for surface water from each of the four sampling locations which failed the general screening phase were entered into Level 2 Biota Case menu page (i.e., four separate evaluations were conducted). RESRAD-BIOTA automatically calculates the missing sediment radionuclide concentration data (i.e., by using the "most probable" radionuclide-specific K_d values) and entered the calculated sediment radionuclide concentrations into the appropriate fields.

Compare Measured Radionuclide Concentrations in Environmental Media with BCGs

RESRAD-BIOTA automatically calculates the radionuclide-specific partial sum of fractions for water and sediment, and then calculates the total sum of fractions. A summary of the comparisons for each location is provided in Table I-6. The results indicated that of the four locations evaluated (Broad Creek, Muddy Branch, Blue Falls Creek, and Blue Falls Creek at Blue Falls Dam), all but Blue Fall Creek (BFCK 3.0) passed the site-specific screening evaluation using mean radionuclide concentration data. Results also indicated that for the remaining location (Blue Falls Creek - which did not pass the screen), the water medium is limiting (see partial sum of fractions for water and sediment, respectively, in Table I-6). It was also determined that Cs-137 and Sr-90 were the radionuclides that provided the greatest contribution to the total sum of fractions (i.e., they were the most limiting radionuclides, providing the greatest contribution to potential dose).

Table I-6 Aquatic System Evaluation: Site-specific screening results for the Poplar Springs Site using mean radionuclide concentrations in surface water

Sampling Location	Average Concentrations Sum of Fractions < 1.0 (Pass/Fail?)	Water Sum of Fractions	Sediment Sum of Fractions	Total Sum of Fractions
Main Plant--On-site Locations:				
Two Falls Creek (TFCK 0.5)	(passed in general screen)			--
Broad Creek (BRCK)	passed	7.21E-01	8.97E-03	0.73
Northwest Tributary (NWTK 0.5)	(passed in general screen)			--
Downstream Locations:				
Muddy Branch (MB 0.6)	passed	9.38E-01	1.45E-02	0.95
Blue Falls Creek (BFCK 3.0)	failed	1.25	1.17E-02	1.26
Blue Falls Creek at Blue Falls Dam (BFCK 1.4)	passed	6.70E-01	8.85E-03	0.68
Other Streams that enter Darlington River:				
Taylor's Creek (TCK 1.0)	(passed in general screen)			--
Beaver Creek (BVCK 2.3)	(passed in general screen)			--

I.1.3.3. Site-Specific Screening using Site-Representative Parameter Values in Place of Default Values (Phase 3 of the Graded Approach)

Review of Data and Parameters for Blue Falls Creek (BFCK 3.0)

Because both maximum and average surface water concentrations collected at Blue Falls Creek exceeded the BCGs in general screening and site-specific screening, respectively, it was necessary to review the data used, limiting organism type responsible for the BCGs, limiting media, and area of evaluation. A summary of this review is provided in Table I-7.

Table I-7 Review of radionuclide concentration data and limiting organism type to determine path forward in the biota dose evaluation

Review the Following:	Comment
Sampling/Data Frequency -- adequate?	Surface water samples were collected and analyzed bimonthly (Jan, March, May, Jul, Sep, Nov): considered to be adequate. Possible Future Activities: * Consider possible need to increase sampling frequency (contact appropriate personnel) * Consider collection of co-located sediment samples (see below)
Radionuclides of concern?	Cs-137 and Sr-90 are the limiting radionuclides contributing the most to the total sum of fractions at this location. Water is the limiting medium; sediment contributes to dose but is not the limiting medium. Maximum and average concentrations detected in surface water for this location: Cs-137: Maximum: 67; Average: 37 pCi/L Sr-90: Maximum: 330; Average: 100 pCi/L
Are the limiting organism types used to derive BCGs reasonable?	Riparian animal -- yes, this receptor is feasible for the evaluation area. Known to be resident.
Consider re-defining or modifying the evaluation area?	Radionuclide data were already time-averaged to generate mean concentrations which are representative of the evaluation area. The location from which the radionuclide concentrations were detected is considered to be a representative indicator for site impacts on natural waterways. No additional modifications to the delineation of the evaluation area will be conducted.

