Radiat Environ Biophys (2010) 49:505–508
DOI 10.1007/s00411-010-0325-x

EDITORIAL

The transfer of radionuclides to wildlife

N. A. Beresford

Received: 5 July 2010 / Accepted: 29 July 2010 / Published online: 15 August 2010

Over the last decade, a number of approaches have been developed to determine the exposure of, and in some instances risk to, non-human biota (i.e. wildlife[1]) from ionizing radiation (USDOE 2002; Copplestone et al. 2001; Brown et al. 2008). These have been developed in response to national legislation and changes in international recommendations with regard to the need to demonstrate that the environment is protected from radioactive releases (e.g. IAEA 2006; ICRP 2007) rather than relying on previous, anthropocentric approaches.

Early in the process of developing these approaches, it was suggested that the parameterization of the variables that describe the transfer of radioactivity between ecosystem components would contribute significantly to the uncertainty in the estimated dose rate (Avila et al. 2004). Recent international evaluations of the available models have shown this to be the case (Vives i Batlle et al. 2007, 2010; Beresford et al. 2008a, 2010a, b; Yankovich et al. 2010a). There are many reasons for this including lack of empirical data for many radionuclide–organism combinations and the theoretical approaches used to derive transfer values when no data exist; use of national data sets; and the conservative nature of some of the parameter values selected to meet the purpose of specific tools (Beresford et al. 2008a, 2010a; Yankovich et al. 2010a). Recognizing the need to improve the model parameterization, the International Atomic Energy Agency (IAEA) is in the process of producing a handbook of radionuclide transfer parameters for application in environmental assessments similar to that available for human food chain modelling (IAEA 2010). To facilitate this, an online database has been established to collate and summarize data (http://wiki.ceh.ac.uk/x/-QHbBg); the database will also be used by the International Commission on Radiological Protection (ICRP) to help further develop their framework for environmental protection (ICRP 2003, 2008). In 2009, the IAEA supported three workshops to bring together scientists who may be able to contribute to the handbook, with one aim being to stimulate the provision of previously unpublished data. The papers in this issue of *Radiation Environmental Biophysics* result from presentations made at these workshops.

The majority of models developed to assess the exposure of wildlife to ionizing radiation use concentration ratios (CRs) to estimate whole-body activity concentrations and, consequently, absorbed dose rates for internal exposure, where the concentration ratio is defined as:

N. A. Beresford (✉)
Centre for Ecology & Hydrology,
Lancaster Environment Centre,
Library Rd., Bailrigg,
Lancaster LA1 4AP, UK
e-mail: nab@ceh.ac.uk

[1] Wildlife is defined here to include all non-domesticated plants, animals and other organisms including feral species (i.e. non-native self-sustaining populations).

$$CR = \left(\frac{\text{Radionuclide whole-body activity concentration } (\text{Bq.kg}^{-1} \text{ fresh mass})}{\text{Radionuclide activity concentration in media (Bq per unit media mass or volume)}} \right)$$

where the media for terrestrial ecosystems is usually soil (Bq kg^{-1} dry mass) and for aquatic ecosystems water (Bq l^{-1}), although for some radionuclides (e.g. ^{3}H, ^{14}C, ^{35}S), whole-body activity concentrations are related to activity concentrations in air (Bq m^{-3}).

This is obviously a simplistic approach that amalgamates many biogeochemical processes. However, to enable consideration of the wide range of radionuclides and wildlife species that may need to be considered in assessments, it currently represents a pragmatic approach that meets the needs of 'prospective' and 'current' exposure (ICRP 2007) assessments. The estimation of whole-body activity concentrations and, consequently, whole-body dose rates (rather than consideration of target tissues) also enables comparison with the available effects data, which originate from studies of external gamma exposure (Garnier-Laplace et al. 2010).

A number of the papers in the current issue of *Radiation and Environmental Biophysics* present data for poorly studied organism types: reptiles (Wood et al. 2010), bats (Gashchak et al. 2010), marsupials (Johansen and Twining 2010) and invertebrates (Dragović and Mandić 2010; Johansen and Twining 2010). In some regulatory assessments, such organisms are often the object of protection (e.g. Copplestone et al. 2003). Other papers present compilations of data previously unavailable in the open literature: Fesenko et al. (2010) provide a review of data for the transfer of radionuclides to marine organisms from the Russian language literature, and Johansen and Twining (2010) summarize data from the grey literature reporting studies conducted in Australia. Takata et al. (2010) demonstrate (for estuarine species) the value of techniques such as inductively coupled plasma (ICP) mass spectrometry and ICP optical emission spectrometry. These techniques can, from a given sample, provide data for a wide range of elements of relevance to radiological assessments many of which are currently poorly understood. Such methodologies are a cost- and resource-effective tool and are also used in the works described by Higley (2010) and Tagami and Uchida (2010).

