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Effects of the new wildlife transfer factors on RESRAD-BIOTA's screening Biota Concentration Guides and previous model comparison studies

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ABSTRACT

The RESRAD-BIOTA Level 1 default Biota Concentration Guides (BCGs) are generic screening environmental medium concentrations based on reasonably conservative concentration ratios (CRs). These CRs had been identified from available literature for a variety of biota organisms. The International Atomic Energy Agency (IAEA) Technical Report Series (TRS) handbook on radionuclide transfer to wildlife was recently published with data that can be compared with the RESRAD-BIOTA values. In addition, previous IAEA Environmental Modeling for Radiation Safety (EMRAS) II Biota Working Group model comparison results are examined by comparing them with those obtained using the new TRS CR values for wildlife. Since the CR affects only internal doses, the effect on the overall dose depends on the relative contribution from internal and external exposure pathways.

1. Introduction

The International Atomic Energy Agency (IAEA) recently published its new Technical Report Series (TRS) handbook on radionuclide transfer to wildlife (Howard et al., 2013). These transfer factors are radionuclide concentration ratios (CRs) between whole organisms (fresh weight) and the medium, either soil (dry weight) or water, for a range of wildlife groups. The CRs can be used to predict radionuclide concentrations in wildlife, and they are most suitable for a screening assessment.

The RESRAD-BIOTA code is biota dose assessment computer software that uses CRs and other parameters along with various methods to estimate radionuclide concentrations in animals and plants for dose calculation (DOE, 2002; ISCORS, 2004). A CR is conventionally termed a Biv in RESRAD-BIOTA and the other RESRAD family of codes (Yu et al., 2001). The symbol Biv stands for concentration factor (bioaccumulation or uptake factor) for radionuclide index i and vegetation pathway index v. A set of default Bivs is used in the RESRAD-BIOTA Level 1 screening analysis to calculate screening environmental concentration values called Biota Concentration Guides (BCGs) considering both external and internal radiological exposures. The Bivs are used to estimate biota whole body concentrations from environmental medium concentrations.

The IAEA TRS wildlife handbook compiles more recent CR data, which were not available at the time the RESRAD-BIOTA default Bivs were determined. Comparison of data from the new handbook, RESRAD-BIOTA, and recent international (EMRAS II) studies allows the assessment of the conservatism associated with the RESRAD-BIOTA default Bivs. This paper compares the CRs and also identifies the impact on the resulting BCGs.

2. RESRAD-BIOTA Bivs

The RESRAD-BIOTA code was developed by Argonne National Laboratory to support implementation of DOE Standard 1153-2002, "A Graded Approach for Evaluating Radiation Doses to Aquatic and Terrestrial Biota" (DOE, 2002). It is used for demonstrating compliance with DOE Order 458.1 requirements (DOE, 2011). The purpose is to ensure that the ecosystem is protected from the effects of radiation and radioactive material due to DOE activities. The RESRAD-BIOTA code has a user-friendly input interface with help files and shows screening results (pass or fail) along with text reports and bar charts (ISCORS, 2004). RESRAD-BIOTA performs three

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levels of analysis ranging from general screening to comprehensive organism- and site-specific dose estimation. The general screening (Level 1) analysis employs screening BCGs, which are limiting radionuclide concentrations in environmental media. If the measured maximum concentrations in a contaminated medium at a site are less than the screening BCGs, and the sum of the ratios between the medium concentrations and the BCGs over all the radionuclides of concern is less than 1, the potential that the biota dose limits might be exceeded is minimal; therefore, further organism- and site-specific analyses are not required (DOE, 2002).

Conservative measures are built into the RESRAD-BIOTA Level 1 screening analysis, in addition to the use of default Bivs. For example, the dose conversion factors used for estimating external exposure are based on a zero mass assumption to maximize the external dose, whereas for internal exposure, the dose conversion factors are based on an infinitely large size assumption, so that no radiation would escape from the organism (i.e., 100% absorption of all radiation energy). In the RESRAD-BIOTA Level 2 site-specific screening analysis, site-representative Bivs can be used instead of the default conservative values. In the RESRAD-BIOTA Level 3 site-specific analysis, a kinetic/allometric model can be selected for estimating tissue concentrations and additional parameters can be used, including the dose conversion factors corresponding to the organism geometry (size and mass), which would result in a more realistic (less conservative) biota dose assessment.