Consider Replacing Default Lumped Parameter Values with Site-Representative Values

The major issues for this evaluation were Cs-137 and Sr-90 surface water concentrations. Therefore, the focus was on the radionuclide-specific default lumped parameters used to derive the BCGs for these two radionuclides. Available site data were reviewed for site-representative lumped parameter values for riparian animals (the limiting organism type for Cs-137 and Sr-90).

After making some preliminary inquiries with site personnel, it was determined that there were no easily-accessible site-specific lumped parameter data for riparian animals. A more extensive search could have been performed (e.g., making contact with other DOE site representatives; conducting a literature search), but it was decided to move on to the site-specific analysis component of the graded approach, focusing on reviewing and potentially modifying additional default parameters and assumptions used in the analysis phase.

Table I-8. Default B_{iv} Values used to derive generic water BCGs for riparian animals

Radionuclide	Lumped Parameter Bq/kg (animal-wet weight) per Bq/L(water)	Comment
Cs-137	54,000	A preliminary search at the Site indicated no known or easily accessible site-specific data for estimating site-specific lumped parameters for riparian animals.
Sr-90	6,200	A preliminary search at the Site indicated no known or easily accessible site-specific data for estimating site-specific lumped parameters for riparian animals.

I.1.3.4. Site-Specific Analysis Using Site-Representative Parameter Values and Assumptions in Place of Default Values (Phase 3 of the Graded Approach)

Review Default Parameter Values and Consider Replacing with Site-Representative Values

A number of default parameters which are used in estimating a riparian animal's internal dose can be considered for modification in site-specific analysis. The default parameters for a riparian animal were reviewed by accessing the Organism-Specific parameters page from the Biota Case menu. These parameters are summarized in Table I-9 below.

Table I-9. Review of default parameter values for possible modification using site-representative values

Parameter	Default Value	Site-Specific Values?
Appropriate Riparian Receptor?	Raccoon	Default organism is known to be resident at the site.
Fraction of intake retained Cs-137 Sr-90	 1 0.3	No known site specific evaluations to conclude otherwise. Default values were used to be conservative.
Food Intake Rate	325 g/d	No known site specific evaluations to conclude otherwise. Default values were used to be conservative.
Correction Factor for Area or Time	1.0	No known site specific evaluations to conclude otherwise. The organism would be expected to be resident in the evaluation area 100% of the time.
Dose Rate Criteria for Riparian Animals	0.1 rad/d	Default dose limit used for riparian animals. Cannot be changed without DOE-AU-22 approval.
Body Mass	8800 g	Default value. Default value was used to be conservative.
Other Kinetic/Allometric Relationship Parameters	Allometric equations and related input parameters representing mechanisms to internal dose to a riparian animal.	A cursory review of the default values for these parameters was made. It was decided to use the default values and equations rather than to obtain more site-representative values for use in the kinetic/allometric models employed in the analysis phase of the graded approach. However, the aquatic animal food source B_{iv} value used as the default food source to the riparian animal was reviewed (in the Aquatic Animal Spreadsheet) and subsequently modified.

Each of the contributing parameters could have been reviewed in detail, with the objective of identifying values more representative of site-specific receptors. It was determined through contact with aquatic biologists and radioecologists at the Poplar Springs Site that a reasonable amount of data relating to bioaccumulation factors ($B_{iv}s$) for fish was available at relevant Poplar Springs Site locations for the Blue Falls Creek evaluation area. Data exists for fish at or near Blue Falls Creek (BFCK 3.0) for Cs-137 and there is some data for Sr-90 in whole fish collected on-site in nearby waterways having similar water chemistry. It was determined that these fish were representative of the expected food sources to a riparian animal at the evaluation area, and that their $B_{iv}s$ would provide more representative food source values to a site-specific riparian animal, in place of the default values used.

With the assistance of the aquatic specialists, site-specific Cs-137 and Sr-90 concentrations measured in fish and in surface water were used to estimate $B_{iv}s$ applicable to the Blue Falls Creek evaluation area. The data and resulting $B_{iv}s$ are shown in Table I-10 and Table I-11.

