DOE-STD-1153-2019 *A Graded Approach for Evaluating Radiation Doses to Aquatic and Terrestrial Biota*

Introduction

The Office of Public Radiation Protection provides technical assistance to Department of Energy (DOE) sites in estimating the potential radiation doses to biota as a result of their site activities.

DOE Order 458.1 Chg 3, *Radiation Protection of the Public and the Environment,* specifies that when actions taken to protect humans from radiation and radioactive materials are not adequate to protect biota, evaluations must be done to demonstrate compliance with paragraph 4.j.(2) of the Order. This is accomplished in one or more of the following ways:

- Use of the graded approach described in DOE-STD-1153-2019, *A Graded Approach for Evaluating Radiation Doses to Aquatic and Terrestrial Biota*;
- Use of an alternative approach to demonstrate that the dose rates to representative biota populations do not exceed the dose rate criteria in DOE-STD-1153-2019; or
- Use of an ecological risk assessment (ERA) to demonstrate that radiation and radioactive material released from DOE operations will not adversely affect populations within the ecosystem.

This Information Brief provides a description of the methods, models, and guidance within a graded approach, as discussed in DOE-STD-1153-2019, that DOE personnel and contractors may use to characterize radiation doses to aquatic and terrestrial biota that are exposed to radioactive materials. When the analyses demonstrate that the criteria in the standard are satisfied, it can be assumed that the biota (ecosystem) is protected. That said, these methods (and the Biota Concentration Guides (BCGs) 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.

To assist with these assessments, the RESRAD-BIOTA (RESidual RADioactivity) computer code, a dose evaluation tool that calculates biota dose estimates based on site-specific parameters, was specifically designed to complement the graded approach and the Biota Concentration Guide's (BCGs) contained in DOE-STD-1153-2019.

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

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

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

Background and Purpose

Basis for Biota Dose Rate Criteria

DOE activities may expose plants and animals to radioactive materials in environmental media or to radioactive materials released in waste streams. The biota dose rate criteria is intended to be a simple, defensible, and user friendly means of demonstrating that the ecosystem is protected from radiation. It has broad applicability, from aquatic animals through terrestrial species, and addresses radiation dose in small organisms (e.g., mice) to large carnivores (e.g., bears). The DOE protection of biota reaffirms "if man is adequately protected then other living things are likely to be sufficiently protected." (ICRP 2014) The ICRP statement uses human protection to infer environmental protection from the effects of ionizing radiation. The assumption is appropriate if humans and biota inhabit the same environment and have common routes of exposure. Exceptions to this assumption include:

(1) Contaminated areas where human access is restricted, but access by biota is possible,
(2) Situations where unique exposure pathways for plants and animals that do not impact humans,
(3) Situations where rare or endangered species are present, and
(4) Situations where other stressors on the plant or animal populations are significant.

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

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

Figure 1. DCRL bands for the applicable RAPs (ICRP 2014)

Overview and Implementation of the Graded Approach

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

- Data Assembly Phase
    - Assemble environmental media data and define evaluation area.
    - Summarize knowledge of sources, receptors, and routes of exposure for the area to be evaluated. Assemble measured radionuclide concentrations in water, sediment, and soil are for subsequent screening.
- General Screening Phase **(RESRAD-BIOTA Level 1)**
    - Compare media concentrations with BCGs.
    - Compare maximum measured radionuclide concentrations in an environmental medium (e.g., water, sediment, soil) with a set of DOE BCGs. Each radionuclide-specific BCG represents the limiting radionuclide concentration in an environmental medium that provides reasonable assurance that the dose criteria are met, in which case no further analysis is required.
- Analysis Phase
    - Site-Specific Screening:
        - Employ site-representative parameters and conditions **(RESRAD-BIOTA Level-2)**
        - Use more realistic site-representative bioaccumulation factors (B_{iv}s) in place of conservative default parameters.
        - Use of mean radionuclide concentrations in place of maximum values, taking into account time dependence and spatial extent of contamination, may be considered.
    - Site-Specific Analysis:
        - Employ kinetic/allometric modeling tool (applicable to riparian and terrestrial animal organism types) provided as part of the graded approach methodology. **(RESRAD-BIOTA Level 3)**
        - Multiple parameters which influence the organism's internal dose (e.g., body mass, consumption rate of food/soil, inhalation rate, lifespan, biological elimination rates) can be modified to represent site and organism-specific characteristics.
        - The kinetic model employs allometric equations relating body mass to these internal dose parameters.
    - Site-Specific Biota Dose Assessment:
        - Employ an ERA involving the collection and analysis of biota samples.
        - The dose assessment would involve a problem formulation, analysis, and risk characterization protocol consistent with the widely-used ERA paradigm.