The terrestrial ecosystem soil Bivs were examined to study the conservatism of the RESRAD-BIOTA Level 1 screening BCGs. For terrestrial ecosystem, two general organism categories were considered by RESRAD-BIOTA, terrestrial animals and terrestrial plants. Default Bivs were developed for each organism category and used for deriving Level 1 screening BCGs for that organism category. Due to limited literature data for terrestrial animals at the time the default Bivs were developed, a probabilistic analysis using Monte-Carlo simulation with the kinetic/allometric method was employed in addition to the use of empirically measured data. The kinetic/allometric method used an empirical formula to estimate food intake rate, inhalation rate, lifespan, and biological decay constant based on the organism body mass and calculated the tissue concentration of radionuclides by considering their accumulation and reduction through radiological and biological decay inside the organism. Normal/lognormal distributions with associated distribution coefficients were assigned to each parameter used in the kinetic/allometric method so that a distribution of the maximum tissue concentrations could be calculated, leading to a distribution of the Biv values (or CRs). The 95th percentile value from the Biv distribution was then selected for comparison with available data. The largest one was used as the default Biv for the RESRAD-BIOTA code. For the terrestrial animal category, most of the default Bivs were the 95th percentile values obtained with Monte-Carlo probabilistic analyses. More detailed information on how the default Bivs were determined can be found in Module 3 of the DOE technical standard document (DOE, 2002).

3. Wildlife concentration ratios

The IAEA TRS handbook on radionuclide transfer to wildlife contains information on distributions of equilibrium CRs, which are the same as Bivs in RESRAD-BIOTA code, for different wildlife groups in generic terrestrial, freshwater, marine, and brackish environments. For each radionuclide and wildlife group/subgroup combination, the distributions are characterized by the arithmetic mean (AM), arithmetic mean standard deviation (AMSD), geometric mean (GM), geometric mean standard deviation (GMSD), and the minimum (Min) and maximum (Max) values. These values were developed through analyses of more than 50,000 on-line data entries comprising approximately 86,000 CRs from 520 reference sources (Howard et al., 2013).

For the generic terrestrial environment, the distributions of CRs for soil were developed for 13 wildlife groups, including 9 for animals and 4 for plants. When appropriate, the CRs for a wildlife group were further sorted and analyzed to obtain the distribution characteristics of subgroup organisms. Table 1 lists the terrestrial wildlife groups/subgroups with distribution characteristics for the elements whose radioisotopes are included in the RESRAD-BIOTA database. For the assessment of conservatism associated with RESRAD-BIOTA default Bivs, the distribution characteristics of CRs developed for the broad wildlife groups were used. When the TRS wildlife handbook did not provide the distribution characteristics for a broad wildlife group, those for a subgroup were used for the assessment. The 95th percentile value listed in the second to last column of Table 1 was calculated using the assumption of a log-normal distribution characterized by the mean (μ), which is the natural logarithm of GM, and standard deviation (σ), which is the natural logarithm of GMSD, listed in the same table. The Bivs listed in the last column of Table 1 are the default Level 1 Bivs used in the RESRAD-BIOTA code.

4. Assessment method

Unlike the IAEA TRS wildlife handbook that differentiates various wildlife groups inhabiting a specific ecosystem, thereby characterizing the distribution of CRs for each wildlife group, the RESRAD-BIOTA default Bivs were developed for two broad categories of organisms – animals and plants – and as such are not directly associated with any specific wildlife group. These default Bivs were selected for screening assessment and were expected to be applicable to any terrestrial or freshwater ecosystem in the United States, regardless of the location and the different wildlife groups that could inhabit the ecosystem. To assess the conservatism of RESRAD-BIOTA default Bivs in light of the new distribution data on CRs contained in the IAEA TRS wildlife handbook, the screening soil BCGs obtained with the Level 1 screening analysis were compared with the wildlife-specific soil BCGs derived using TRS CR distribution data with the RESRAD-BIOTA Level 3 analysis. The organism wizard featured in the RESRAD-BIOTA Level 3 analysis was used to create the organism representing each wildlife group considered in the IAEA TRS handbook.

Table 2 lists the reference organisms selected for each wildlife group, their body mass, dimensions, and the RESRAD-BIOTA input parameter values. Among the 13 reference organisms, 9 were taken from the Reference Animals and Plants (RAPs) defined by ICRP (ICRP, 2008), 2 were taken from the Framework for Assessment of Environmental Impact (FASSET) database (FASSET, 2003), and the remaining 2 were picked on the basis of empirical judgment. These reference organisms were thought to possess the basic biological characteristics of the wildlife group they represent and can be used for the purpose of relating exposure to radiation dose for each particular wildlife group. Among the eight predefined geometries that are included in RESRAD-BIOTA database for considering organisms of different sizes and body masses, the geometry associated with a body mass closest to the mass of the reference organism was selected for dose calculations. The geometry factor for soil was specified to reflect the location relative to the ground surface where the reference organism would incur external radiation. In general, if a reference organism would spend time in soil (i.e., below ground surface), a geometry factor of 1 was specified to simulate an infinite (4π) source geometry; otherwise, a geometry factor of 0.5 was specified simulating a semi-infinite (2π) source geometry. For vegetative organisms, a geometry factor of 0.5 was specified to consider that most of the plant mass is located above