Table I-10. Site-specific bioaccumulation information for Cesium-137

Species	Water Concentration (Bq/L)	Tissue Concentration (Bq/kg)[1]	Bioaccumulation Factor (L/kg)[2]	Reference
Bluegill	1.52 Bq/L	BFCK 2.9 (N=7): 7900 ± 3400 Bq/kg dw BFCK 2.3 (N=5): 4600 ± 752 Bq/kg dw	1040 605	PSS/TM-11295 - Third Report of the PSS BMAP for Blue Falls Creek Watershed and the Darlington River (Tables 8.2-water and 8.11-fish)
Sunfish (includes bluegill and redbreast sunfish)	5.2 Bq/L	BFCK 3.5 (N=8): 21600 ± 2200 Bq/kg dw BFCK 2.9 (N=8) 29800 ± 9100 Bq/kg dw BFCK 2.3 (N=8): 13600 ± 8400 Bq/kg dw	830 1150 520	PSS/TM-10804 - Second Report of the PSS BMAP for Blue Falls Creek Watershed and the Darlington River (Table 8.23) Water Data Table 5.2.26 Environmental Surveillance of the PSS and Surrounding Environs (ES/ESH-1/V2)
Redbreast Sunfish	1.52 Bq/L	BFCK 2.9 (N=5): 7600 ± 1300 Bq/kg dw	1000	PSS/TM-11358- Third Report of the PSS BMAP for Blue Falls Creek Watershed and the Darlington River (Tables 8.2-water and 8.11-fish)

[1] Tissue concentrations were measured in fish fillets. It is assumed that the tissue concentrations in fillets are representative of whole body concentrations. This is appropriate, given that Cs-137 is known to concentrate in muscle tissues.
[2] It is assumed that fish are about 80% water; therefore, the dry weight of fish is divided by 0.2 to convert dry weight to wet weight.

Table I-11. Site-specific bioaccumulation information for Strontium-90

Species	Water Concentration (Bq/L)	Tissue Concentration (Bq/kg)	Bioaccumulation Factor (L/kg)	Reference
Bluegill	4.8 Bq/L	520 ± 140 Bq/kg ww (Whole body) N=5	110	PSS/TM-10804 - Second Report of the PSS BMAP for Blue Falls Creek Watershed and the Darlington River (Table 8.1) Blue Falls Creek Water Data Table 2.2.1 Environmental Surveillance of the PSS and Surrounding Environs (ES/ESH-4/V2).
Gizzard Shad	4.8 Bq//L	370 ± 360 Bq/kg ww (Whole body) N=5	80	PSS/TM-10804 - Second Report of the PSS BMAP for Blue Falls Creek Watershed and the Darlington River (Table 8.1) Blue Falls Creek Water Data Table 2.2.1 Environmental Surveillance of the PSS and Surrounding Environs (ES/ESH-4/V2)
Largemouth Bass	4.8 Bq/L	230 ± 120 Bq/kg ww (Whole body) N=5	50	PSS/TM-10804 - Second Report of the PSS BMAP for Blue Falls Creek Watershed and the Darlington River (Table 8.1) Blue Falls Creek Water Data Table 2.2.1 Environmental Surveillance of the PSS and Surrounding Environs (ES/ESH-4/V2)

Modification of Default B_{iv} Values for Organisms Consumed by the Limiting Organism

The Aquatic Animal Spreadsheet within RESRAD-BIOTA was accessed and the default B_{iv} values for Cs-137 and Sr-90 were reviewed. Based on literature reviews, calculated values (Table I-10 and Table I-11), and consultations with the aquatic specialists**,** the following site-specific B_{iv}s for fish were selected:

- Cs-137: 1150 (L/kg). Most conservative estimated bioaccumulation factor for fish collected at or near the sampling location (BFCK 2.9).
- Sr-90: 110 (L/kg). Most conservative estimated bioaccumulation factor for fish collected on the Poplar Springs Site.

