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RADIATION IMPACTS ON AQUATIC & TERRESTRIAL BIOTA - VOL 2 OF 2

Main Category:	Nuclear Engineering
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Course #:	NUC-136
Course Content:	90 pgs
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NUC-136 EXAM PREVIEW

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Exam Preview:

1. According to the reference material, the highest concentrations of potassium, about 0.6% by weight, are found in wet tissues such as lettuce. Lower concentrations, about 0.2%, are found in dry materials such as nuts.
    a. True
    b. False
2. _____ was not included in the original DOE Standard because it is naturally occurring and is unlikely to contribute a significant dose.
    a. Strontium-90
    b. Cesium-137
    c. Potassium-40
    d. Plutonium-238
3. According to the reference material, the key to estimating body burdens in biota is an expression for intake that can account for potential change with size of the organism.
    a. True
    b. False
4. According to the reference material, which organism type has a site-specific screening that: allows the user to modify the Biv,aa,i (the wet weight bioaccumulation factor) to a more site-representative value. All other aspects of the calculations remain the same.
    a. Terrestrial Animals
    b. Riparian Animals
    c. Terrestrial plants
    d. Aquatic Animals

5. According to the Estimating Intake section of the reference material, the metabolic rate is known to scale to body mass to the _ power.
    a. 3/8
    b. 1/2
    c. 3/4
    d. 4/5
6. According to the reference material, 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.
    a. True
    b. False
7. 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 ___ power (Cs, Sr, Co). Iodine scaled at W0.13 and 3H scaled at W0.55.
    a. 1/8
    b. 1/4
    c. 3/8
    d. ½
8. Using Table G-11 Factors Used in Assessing the Relative Contribution to Internal Dose from Animal Inhalation versus Ingestion, which of the following values corresponds to the correction factor for ^{231}Pa?
    a. 200
    b. 250
    c. 750
    d. 1000
9. According to the reference material, 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.
    a. True
    b. False
10. Using Table H-2 Reference organism geometries, which of the following organisms has the smallest mass (kg)?
    a. Wild grass
    b. Bees
    c. Brown seaweed
    d. Earthworm

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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

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"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)

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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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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.

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	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

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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.

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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

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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

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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

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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.

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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

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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.

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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.

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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.

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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

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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	1E+05	4E+03	Terrestrial Animal
Ce-144	1E+08	3E+06	Terrestrial Animal	5E+04	1E+03	Terrestrial Animal
Cs-135	3E+08	8E+06	Terrestrial Animal	1E+04	3E+02	Terrestrial Animal
Cs-137	2E+07	6E+05	Terrestrial Animal	8E+02	2E+01	Terrestrial Animal
Co-60	4E+07	1E+06	Terrestrial Animal	3E+04	7E+02	Terrestrial Animal
Eu-154	8E+07	2E+06	Terrestrial Animal	5E+04	1E+03	Terrestrial Animal
Eu-155	1E+09	3E+07	Terrestrial Animal	6E+05	2E+04	Terrestrial Animal
H-3	9E+09	2E+08	Terrestrial Animal	6E+06	2E+05	Terrestrial Animal
I-129	2E+08	6E+06	Terrestrial Animal	2E+05	6E+03	Terrestrial Animal
I-131	7E+07	2E+06	Terrestrial Animal	3E+04	9E+02	Terrestrial Animal
Pu-239	7E+06	2E+05	Terrestrial Animal	2E+05	6E+03	Terrestrial Animal
Ra-226	3E+05	8E+03	Terrestrial Animal	2E+03	5E+01	Terrestrial Animal
Ra-228	3E+05	7E+03	Terrestrial Animal	2E+03	4E+01	Terrestrial Animal
Sb-125	3E+08	7E+06	Terrestrial Animal	1E+05	3E+03	Terrestrial Animal
Sr-90	2E+06	5E+04	Terrestrial Animal	8E+02	2E+01	Terrestrial Animal
Tc-99	6E+08	2E+07	Terrestrial Animal	2E+05	4E+03	Terrestrial Animal
Th-232	2E+06	5E+04	Terrestrial Animal	6E+04	2E+03	Terrestrial Animal
U-233	1E+07	4E+05	Terrestrial Animal	2E+05	5E+03	Terrestrial Animal
U-234	1E+07	4E+05	Terrestrial Animal	2E+05	5E+03	Terrestrial Animal
U-235	2E+07	4E+05	Terrestrial Animal	1E+05	3E+03	Terrestrial Animal
U-238	2E+07	4E+05	Terrestrial Animal	6E+04	2E+03	Terrestrial Animal
Zn-65	6E+06	2E+05	Terrestrial Animal	2E+04	4E+02	Terrestrial Animal
Zr-95	8E+07	2E+06	Terrestrial Animal	4E+04	1E+03	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.