Any of the phases within the graded approach may be used at any time, but the general screening methodology will usually be the simplest, most cost-effective, and least time-consuming. The RESRAD-BIOTA model (ISCORS 2004) is the

recommended tool for implementing the screening and analysis methods. The graded approach and BCGs can be used in support of other types of environmental assessments provided that the user ensures issues specific to the alternative application are appropriately addressed. Other environmental assessments might include the following:

- Environmental risk assessments for hazardous material sites (Superfund)
- Natural resource damage assessment process
- NEPA (National Environmental Policy Act) determinations

Key Features

The graded approach was designed for flexibility and acceptability:

- It provides users with a tiered approach for demonstrating compliance with biota dose rate criteria that is generally cost effective and easy to implement;
- It allows for the use of measured radionuclide concentrations in environmental media typically collected as part of routine environmental surveillance programs;
- It is designed for multiple applications; for example, the technical standard is applicable to demonstrations of compliance with biota dose rate criteria and for use in ERAs of radiological impact;
- It provides a framework that supports the use of site-specific information;
- It incorporates ERA concepts and provides guidance for site-specific biota dose assessments, where needed, employing the widely-used ERA paradigm; and
- It provides users with "a place to start" and "an analysis path forward." For example, the BCG's are not stand-alone criteria; exceedance of BCGs leads the user to the more-detailed tiers of analysis as needed in a stepwise manner as described in the standard.

Data Assembly Phase

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

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

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

General Screening Phase

The General Screening Phase provides a method to easily apply data on radionuclide concentrations in an environmental medium to evaluate compliance with the dose rate criteria for biota. The radionuclide data concentrations are compared with a set of generic Biota Concentration Guides (BCGs). The radionuclide-specific DOE BCGs represent limiting

radionuclide concentration in environmental media, which would not result in DOE's established or recommended dose rate criteria for biota to be exceeded. The generic BCG's are detailed in Appendix G of the Standard.

The general screening phase compares data on radionuclide concentrations in environmental media with generic BCGs. The comparison is determined by the sum of fractions rule.

The general assembly phase looks at the aquatic system considerations. Included in this review is a review of water and sediment equations. They are the most probable values for the Distribution coefficient for solids/solutions referenced from Appendix D. Additionally, the sum of fractions of less-than-one passes general screening for the aquatic receptor.

For terrestrial system considerations, again one finds the water and soil equations. The aquatic and terrestrial systems are not typically collocated, although the water is a likely source of drinking water for a terrestrial animal. Consideration has to be given to the home range of site terrestrial animals and temporal availability of potential drinking water.

The general screening phase contains an addition dealing with high background levels of naturally occurring radionuclides. The radiation dose rates at local background reference sites can be used to ensure that the site-related dose rates represent an actual increase in exposure. The evaluation area has higher background levels that may be taken into account when determining compliance of DOE activities. Two examples of the general screening phase using two isotopes of Radium-226 and Radium-228 are discussed further in Appendix G of the standard. The background levels are estimated based on data for uncontaminated areas. If the sum of fractions is greater than one, the sum should be compared with the sum of fractions calculated using measured radionuclide concentration from the background area. If the sum of fractions from the contaminated area is less than the background area, the contamination has passed the general screening evaluation and the results can then be documented.

Analysis Phase

The analysis phase includes increasingly more detailed components for evaluating doses to biota. There are three components to this phase: (1) site-specific screening; (2) site-specific analysis; and (3) site-specific biota dose assessment. In the analysis phase, one moves away from the default parameters and assumptions, which typically requires greater involvement of health physicists and radioecologists/radiobiologists to develop the site-specific parameters. This often results in less conservative and more realistic site-representative BCGs, and sites should be careful to document the rationale it uses for its site-specific parameters when reporting biota dose evaluation results.