Enter Site-Representative Parameter Values into RESRAD-BIOTA

First, select riparian animal under “Organism Type” and then select edit. On the “Input Source” tab there is a column called “Use Allom”; toggle yes for Cs-137 and Sr-90. Then go to “Allometric” tab and select “Food Chain” tab and then select “Food Source Characteristics.” On “Food Source Characteristics”

replace the default B_{iv}s to the site specific Cs-137 and Sr-90 B_{iv} values listed above. The BCGs for Cs-137 and Sr-90 were automatically updated within RESRAD-BIOTA to reflect these site-specific input values. The site-specific BCGs for these two radionuclides were shown in the Level 3 BCG Report with our mean measured radionuclide concentration data. A new partial and total sum of fractions is automatically calculated.

Compare Measured Radionuclide Concentrations in Environmental Media with BCGs

Due to the adjustment of the Cesium-137 B_{iv} to 1150 and the Sr-90 B_{iv} to 110, the total sum of fractions for Blue Falls Creek was less than 1.0, indicating that it passed the site-specific analysis.

It is also noteworthy that had we used the site-specific food source B_{iv} values compared with maximum measured radionuclide concentration data rather than mean values, the total sum of fractions for our riparian animal would also have passed. This would be a useful approach if we were required by regulators or stakeholders to use only maximum measured radionuclide concentrations in our evaluation. This point highlights one example regarding the flexibility of the graded approach.

I.2. Terrestrial System Cases (Levels 1-3)

This example is adapted from a terrestrial biota dose assessment conducted on the DOE's Nevada National Security Site (NNSS) in 2003 (Bechtel Nevada 2004). The NNSS is a very large (1360 square mile) site with areas of soil contamination from the testing of nuclear explosive devices that took place from 1951 to 1992. The steps for conducting an assessment are demonstrated with particular emphasis on issues related to selecting dose evaluation areas and adjusting RESRAD-BIOTA model parameters to determine if the potential dose exceeds the 0.1 rad/day (0.001 Gy/day) limit set to protect terrestrial animal populations or the 1 rad/day (0.01 Gy/day) limit set to protect plant populations. The graded approach outlined in this Standard is a three-step process consisting of a data assembly step, a general screening step, and if necessary, an analysis step (Table I-13).

Furthermore, the analysis step consists of site-specific screening which may progress to a site-specific analysis or even to a site-specific biota dose assessment consistent with a comprehensive ecological risk assessment (EPA 1998).

Concentration values for radionuclides in soil, water, and sediment included in this Standard are used as a guide for determining if biota are potentially receiving radiation doses that exceed the criteria. These concentrations are called the Biota Concentration Guide (BCG) values. They are defined as the maximum concentration of a radionuclide that would not cause dose rate criteria to be exceeded using conservative uptake and exposure assumptions. The BCGs are derived from the sum of internal and external contributions. RESRAD-BIOTA is the software used to more easily make the comparisons between a site's radionuclide concentrations and BCGs. Default BCGs used in early stages are quite conservative. As more realistic uptake and exposure parameters are entered in RESRAD-BIOTA, the BCG values are adjusted accordingly.

Table I-12 A Working Example of the Graded Approach for Evaluating Radiation Doses

Process Step	Process Step Description	Process Results and Next Step of Evaluation
1) Data Assembly	Knowledge of radionuclide sources, plant and animal receptors, and routes of exposure is summarized. Existing data on radionuclide concentrations in soil, water, and sediment are assemble. Contaminated areas with sufficient data are identified as dose evaluation areas (DEAs).	If there is sufficient data on site-related radionuclides in the environment and exposed biota to identify DEAs and concentration data are adequate to identify maximum, median, and average concentrations within DEAs then proceed to General Screening, else need to gather more data.
2) General Screening (Level 1 Screen)	Maximum radionuclide concentrations in soil and water are compared with BCG values for each radionuclide.	If the sum of fractions of maximum radionuclide concentrations in soil, water, and sediment in a DEA divided by the BCG values is < 1 then there is no evidence that biota dose rate criteria are being exceeded. Document results. If the sum of fractions is ≥ 1, then proceed to the Site-specific Screening.
3) Analysis Site-Specific Screening (Level 2 Screen)	Average radionuclide concentrations are used in place of maximum concentrations and screened against BCG values. More realistic, site-representative, bioaccumulation factors (B_{iv}) can be used in place of default values.	If the sum of fractions of average radionuclide concentrations in soil, water, and sediment in a DEA divided by the BCG values is < 1 then there is no evidence that biota dose rate criteria are being exceeded. Document results. If the sum of fractions is ≥ 1, then proceed to the Site-specific Analysis.
Site-Specific Analysis (Level 3 Screen)	More realistic, site-representative, parameters can be used. For example; receptor geometry, metabolic and intake rates, and residence time in a DEA, to name a few, can be edited. Measured tissue concentrations can also be used.	If the sum of fractions of average radionuclide concentrations in soil, water, and sediment in a DEA divided by the BCG values is < 1 then there is no evidence that biota dose rate criteria are being exceeded. Document results. If the sum of fractions is ≥ 1, then parameters can be adjusted as new data is obtained in an iterative process within this step. If the sum of fractions is still ≥ 1 after all best available data have been used, then proceed to the Site-specific Biota Dose Assessment.
Site-Specific Biota Dose Assessment	A site-specific biota dose assessment is conducted consistent with a comprehensive ecological risk assessment (EPA 1998).	Take action according to results of the comprehensive site-specific biota dose assessment.