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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.

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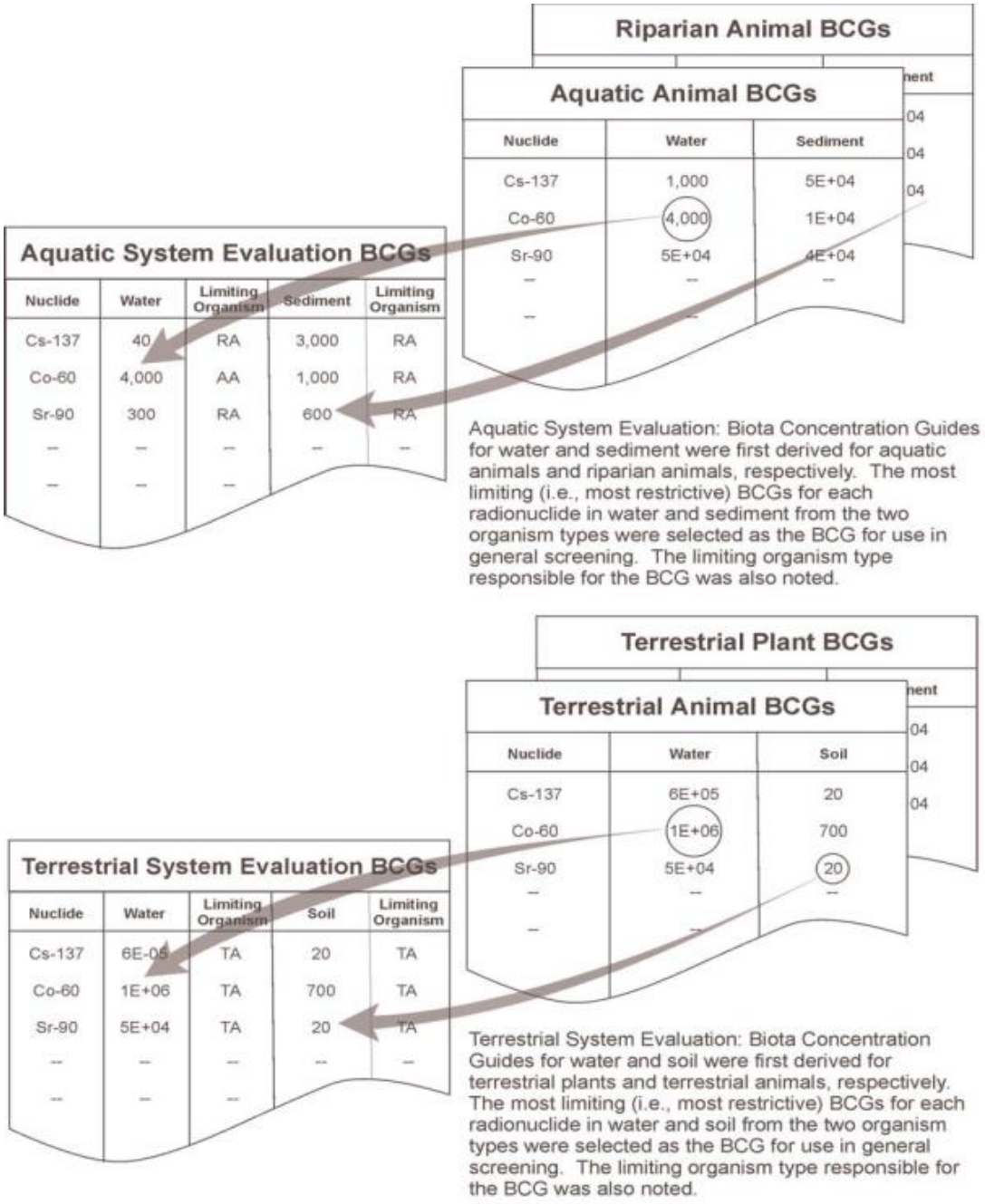

Figure G-1 Selection of Biota Concentration Guides (BCGs) for Use in Aquatic and Terrestrial System Evaluations

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

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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.

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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

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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.

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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$_w$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.

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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.