Whilst these papers, and other recent works, make valuable additions to the data underlying wildlife assessment models, we have to acknowledge that, realistically, we will never have parameters for all of the potential radionuclide–species combinations that may be required in assessments. To overcome this lack of data, a number of approaches have been derived and used in the existing models (Copplestone et al. 2003; Beresford et al. 2008b; USDOE (United States Department of Energy) 2002). In some cases, the resultant parameters used in the models are only intended to be applicable in initial screening level assessments, which aim to be conservative (Copplestone et al. 2003; Brown et al. 2008). Recent intercomparison exercises have shown that the applications of such parameters would generally result in conservative (i.e. high) estimates of internal dose rate as intended, although in some instances, they would underestimate (Beresford et al. 2008a, 2010a, b; Yankovich et al. 2010a). There is a need for scientifically robust approaches to provide parameters for radionuclide–species combinations for which there are no data. The requirements for such parameters will vary and include the need to be inclusive in initial screening level assessment models and the need to consider protected species (for which it may not be possible to obtain data) in more refined assessments.

Three of the papers in this issue of *Radiation Environmental Biophysics* evaluate approaches to estimate radionuclide transfer to wildlife when appropriate data are not available (Higley 2010; Tagami and Uchida 2010; Willey 2010). Biological scaling, or allometry, is the consideration of the effect of size on biological variables. Many different variables have been shown to be dependent on mass (e.g. Peters 1983). The dependence of a biological variable Y on a body mass M is typically characterized by allometric equations of the form $Y = aM^{b}$. Radioecological transfer parameters for terrestrial and aquatic animals for, to date, a limited number of radionuclides have been shown to fit such allometric relationships (e.g. Higley et al. 2003; Vives i Batlle et al. 2009). However, Higley (2010) reports that evidence to support the concept of using allometric scaling functions to estimate radionuclide activity concentrations in plants was inconclusive. This is perhaps not surprising as Tagami and Uchida (2010) present an analysis of tree and crop leaf data that suggest that CR values derived for crops [which are relatively numerous (IAEA 2010)] could be applied to predict radionuclide transfer to trees if data for trees were lacking. The data presented by Higley (2010) suggest that the ionic potential of an element could be used to predict its CR for plants. Willey (2010) demonstrates that radionuclide transfer to plants can be related to plant evolutionary history (or phylogeny), with, for instance, monocots being shown to have lower CR values for the elements considered (Cs, Sr, Co, Cl and Ru) than eudicots. The potential phylogenetic influence of radionuclide uptake has also recently been demonstrated for marine fish by Jeffree et al. (2010).

Much of the available radioecological data for wild species originate from measurements taken for human food chain assessments. These data are, therefore, for tissues consumed by humans (typically for animal muscle). To utilize these data for the purposes of environmental assessment, we need to be able to convert tissue-specific data to whole-body activity concentrations. To enable best use of tissue-specific data to be made, Yankovich et al. (2010b) provide a series of look-up tables for a wide range of elements with whole-body/tissue-specific concentration ratios for marine, freshwater and terrestrial organisms.

The forthcoming IAEA handbook of transfer parameters for wildlife will make a significant contribution to the ongoing development of models to enable assessments of the potential impact of ionizing radiation on wildlife. However, it will be far from complete and is likely to present collated CR values at broad ecosystem and organism levels. There will be an ongoing need to better represent the variability observed in wildlife radionuclide CR values and further develop scientifically robust approaches, such as phylogenetic and allometric relationships, to provide transfer parameter values when data are lacking. The level of 'acceptable' uncertainty in transfer parameters varies with assessment level and, potentially, radionuclide (as some radionuclides contribute relatively little to overall releases). For more refined assessments, there may be the need to develop more mechanistically based models. As far as possible, such developments should not be conducted in isolation from the development of models to assess humans. Many of the factors influencing transfer are predominantly the same for humans (via foodstuffs) and wildlife; some existing human food chain models, especially those for aquatic systems, should be readily adaptable for wildlife assessments. Similarly, there has been much international effort to establish databases of parameters describing the transfer of radionuclides to human foodstuffs (IAEA 2010) and wildlife (http://wiki.ceh.ac.uk/x/-QHbBg). However, as noted by Copplestone et al. (2010), these activities are being conducted separately and in future should be combined to better use resources and ensure consistency between the data underpinning human and wildlife assessments.