Site-Specific Screening: RESRAD-BIOTA Level 2 Evaluation

In the site-specific screening, the DOE sites apply knowledge of site-specific conditions and receptors, using mean radionuclide concentrations instead of default values used in the level 1 screening. Sites will need to account for time dependence and spatial extent of contamination, and may need to consider parameters representative of site-specific receptors. This stage may assess the representativeness of input data on radionuclide concentration in environmental media and delineation of the evaluation area. During this screening, there are several questions to consider, such as: (1) should we use the mean radionuclide concentrations rather than the maximum values; (2) should we adjust or redefine the evaluation area looking at spatial-temporal extent of the contamination regarding the receptor habitats; or (3) should limiting organism types be reflective of media and the radionuclides expected to be in the evaluation area?

Sites should consider using mean radionuclide concentrations in place of maximum concentrations, and also consider using location-specific data for individual radionuclides in specific environmental media used in the screening process. Sites should account for spatial and temporal distributions of radionuclides in the environment when estimating mean values for radionuclides to use.

Radionuclide concentrations may be adjusted to account for spatial and temporal distributions and bring them closer to the mean values. Radionuclides are intermittently discharged, concentrations of radionuclides discharged may have to be adjusted over time based on discharge records. Correction factor for exposure area organism resonance time may be applied to account for intermittent sources of exposure. Since contamination exhibits a decreasing gradient of concentration away from the source, the mean concentration of contaminants within the contaminated area may be used taking into account the intersections with distinct habitats. If the area has documented high background levels of naturally occurring radionuclides, these background levels may be taken into account when determining compliance with DOE activities with the recommended background limits.

The sites should use less-than-detectable values. A best practice recommendation is to report and use all results in summary statistics, whether positive, negative, or zero, as measured. If a substantial number of less-than-detectable values are identified, additional actions may be needed to obtain useful data. These may include:

- Refining the evaluation area by reducing it into smaller evaluation areas;
- Reviewing the distribution of contaminants, as well as the quality and spatial-temporal distribution of the radionuclide concentration data; and
- Evaluating the habitats of the receptors and the ecological susceptibility of those receptors.

Following a review of the initial screening evaluation (i.e., RESRAD-BIOTA Level 1), a new screening evaluation (i.e., RESRAD-BIOTA Level 2 screening evaluation) may be performed using revised radionuclide concentration data, new evaluation areas, or other values that may have been updated. Results of this evaluation would be compared to the refined data on measured radionuclide concentrations corresponding to appropriate evaluation areas with the generic BCG's (i.e., RESRAD-BIOTA Level 1 BCGs). Following the RESRAD-BIOTA Level 2 screening evaluation, a sum of fractions evaluation must be performed. If the sum of fractions is less than one, then the site has passed the site-specific screening evaluation and no further analysis is required. If the sum of fractions is greater than one, then a site-specific analysis is required.

Prior to proceeding to a Level 2 site-specific assessment, the sites should assess the representativeness of the default parameters/assumptions for generic BCGs and select site-specific parameters and generate site-specific BCGs. The following considerations should inform the selection of a site-specific receptor:

- Select a receptor that receives a high degree of exposure;
- Select one that has a high degree of radiosensitivity; and
- Select one that has a high degree of bioaccumulation.

In performing the Level 2 site-specific assessment, default parameters can be replaced with site-specific parameters, along with identifying the radionuclide-specific limiting media and organism types for which the generic BCGs are derived. This includes identifying environmental media and radionuclides that provide the greatest contribution to the potential dose. NOTE: The generic BCGs for each limiting organism for each radionuclide are located in Appendix G of the Standard.

Site-specific bioaccumulation factors should be reviewed and selected. In the general screening phase, the conservative default bioaccumulation factors are used for internal dose estimates. Locally-derived values for site-specific receptors, values published in scientific literature, or site-specific technical reports for bioaccumulation factors representative of site-specific conditions and receptors may be utilized. For more information regarding site-specific bioaccumulation factors, refer to Appendix F of the Standard.

The site-representative distribution coefficient (K_d) should be reviewed and selected. Locally-derived K_d values should include site-specific conditions and receptors. Additionally, K_d values published in scientific literature or other site-specific technical reports may be appropriate. Site-representative K_d values should be entered into RESRAD-BIOTA Level 2

evaluations and used in generating site-specific BCGs. For more information regarding the use of site-representative K_d values, refer to Appendix D of the Standard.