I.2.1. Data assembly

The goal of the data assembly step in this example is to define the terrestrial biota dose evaluation areas (DEAs) on the NNSS and the exposed biotic populations. It is up to each site doing the assessment to ensure the defensibility of the data. Only radionuclide concentrations in soil and water are needed for a Terrestrial Dose Assessment. Sediment concentrations can be entered in RESRAD-BIOTA but they won't be considered. If your site has contaminated sediment, conduct an Aquatic Dose Assessment which includes riparian animals. The environmental monitoring organization will normally provide radionuclide concentration data. Note that the site-wide maximum radionuclide concentrations can be used at this point in the General Screening step with the entire site being the DEA (see section below). If the sum of fractions of maximum radionuclide concentrations in soil and water divided by the BCG values is < 1 then there is no evidence that biota dose rate criteria are being exceeded and the assessment can be documented. If the sum of fractions is ≥ 1, the data should be grouped by locations that make sense from a spatial and radiological source perspective. On the NNSS, the best data for concentrations of radionuclides in soil comes from the Radionuclide Inventory and Distribution Program (RIDP) conducted from 1981 through 1986. RIDP compiled the most comprehensive data on radionuclide concentrations in NNSS surface soil from a combination of field exposure rate measurements, field gamma spectroscopy measurements, aerial surveys of external exposure rate, and soil samples. Thirty-one soil contamination regions were defined by RIDP. These were based primarily on the source of the radiological contamination (i.e., specific nuclear explosive device tests) then secondarily on filling gaps between those testing areas. Because it was known that the overall site-wide maximum concentrations exceeded BCGs in the General (Level 1) Screen, the NNSS would need to be divided into smaller areas over which averaging of soil concentrations made sense. The 31 RIDP areas then became the starting point for defining the DEAs. Site ecologists were then consulted to determine if isolated populations of any plant or animal resided within the RIDP boundaries which would require a specific DEA to be defined for that population. No such populations were identified. In fact, due to the wide-spread and uniform habitats on the NNSS, it could be argued that DEAs could be expanded beyond the RIPD boundaries to capture the populations but because radionuclide concentration data were sparse beyond RIDP boundaries, and expanding the size would only lower average concentrations, it was decided to stick with the RIDP-defined areas as DEAs.

I.2.2. General Screening: Level 1 Screen

The goal of General Screening is to determine whether the sum of the fractions of maximum radionuclide concentrations in soil and water in a DEA divided by the BCG values are < 1. For each of the DEAs maximum radionuclide concentrations were entered into the RESRAD-BIOTA software set for a Level 1 Terrestrial Ecosystem. The RESRAD-BIOTA software then computed the fractions (maximum radionuclide concentration/BCG) and the sum of fractions (total fractions for all radionuclides). If the sum of fractions in a screen was < 1 within a DEA, the potential dose to biota is expected to be less than the dose rate criteria within that DEA.

The sums of fractions for the Level 1 Screen are listed in (Table I-14). Seven DEAs passed the Level 1 screen. The potential dose to biota in these seven DEAs, therefore, is expected to be < 1 rad/day (0.01 Gy/day) to plants and < 0.1 rad/day (1 mGy/day) to animals. No further action is required on these DEAs except to document the process and results.