Acknowledgments I would like to thank all the authors who contributed to this issue, the IAEA for supporting the three workshops from which the papers arise and Werner Rühm, editor of Radiation and Environmental Biophysics, for agreeing to and supporting this issue. Thanks also go to Mat Johansen (ANSTO), Jordi Vives i Batlle (Westlakes Scientific Consulting), John Twining (ANSTO), Neil Willey (University of the West of England) and Cath Barnett (CEH) for commenting on the draft of this editorial.

References

Avila R, Beresford NA, Agüero A, Broed R, Brown J, Iospje M, Robles B, Suañez A (2004) Study of the uncertainty in estimation of the exposure of non-human biota to ionizing radiation. J Radiol Prot 24:A105–A122

Beresford NA, Barnett CL, Brown J, Cheng J-J, Copplestone D, Filistovic V, Hosseini A, Howard BJ, Jones SR, Kamboj S, Kryshev A, Nedveckaite T, Olyslaegers G, Saxén R, Sazykina T, Vives I Batlle J, Vives-Lynch S, Yankovich T, Yu C (2008a) Inter-comparison of models to estimate radionuclide activity concentrations in non-human biota. Radiat Environ Biophys 47:491–514

Beresford NA, Barnett CL, Howard BJ, Scott WA, Brown JE, Copplestone D (2008b) Derivation of transfer parameters for use within the ERICA Tool and the default concentration ratios for terrestrial biota. J Environ Radioact 99:1393–1407

Beresford NA, Barnett CL, Brown JE, Cheng J-J, Copplestone D, Gashchak S, Hosseini A, Howard BJ, Kamboj S, Nedveckaite T, Olyslaegers G, Smith JT, Vives i Batlle J, Vives-Lynch S, Yu C (2010a) Predicting the radiation exposure of terrestrial wildlife in the Chernobyl exclusion zone: an international comparison of approaches. J Radiol Prot 30:341–373

Beresford NA, Hosseini A, Brown JE, Cailes C, Beaugelin-Seiller K, Barnett CL, Copplestone D (2010b) Assessment of risk to wildlife from ionising radiation: can initial screening tiers be used with a high level of confidence? J Radiol Prot 30:265–284

Brown JE, Alfonso B, Avila R, Beresford NA, Copplestone D, Pröhl G, Ulanovsky A (2008) The ERICA Tool. J Environ Radioact 99:1371–1383

Copplestone D, Bielby S, Jones SR, Patton D, Daniel P, Gize I (2001) Impact assessment of ionising radiation on wildlife. R&D Publication. Environment Agency, Bristol, p 128

Copplestone D, Wood MD, Bielby S, Jones SR, Vives J, Beresford NA (2003) Habitat regulations for stage 3 assessments: radioactive substances authorisations. R&D Technical Report P3-101/SP1a, Environment Agency, Bristol

Copplestone D, Brown JE, Beresford NA (2010) Considerations for the integration of human and wildlife radiological assessments. J Radiol Prot 30:283–297

Dragović S, Janković Mandić Lj (2010) Transfer of radionuclides to ants, mosses and lichens in semi-natural ecosystems. Radiat Environ Biophys. doi:10.1007/s00411-010-0319-8

Fesenko S, Fesenko J, Titov I, Karpenko E, Sanzharova N, Gondin Fonseca AM Brown J (2010) Radionuclide transfer to marine biota species: review of Russian language studies. Radiat Environ Biophys. doi:10.1007/s00411-010-0324-y

Garnier-Laplace J, Della-Vedova C, Andersson P, Copplestone D, Cailes C, Beresford NA, Howard BJ, Howe P, Whitehouse P (2010) A multi-criteria weight of evidence approach for deriving ecological benchmarks for radioactive substances. J Radiol Prot 30:215–233

Gashchak S, Beresford NA, Maksimenko A, Vlaschenko AS (2010) Strontium-90 and caesium-137 activity concentrations in bats in the Chernobyl exclusion zone. Radiat Environ Biophys. doi:10.1007/s00411-010-0322-0

Higley KA (2010) Estimating transfer parameters in the absence of data. Radiat Environ Biophys. doi:10.1007/s00411-010-0326-9

Higley KA, Domotor SL, Antonio EJ (2003) A kinetic-allometric approach to predicting tissue radionuclide concentrations for biota. J Environ Radioact 66:61–74

IAEA (International Atomic Energy Agency) (2006) Fundamental safety principles. Safety Fundamentals SF-1. IAEA, Vienna

