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DOE STANDARD

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

U.S. Department of Energy
Washington, D.C. 20585

AREA ENVR

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Foreword

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

2. The graded approach to biota dose evaluation can be used to address requirements for radiological protection of the environment contained in DOE Orders. It can also be used to support radiological protection of the environment program elements within Environmental Management Systems (EMS) at DOE sites.

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

4. This technical standard and the RAD-BCG Calculator (an electronic calculational tool provided with the technical standard) can be downloaded from the Department's Biota Dose Assessment Committee (BDAC) web site (http://homer.ornl.gov/oepa/public/bdac).

5. The graded approach to biota dose evaluation and associated guidance contained in this technical standard is also intended for use with the RESRAD-BIOTA code. The RESRAD-BIOTA dose evaluation code was designed to be consistent with the graded approach and the BCGs contained herein.

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

   (a) they are explicitly stated to be requirements in a DOE requirements document; or

   (b) the organization makes a commitment to meet a standard in a contract or in an implementation plan or program plan required by a DOE requirements document.

   Throughout this standard, the word "shall" is used to denote actions which must be performed if the objectives of this standard are to be met. If the provisions in this standard are made requirements through one of the two ways discussed above, then the "shall" statements would become requirements. However, "should" statements would not automatically be converted to "shall" statements if provisions in this standard become requirements, as this action would violate the consensus process used to approve this standard.

7. This technical standard has undergone extensive review throughout its development: (1) it was prepared and reviewed by the Department's Biota Dose Assessment Committee (BDAC), an approved DOE Technical Standards Program topical committee; (2) it has undergone a formal DOE review and comment resolution process as required by the Department's Technical Standards Program; (3) it was made available to other federal agencies for their review and comment through the Interagency Steering Committee on Radiation Standards (ISCORS); (4) it was reviewed by an independent external technical expert; and (5) five papers on the graded approach methodology and associated guidance contained in this technical standard have undergone external peer review for publication in scientific journals.

8. Comments in the form of recommendations, pertinent data, and lessons learned from implementation of DOE's graded approach to biota dose evaluation that may improve future versions of this technical standard, the RAD-BCG Calculator, or the RESRAD-BIOTA code, are welcome and should be sent to:

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Acknowledgments

This voluntary consensus technical standard was prepared by the Department's Air, Water and Radiation Division (EH-412) and the Core Team of the Biota Dose Assessment Committee (BDAC). The BDAC is a technical standards topical committee organized under the Department of Energy Technical Standards Program. The purpose of the BDAC is (a) to assist, consistent with DOE needs, in developing and promoting technical standards and associated guidance for DOE-wide applications in assessing radiation dose to biota, (b) to serve as a major forum within DOE for obtaining technical assistance, discussing technical issues, and sharing lessons learned regarding biota dose standards and assessment methods, and (c) to serve as a technical resource and advisory group for DOE program and field elements in the design and review of site-specific biota dose assessments. The committee has broad representation from DOE Offices, national laboratories, universities, and the private sector. The BDAC charter can be obtained from the BDAC web site at: http://homer.ornl.gov/oepa/public/bdac.

A guiding principle for the BDAC is that both "developers" and "users" be part of the methods development process. Consistent with the BDAC's values and guiding principles documented in the BDAC charter, this technical standard was prepared using an interdisciplinary team approach. Each member of the Core Team brought with them specific expertise in health physics, ecology, radioecology, environmental monitoring, or risk assessment. The collective knowledge gained through this teaming orientation proved to be essential for developing the methods and implementation guidance presented in this technical standard.

The Core Team consists of the following members: Mr. Ernest Antonio, Pacific Northwest National Laboratory (PNNL); Dr. Gordon Bilyard, PNNL; Mr. Stephen Domotor, DOE-EH-412; Dr. Gary Friday, Westinghouse Savannah River Company (WSRC); Dr. Kathryn Higley, Oregon State University; Mr. Daniel Jones, Oak Ridge National Laboratory (ORNL); Dr. David Kocher, SENES-Oak Ridge; Dr. Randall Morris, Environmental Science and Research Foundation, and TREC, Inc.; Dr. Bradley Sample, CH_2MHill; and Ms. Patricia Scofield, ORNL.

Members of the Core Team, and other members of the BDAC, served as lead developers or contributors for several key areas of the technical standard. These individuals, and their specific contributions, are highlighted below. We are grateful to them for their contributions.