The remaining terrestrial DEAs had a sum of fractions > 1. These DEAs then require a Site-Specific Screening. In all cases the limiting organism was a terrestrial animal. The radionuclides primarily contributing to the failure of the Level 1 Screen for these DEAs were ^{137}Cs (in 96% of the DEAs), ^{90}Sr (in 84%), ^{241}Am (in 20%), and ^{239}Pu (in 16%) (Table I-13).

Table I-13 Results of the Level 1 Screen (using maximum concentrations) of dose evaluation areas (DEAs) on the NNSS

Dose Evaluation Area (DEA)	Area (km^2)	Sum of Fractions	Key Radionuclides Contributing to Failure
DEAs Passing Level 1 Screen			
Area 19	384.1	0.18	None
GMX	1.0	0.27	None
Johnnie Boy North of GZ	7.3	0.14	None
Kay Blockhouse	0.4	0.04	None
Plutonium Valley	8.8	0.34	None
RWMS 5	0.4	0.10	None
Yucca Flat	40.1	0.84	None
DEAs Failing Level 1 Screen			
Baneberry	13.5	60.71	^{137}Cs, ^{90}Sr
Buggy Site	0.8	43.67	^{137}Cs, ^{90}Sr
Cabriolet	11.7	19.83	^{137}Cs, ^{90}Sr
Danny Boy	2.3	23.78	^{137}Cs, ^{90}Sr
Diablo	10.4	36.77	^{137}Cs, ^{90}Sr
East Part of Area 18	55.7	2.22	^{241}Am
Frenchman Lake	5.7	20.18	^{137}Cs, ^{90}Sr
Galileo	12.4	12.08	^{137}Cs, ^{90}Sr
Hornet	22.0	14.32	^{137}Cs, ^{90}Sr
Johnnie Boy GZ	3.0	17.75	^{137}Cs, ^{90}Sr
Kepler	25.1	23.02	^{137}Cs, ^{90}Sr
Little Feller I	1.6	15.21	^{241}Am, ^{137}Cs, ^{239}Pu, ^{90}Sr
Little Feller II	0.8	9.60	^{241}Am, ^{137}Cs, ^{239}Pu, ^{90}Sr
Near T tunnel	0.4	23.80	^{137}Cs
NRDS	2.3	7.81	^{137}Cs, ^{90}Sr
Pin Stripe	1.6	1.29	^{137}Cs, ^{90}Sr
Quay	17.4	15.46	^{137}Cs, ^{90}Sr
Schooner	4.4	3.71	^{137}Cs, ^{90}Sr
Sedan	19.9	253.12	^{241}Am, ^{137}Cs, ^{239}Pu, ^{90}Sr
Shasta	12.7	14.28	^{137}Cs, ^{90}Sr
Smoky	8.5	304.98	^{241}Am, ^{137}Cs, ^{239}Pu, ^{90}Sr
Whitney	7.0	22.35	^{137}Cs, ^{90}Sr
Wilson	19.4	5.85	^{137}Cs, ^{90}Sr
Yucca Flat South	115.3	3.07	^{137}Cs

I.2.3. Site-Specific Screening: Level 2 Screen

The goal of Site-Specific Screening is to determine whether the sum of fractions of average radionuclide concentrations in soil and water in a DEA divided by the BCG values are < 1. Average concentrations of each radionuclide in each DEA were calculated (see Appendix C for guidance on averaging). The RESRAD-BIOTA software was used for the Level 2 Screen in the same manner described above for the Level 1 Screen, only this time using average radionuclide concentrations instead of the maximum values.

The sums of fractions from the Level 2 Screen are listed in Table I-14. All DEAs, except Sedan, had a resultant value < 1 and therefore passed the screen meaning the potential dose to populations of biota is expected to be less than the dose rate criteria within those DEAs. The Sedan DEA had a sum of fractions of 1.60 with the limiting organism being a terrestrial animal. The radionuclides contributing to the Sedan DEA failing the Level 2 Screen were ^{137}Cs and ^{90}Sr which had average concentrations in soil 91% and 67% of their associated BCG values, respectively.