IAEA (International Atomic Energy Agency) (2010) Handbook of parameter values for the prediction of radionuclide transfer in terrestrial and freshwater environments. IAEA-TRS 472. IAEA, Vienna

ICRP (International Commission on Radiological Protection) (2003) A framework for assessing the impact of ionising radiation on non-human species. ICRP Publication 91, Ann. ICRP 33. Elsevier, Amsterdam

ICRP (International Commission on Radiological Protection) (2007) Recommendations of the International Commission on Radiological Protection. ICRP Publication 103, Ann. ICRP 37. Elsevier, Amsterdam

ICRP (International Commission on Radiological Protection) (2008) Environmental protection: the concept and use of reference animals and plants, Annals of the ICRP, Publication 108, Ann. ICRP 38. Elsevier, Amsterdam

Jeffree RA, Oberhansli F, Teyssie J-L (2010) Phylogenetic consistencies among chondrichthyan and teleost fishes in their bioaccumulation of multiple trance elements from seawater. Sci Tot Environ 408:3200–3210

Johansen MP, Twining JR (2010) Radionuclide concentration ratios in Australian terrestrial wildlife and livestock: data compilation and analysis. Radiat Environ Biophys. doi:10.1007/s00411-010-0318-9

Peters RH (1983) The ecological implications of body size. Cambridge University Press, Cambridge

Tagami K, Uchida S (2010) Can elemental composition of crop leaves be used to estimate radionuclide transfer to tree leaves? Radiat Environ Biophys. doi:10.1007/s00411-010-0316-y

Takata H, Aono T, Tagami K, Uchida S (2010) Concentration ratios of stable elements for selected biota in Japanese estuarine areas. Radiat Environ Biophys. doi:10.1007/s00411-010-0317-x

USDOE (United States Department of Energy) (2002) A graded approach for evaluating radiation doses to aquatic and terrestrial biota. Voluntary Consensus Technical Standard, DOE-STD-1153–2002. USDOE, Washington, DC

Vives i Batlle J, Balonov M, Beaugelin-Seiller K, Beresford NA, Brown J, Cheng J-J, Copplestone D, Doi M, Filistovic V, Golikov V, Horyna J, Hosseini A, Howard BJ, Jones SR, Kamboj S, Kryshev A, Nedveckaite T, Olyslaegers G, Pröhl G, Sazykina T, Ulanovsky A, Vives Lynch S, Yankovich T, Yu C (2007) Inter-comparison of unweighted absorbed dose rates for non-human biota. Radiat Environ Biophys 46:349–373

Vives i Batlle J, Wilson RC, Watts SJ, McDonald P, Craze A (2009) Derivation of allometric relationships for radionuclides in marine phyla. Radioprotection 44:47–52

Vives i Batlle, J, Beaugelin-Seiller, K, Beresford, NA, Copplestone, D, Horyna, J, Hosseini, A, Johansen, M, Kamboj, S, Keum, D-K, Kurosawa, N, Newsome, L, Olyslaegers,G, Vandenhove, H, Ryufuku, S, Vives Lynch, S, Wood, MD, Yu C (2010) The estimation of absorbed dose rates for non-human biota: an extended inter-comparison. Radiat Environ Biophys (submitted)

Willey NJ (2010) Phylogeny can be used to make useful predictions of soil-to-plant transfer factors for radionuclides. Radiat Environ Biophys. doi:10.1007/s00411-010-0320-2

Wood MD, Beresford NA, Semenov DV, Yankovich TL, Copplestone D (2010) Radionuclide transfer to reptiles. Radiat Environ Biophys. 10.1007/s00411-010-0321-1

Yankovich TL, Vives i Batlle J, Vives-Lynch S, Beresford NA, Barnett CL, Beaugelin-Seiller K, Brown JE, Cheng J-J, Copplestone D, Heling R, Hosseini A, Howard BJ, Kamboj S, Kryshev AI, Nedveckaite T, Smith JT, Wood MD (2010a) An International model validation exercise on radionuclide transfer and doses to freshwater biota. J Radiol Prot 30:299–340

Yankovich TL, Beresford NA, Wood M, Aono T, Andersson P, Barnett CL, Bennett P, Brown J, Fesenko S, Hosseini A, Howard BJ, Johansen M, Phaneuf M, Tagami K, Takata H, Twining J, Uchida S (2010b) Whole-body to tissue concentration ratios for use in biota dose assessments for animals. Radiat Environ Biophys. doi:10.1007/s00411-010-0323-z