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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

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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.

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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.

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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.

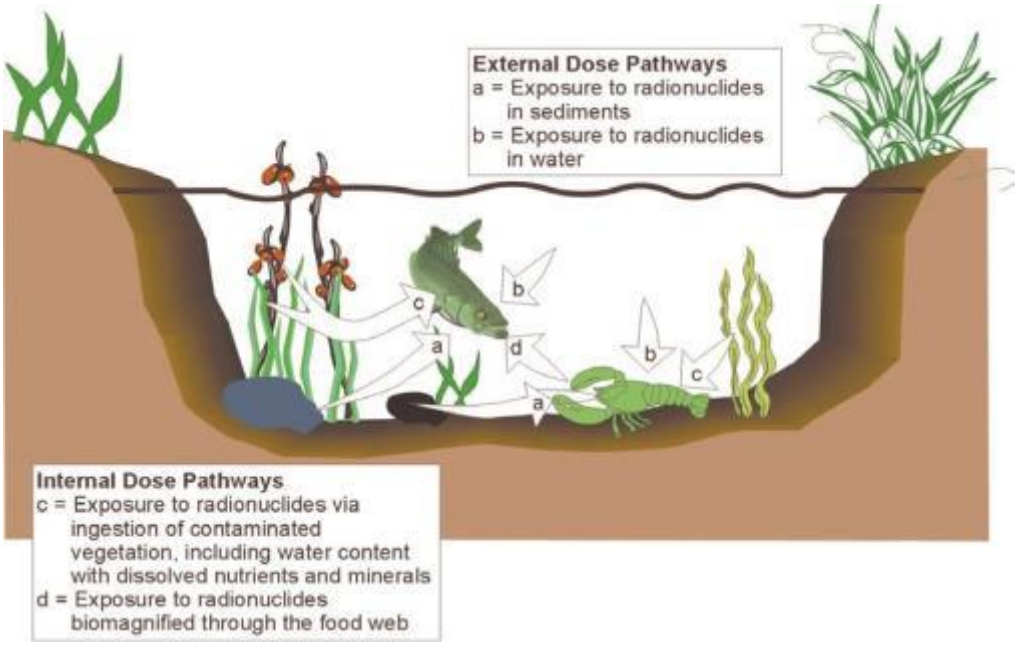

Figure H-1 Exposure Pathways for Aquatic Animals

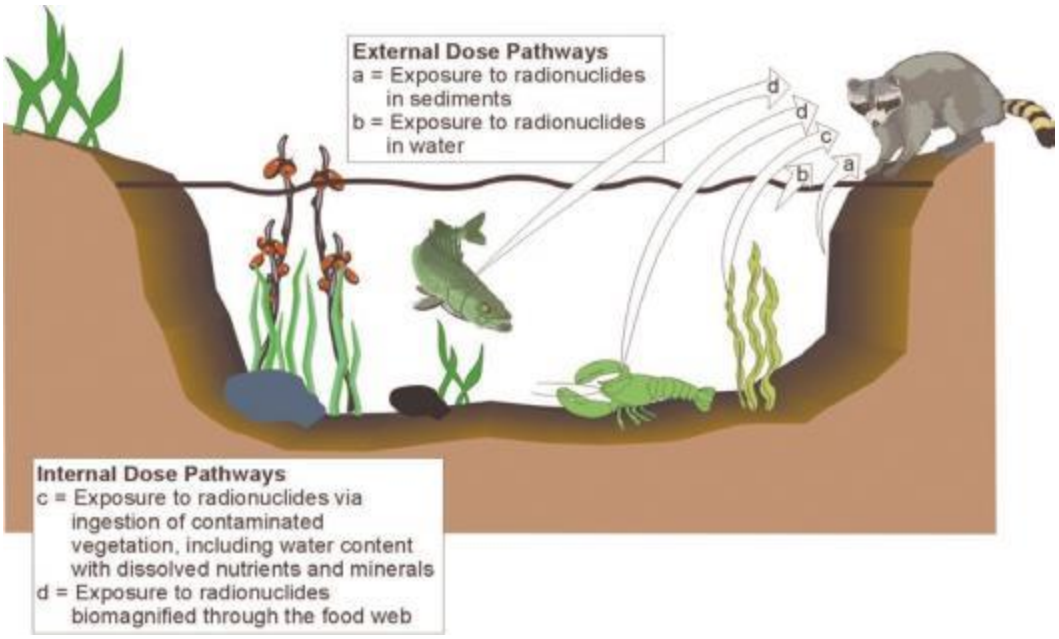

Figure H-2 Exposure Pathways for Riparian Animals

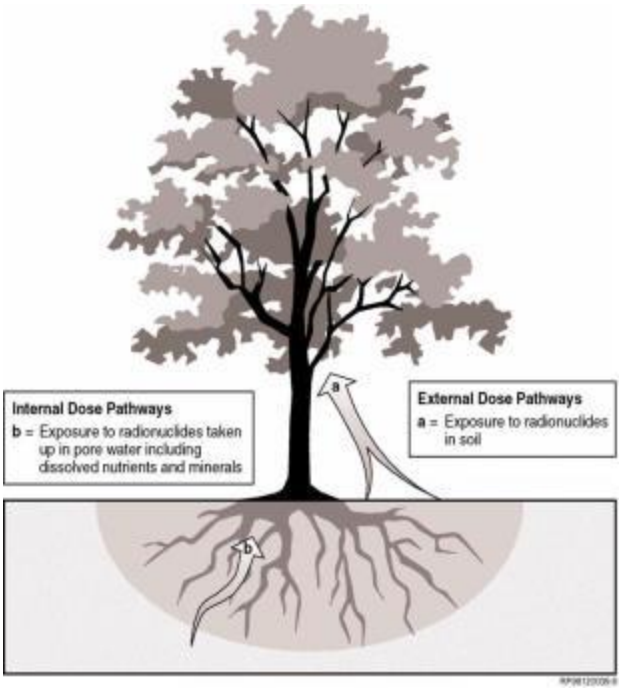

Figure H-3 Exposure Pathways for Terrestrial Plants

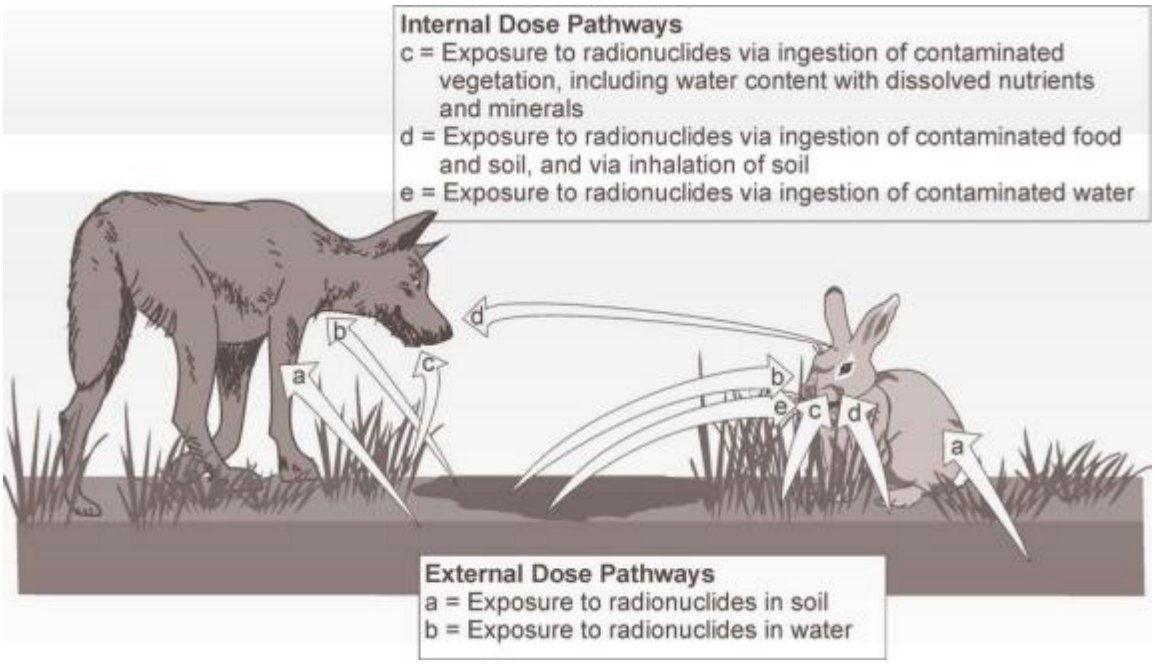

Figure H-4 Exposure Pathways for Terrestrial Animals

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.

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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.

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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.

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- 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*

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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.

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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.

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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

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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

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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.

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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.

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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)

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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.

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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.

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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.

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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.

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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.

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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.

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