Notice that except for determining DEA boundaries, there has been no discussion of specific populations being examined or specific parameters associated with exposed populations. That is because all previous steps have used the conservative default parameters in RESRAD-BIOTA. The Level 2 Screen is the first where a parameter can be adjusted besides the radionuclide concentrations in environmental media. Within the Level 2 Screen one can edit the Organism parameters; specifically the bioaccumulation factor (B_{iv}) values (also known as concentration ratios). The default B_{iv} values are in general very conservative but can be made more realistic by entering site-specific concentration ratios for species of interest at your site. For the Terrestrial Ecosystem this is the plant or animal wet-weight concentration to soil concentration for the Soil B_{iv} and the animal wet-weight concentration to water concentration for the Water B_{iv}. Note that there is no plant to contaminated water B_{iv} in RESRAD-BIOTA. The default ^{137}Cs and ^{90}Sr Soil B_{iv} values are 110 and 75.8, respectively. Site-specific data for the NNSS shows the median concentration ratio for tissue to soil to be 0.3 for ^{137}Cs and 0.1 for ^{90}Sr. Entering the site-specific B_{iv} values into RESAD-BIOTA resulted in a sum of fractions of 0.02 for the Sedan DEA and serves to demonstrate the potential dose to biota within the Sedan DEA is expected to be less than the dose rate criteria set to protect plant and animal population (Table I-14).

Table I-14 Results of the Level 2 Screen (using average concentrations) of dose evaluation areas (DEAs) on the NNSS

Dose Evaluation Area (DEA)	Area (km^2)	Sum of Fractions	Key Radionuclides Contributing to Failure (% of BCG)
DEAs Passing Level 2 Screen (using default B_{iv} values)			
Baneberry	13.5	0.52	None
Buggy Site	0.8	0.93	None
Cabriolet	11.7	0.18	None
Danny Boy	2.3	0.36	None
Diablo	10.4	0.53	None
East Part of Area 18	55.7	0.06	None
Frenchman Lake	5.7	0.06	None
Galileo	12.4	0.20	None
Hornet	22.0	0.34	None
Kepler	25.1	0.21	None
Little Feller I	1.6	0.15	None
Little Feller II	0.8	0.30	None
Near T tunnel	0.4	0.00	None
NRDS	2.3	0.04	None
Pin Stripe	1.6	0.05	None
Quay	17.4	0.11	None
Schooner	4.4	0.17	None
Shasta	12.7	0.60	None
Smoky	8.5	0.76	None

Dose Evaluation Area (DEA)	Area (km^2)	Sum of Fractions	Key Radionuclides Contributing to Failure (% of BCG)
Whitney	7.0	0.45	None
Wilson	19.4	0.22	None
Yucca Flat South	115.3	0.02	None
NNSS Area 8	35.9	0.40	None
NNSS Area 10	52.1	0.56	None
DEA Failing Level 2 Screen (using default B_{iv} values)			
Sedan	19.9	1.60	^{137}Cs (91%), ^{90}Sr (67%)
DEA Passing Level 2 Screen (using site-specific B_{iv} values)			
Sedan	19.9	0.02	None

I.2.4. Site-Specific Analysis: Level 3 Screen

Had average radionuclide concentrations in soil and water and site-specific B_{iv} values still resulted in the sum of fractions (concentrations in soil and water to BCG values) > 1, then the next step would be the Site-specific Analysis (Level 3 Screen). This step differs from the Level 2 Screen in that more realistic and site-representative parameters are to be used for uptake and dose estimations for specific plant and animal species. For example, receptor geometry, metabolic and intake rates, and residence time in a DEA, to name a few, can be edited. Measured tissue concentrations can also be used. All of this can be accessed through the *Organism-Specific Parameters* window in RESRAD-BIOTA. See Appendix H of this Standard for descriptions of the various parameters used to determine BCG values and potential dose to biota. Instead of using the default Terrestrial Animal or Terrestrial Plant, a new organism can be created to perhaps better match the site-specific plant or animal of interest. In addition to the parameters already listed above, External Exposure Geometry Factors in the created organisms can be adjusted (see Appendix H of this Standard for exposure parameters). All of this provides an extremely flexible tool for modeling various organisms.