Technical Standard Development

BDAC Chairperson: Mr. Stephen Domotor (EH-412); technical standard preparation, integration, and coordination: Mr. Stephen Domotor (EH-412), with support from Ms. Audrey Lamanna, Ms. Melissa Hatcher, Mr. Jamie McDonald, and Mr. Clyde Lichtenwalner (Energetics, Inc.); screening methodology concepts and development: Dr. Kathryn Higley (Oregon State University) and Dr. David Kocher (SENES-Oak Ridge); kinetic/allometric modeling concepts and development, and RAD-BCG Calculator design: Dr. Kathryn Higley (Oregon State University).

Specific Contributions

Conceptual framework and application of the graded approach: Mr. Stephen Domotor (EH-412), with support from the BDAC Core Team; primer on ecological risk assessment concepts and issues concerning the evaluation of radiation as a stressor: Mr. Daniel Jones (ORNL); interpretation and application of biota dose limits: Dr. David Kocher (SENES-Oak Ridge); sources, receptors, and routes of exposure: Dr. Gordon Bilyard (PNNL); defining the area of evaluation: Dr. Randall Morris (Environmental Science and Research Foundation, and TREC, Inc.); dealing with high background levels of naturally-occurring radionuclides: Dr. Randall Morris (Environmental Science and Research Foundation, and TREC, Inc.) and Mr. Daniel Jones (ORNL); soil sampling guidance: Dr. Gordon Bilyard (PNNL) and Mr. Daniel Jones (ORNL); biota sampling guidance: Mr. Daniel Jones (ORNL) and Dr. Bradley Sample (CH_2MHill); guidance on radiation weighting factor for alpha particles: Dr. David Kocher (SENES-Oak Ridge); evaluating dose to individual organisms: Dr. David Kocher (SENES-Oak Ridge); derivation of dose coefficients, dose equations and models, and BCGs: Dr. Kathryn Higley (Oregon State University), Dr. David Kocher (SENES-Oak Ridge), Mr. Ernest Antonio (PNNL), and Mr. Stephen Domotor (EH-412); preparation of example applications of the graded approach: Mr. Ernest Antonio (PNNL) and Ms. Patricia Scofield (ORNL).

We are grateful to Dr. Gary Friday of the Westinghouse Savannah River Corporation (WSRC) for his valuable comments and recommendations concerning ecological risk issues and technical considerations.

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We thank all of the BDAC members who provided comments and recommendations on previous drafts of this technical standard, and who provided recommendations on the screening and analysis methods which were piloted at the 1999 BDAC Meeting. We also thank the representatives from federal and state agencies, and international organizations, who provided review comments on previous drafts of this technical standard.

We thank Mr. Fred Baes (ORNL) for BDAC web site design, database design, and maintenance support.

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We thank Mr. Andrew Lawrence, Director of the Office of Environmental Policy and Guidance (EH-41); Mr. Andrew Wallo III, Director of the Air, Water, and Radiation Division (EH-412); and Mr. Harold Peterson, EH-412 Environmental and Radiological Evaluation Unit Leader, for sponsoring the BDAC and supporting the development of this technical standard.

We thank Mr. Raymond Berube, Deputy Assistant Secretary for Environment (EH-4), for his support and recognition of the BDAC's pioneering spirit and efforts in developing the biota dose evaluation methods in this technical standard.

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Scope, Purpose and Organization

This technical standard provides methods, models, and guidance within a graded approach that the U.S. Department of Energy (DOE) and its contractors may use to evaluate doses of ionizing radiation to populations of aquatic animals, terrestrial plants, and terrestrial animals from DOE activities for the purpose of demonstrating protection relative to Dose Rate Guidelines. It provides dose evaluation methods that can be used to meet the requirements of DOE Order 5400.5, "Radiation Protection of the Public and the Environment" (1990a) and DOE Order 5400.1, "General Environmental Protection Program" (1990b). The technical standard assumes a threshold of protection for plants and animals at the following doses: for aquatic animals, 1 rad/d (10 mGy/d); for terrestrial plants, 1 rad/d (10 mGy/d); and for terrestrial animals, 0.1 rad/d (1 mGy/d). Available data indicate that dose rates below these limits cause no measurable adverse effects to populations of plants and animals.

The DOE graded approach includes a screening method and three more detailed levels of analysis for demonstrating compliance with applicable dose limits for protection of biota. The general screening method provides appropriately conservative limiting concentrations of radionuclides in environmental media (termed "Biota Concentration Guides" or BCGs). Radionuclide concentrations in samples of environmental media are easily compared with the BCGs to evaluate compliance with biota dose limits. The three more detailed analysis methods require more effort, but yield more accurate and realistic biota dose evaluations.