Following the selection of site-specific conditions and receptors, a RESRAD-BIOTA Level 2 site-specific assessment should result in more realistic, site-representative BCGs. If the sum of fractions is less than one, then the site has passed the site-specific assessment and no further analysis is required. If the sum of fractions is still greater than 1, then a RESRAD-BIOTA Level 3 evaluation is required.

Site-Specific Analysis: RESRAD-BIOTA Level 3 Evaluation

The site-specific analysis employs the kinetic/allometric model for a more rigorous analysis of riparian and terrestrial animal types. This analysis requires a site-specific evaluation to riparian or terrestrial animals of known characteristics.

In this stage, the site will first assess the representativeness of its default parameters/assumptions for kinetic/allometric models where site-specific parameters are selected to generate site-specific BCGs; ,these should be replaced as necessary. Next, the site will identify the radionuclide-specific limiting medium and organism type, from which the general or site-specific BCGs were derived, to determine the greatest contribution to potential dose. As mentioned previously, Appendix G has limiting organism types and BCGs. If a limiting organism is not listed, the exposure area or receptor residence time must be considered. There is also consideration needed for other correction factors. The factors that are looked at here are correction factors for the exposure area, receptor residence time, temporal and spatial variability, non-uniform distribution of radionuclides, and organisms across the population.

In the general phase and site-specific screening analyses, the residence time and contaminated media are conservatively set to one hundred percent for sources of exposure. For a site-specific analysis, factors to consider for updating the receptor residence time include the fraction of time applied to specific receptor's home range, as well as movements and behaviors relative to the evaluation area. A correction factor for the contaminated media can be applied to account for an intermittent source of exposure to all receptors in the evaluation area where the radionuclide distribution is uniform or non-uniform in the environment.

For riparian and terrestrial animals, individual parameters will be modified that relate to internal exposure pathways for site-specific conditions and receptors, using available biota tissue data. This can be used if:

- the data is available and appropriate,
- the data is representative of species within the evaluation area that is capable of receiving higher dose, and
- the data reflects representative sampling of the population with the evaluation area.

For riparian and terrestrial animals, review and select the food source parameter values representative of site-specific receptors. Appendix F of the Standard has radionuclide-specific default bioaccumulation values for aquatic animals and terrestrial plants for default food source parameter values for each respectively. Following the RESRAD-BIOTA analysis, compare the data on radionuclide concentrations in the environmental media with the newly generated site-specific BCGs. Use of the parameter values and correction factors result in more realistic, site-representative BCGs.

In performing a site-specific biota dose assessment (RESRAD-BIOTA Level 3 evaluation and the graded approach), determine if additional analysis is warranted. This may involve the actual collection and analysis of biota from the evaluation area. Measured concentrations of radionuclides can be used to give a more realistic estimate of internal dose contribution to a site-specific receptor. It is important to note that exceeding BCGs does not mean a mandatory decision for remediation of the evaluation area, but it does indicate further investigation is necessary. If further investigation is needed, the ecological relevance and susceptibly of the effected population, the size of the contaminated area, and the persistence of contaminants and impacts of the remediation alternatives are all recommended topics for further analysis.

If radionuclide concentrations in environmental media exceed the BCGs, follow up actions may include a detailed dose assessment, the removal of the source of contamination by reducing or eliminating discharge, or remediating existing environmental contamination. Other factors to consider include the geographical extent of the contamination, magnitude of potential or observed effects of the contamination relative to the level of biological organization affected, the likelihood that these effects could occur or will continue to occur, and the presence of genetically isolated populations.

The recommended approaches to designing and conducting the site-specific dose assessment include performing an ERA and ensuring that the resulting dose assessments are technically sound. Further exploration of these three phases can be found in Appendix I of the Technical Standard, which contains several detailed examples of the graded approach in practice. The purpose of the standard is to assess radiation risk to the effected populations in the ecosystem and ensure they are protected using the most cost effective approaches available.

References:

International Commission on Radiological Protection (ICRP) 2014. Protection of the Environment under Different Exposure Situations. ICRP Publication 124.

Interagency Steering Committee on Radiation Standards (ISCORS), 2004. RESRAD-BIOTA: A tool for implementing a Graded Approach to Biota Dose Evaluation. ISCORS Technical Report 2004-02 (U.S. Department of Energy report DOE/EH-0676), Washington, D.C.

Argonne National Laboratory. RESidual RADioactivity (RESRAD)-BIOTA. https://resrad.evs.anl.gov/codes/resrad-biota/.

Additional Source of Information

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