This technical standard is designed to be user-friendly, and is organized into three principal Modules for ease of implementation. Material in each Module is cross-referenced to pertinent sections in other Modules. There is some duplication of material across Modules by design, in order to allow each to be used separately, if desired. Module 1 serves as the principal users guide for step-by-step implementation of the graded approach to biota dose evaluation. Module 2 serves as a resource guide, providing detailed guidance for implementing key elements of the graded approach identified in Module 1, and providing a "primer" on technical issues to be considered when evaluating radiation as a stressor to the environment. Module 3 serves as a technical reference source, providing the technical basis for the derivation of dose models, screening values, and selection of default assumptions and parameters applied in the graded approach. The organization and content of the technical standard are provided in Figure 1.

MODULE	CORRESPONDING SECTION NUMBER & CONTENTS
Module 1 - Principles and Application *Provides user-friendly guidance and instructions for application*	1. Purpose and background. Provides basis for the technical standard, biota dose limits, and protection of populations. 2. Overview of the DOE graded approach. Describes the process for using BCGs in screening and analysis methods to evaluate doses to biota. 3. Application considerations. Provides principal and potential uses of the graded approach. 4-8. Step-by-step guidance for implementation. Provides stepwise guidance for progressing through the data assembly, general screening, and analysis phases. Provides BCG look-up tables, use of RAD-BCG Calculator, and reporting guidelines. 9. Example applications. Provides examples of implementing the graded approach using actual site data.
Module 2 - Detailed Guidance *Provides specific guidance, details, and discussions by topic to support the application of the graded approach*	1. Primer on evaluating radiation as a stressor to the environment. 2. Sources, receptors, and routes of exposure. Includes direct air pathway and direct radiation considerations. 3. Spatial and temporal averaging regarding application of dose limits and mean radionuclide concentrations. 4. Defining the area of evaluation. 5. Soil sampling. 6. Biota sampling. 7. Radiation weighting factor for alpha particles. 8. Evaluating doses to individual organisms.
Module 3 - Methods Derivation *Provides a detailed description of dose models, equations, and default parameters*	1. Introduction and basis for the graded approach. Presents pathways, radionuclides, media types, and organism-types addressed. 2. Dose coefficients. Provides internal and external dose conversion factors. 3. Equations and models for calculating doses to biota and deriving BCGs. 4. Default parameters and their sources.

Figure 1 Organization and Contents of the DOE Technical Standard

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Definitions

As defined and used in this technical standard:

Absorbed Dose (D) is the 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, alpha radiation can be blocked by a sheet of paper. 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.

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 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. This ratio is typically described through a bioaccumulation factor (B_{iv}).

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 limits 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.

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, the inputs to the decision, the 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.

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.

Gamma Rays are high-energy electromagnetic photons similar to X-rays. They are highly penetrating and 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:

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

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

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

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:

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

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

Herbivore is a plant-eating animal.

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).

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 isotope, either stable or unstable, of any chemical element.

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 refers to the totality of features and characteristics of a material, process, product, service, or activity that bears on its ability to satisfy a given purpose.

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 equal to an energy of 100 ergs per gram of irradiated material.

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

Radioactive Material refers to any material or combination of materials that contain radionuclides that spontaneously emits 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 half-life.

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.

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 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 (i.e., 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 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:

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

where $\bar{X}$ = average value of the samples measured;

n = number of samples measured; and

X_i = individual measurement value for sample I.

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

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

where F is the mean value of the population and N is the 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 = value of sample i;

$\bar{X}$ = average of 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 F is the mean value of the population and N is the 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
ASTM	American Society for Testing and Materials
B_{iv}	bioaccumulation factor
BCG	Biota Concentration Guide
BDAC	Biota Dose Assessment Committee
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
CV	coefficient of variation
D	absorbed dose
H	dose equivalent
DOE	U.S. Department of Energy
DQO	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
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
K_d	solid/solution distribution coefficient
M&O	management and operating (contractor)

NCRP	National Council on Radiation Protection and Measurements
NEA	Nuclear Energy Agency
NEPA	National Environmental Policy Act
NIST	National Institute of Standards and Technology
NOAEL	No Observed Adverse Effects Levels
NRC	U.S. Nuclear Regulatory Commission
NRDA	Natural Resource Damage Assessment
PRA	population-relevant attribute
QA	quality assurance
QC	quality control
QF	quality factor
RBE	relative biological effectiveness
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_T	tissue or organ weighting factor