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Establishing a database of radionuclide transfer parameters for freshwater wildlife

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A B S T R A C T

Environmental assessments to evaluate potentials risks to humans and wildlife often involve modelling to predict contaminant exposure through key pathways. Such models require input of parameter values, including concentration ratios, to estimate contaminant concentrations in biota based on measurements or estimates of concentrations in environmental media, such as water. Due to the diversity of species and the range in physicochemical conditions in natural ecosystems, concentration ratios can vary by orders of magnitude, even within similar species. Therefore, to improve model input parameter values for application in aquatic systems, freshwater concentration ratios were collated or calculated from national grey literature, Russian language publications, and refereed papers. Collated data were then input into an international database that is being established by the International Atomic Energy Agency. The freshwater database enables entry of information for all radionuclides listed in ICRP (1983), in addition to the corresponding stable elements, and comprises a total of more than 16,500 concentration ratio ($CR_{wo\text{-}water}$) values.

Although data were available for all broad wildlife groups (with the exception of birds), data were sparse for many organism types. For example, zooplankton, crustaceans, insects and insect larvae, amphibians, and mammals, for which there were $CR_{wo\text{-}water}$ values for less than eight elements. Coverage was most comprehensive for fish, vascular plants, and molluscs. To our knowledge, the freshwater database that has now been established represents the most comprehensive set of $CR_{wo\text{-}water}$ values for freshwater species currently available for use in radiological environmental assessments.

1. Introduction

A number of approaches and associated computer codes was developed over the first decade of this century to estimate the exposure of wildlife species (or 'non-human biota') to ionising radiation (e.g., Copplestone et al., 2003; Brown et al., 2008; ICRP, 2008; Strand et al., 2009; USDOE, 2002, 2004). These were

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initially developed to meet national requirements to assess the risk of radioactive releases to the environment on wildlife; latterly, such approaches have been used to address changes in international recommendations that require demonstration that wildlife is protected from the harmful effects of ionising radiation due to radioactive releases into the environment or site contamination (IAEA, 2006; ICRP, 2007), rather than relying on previous, anthropocentric approaches to radiation protection.

As these models have been developed, evaluations of their effectiveness in assessment applications and model inter-comparison exercises have begun (e.g., Beresford et al., 2008a,b, 2010a,b; Wood et al., 2008, 2009; Yankovich et al., 2010a,b; Vives i Batlle et al., 2007, 2011). Such assessments have demonstrated that the largest contribution to variability between model predictions could be attributed to the parameterisation of the transfer components of the models. This reflected the variability of corresponding measured data in natural ecosystems. Furthermore, for many of the radionuclide–organism combinations which need to be assessed, there are no data, which has led to a variety of extrapolation methods being used (Beresford, 2010). An International Atomic Energy Agency (IAEA) working group evaluating available assessment models for wildlife suggests that there is a need to share knowledge of radionuclide transfer to biota and to provide authoritative collations of available data (Beresford et al., 2009). It was suggested that a document for biota, equivalent to the IAEA (2009, 2010) handbook on transfer parameters for human food chains, should be produced. This recommendation was accepted by the IAEA and a working group was established to produce a wildlife transfer parameter handbook (Howard et al., 2013). Concurrently, the International Commission on Radiological Protection (ICRP, 2008) published the first elements of its proposed framework for environmental protection, which is based around a series of Reference Animals and Plants (RAPs). This report presented look-up tables of dose conversion factors (to convert environmental and organism radionuclide activity concentrations to dose rates), along with a consideration of biological effects of exposure; however, it did not present parameters to predict the radionuclide activity concentrations in organisms. To address this, a task group was initiated to develop a subsequent report presenting transfer parameters for the ICRP's RAPs (Strand et al., 2009).

Most of the available models assessing wild species use activity concentration ratios ($CR_{\text{wo-media}}$) of whole-organism (or whole-body)-to-medium. For freshwater species, the medium is usually water, where $CR_{\text{wo-water}}$ is defined as

$$CR_{\text{wo-water}} = \frac{\text{Activity concentration in whole organism}\left(\text{Bq kg}^{-1}\text{ fresh weight}\right)}{\text{Activity concentration in}\left(\text{filtered}\right)\text{water}\left(\text{Bq L}^{-1}\right)}$$

Acknowledging that the CR approach has some limitations (Vives i Batlle et al., 2008; Wood et al., 2013), it currently represents the most pragmatic option compared with other methods of quantifying radionuclide transfer, as there is a relatively large amount of relevant information available for different organisms, elements and ecosystems. It is also relatively simple to use and consistent with approaches applied in some human and ecological risk assessment models (IAEA, 2009, 2010). Given this, and as it is already commonly used in most available wildlife assessment models (e.g., Brown et al., 2008; Copplestone et al., 2003; USDOE, 2004), both the IAEA and ICRP have accepted it as, at least, an initial approach to recommend (Strand et al., 2009; IAEA, in preparation). Whole organism, rather than tissue-specific, CR values are used for wildlife assessments to enable comparison to the available radiation effects data, which are largely presented as whole-organism dose rates for external gamma-irradiation studies (Garnier-Laplace et al., 2010).

In this paper, we describe and discuss the data collated to derive radionuclide $CR_{\text{wo-water}}$ values for freshwater wildlife which have subsequently been used to develop an IAEA handbook and ICRP report (IAEA, in preparation; Strand et al., 2009). Some discussion of the terrestrial and marine datasets can be found elsewhere (Howard et al., 2013; Copplestone et al., 2013; Wood et al., 2013; Brown et al., 2013).

2. Data compilation

Data were collated via an on-line database (http://www.wildlifetransferdatabase.org/), which is described fully by Copplestone et al. (2013). The on-line database allowed free data entry by any individual, with entries being quality controlled prior to acceptance. However, the majority of the freshwater data was collated by the authors of this paper from national grey literature, Russian language publications, and refereed papers.

The database includes all radionuclides listed in ICRP (1983), in addition to the corresponding stable elements.

Although not presented here, the database described by Copplestone et al. (2013) also includes a substantial number (approximately 20,000 values) of freshwater $CR_{\text{wo-sediment}}$ values (i.e. relating whole-organism activity concentrations to the dry weight activity concentration in sediment). The majority of these data is from monitoring programmes collated from the Canadian uranium industries. Whilst we acknowledge that some assessors may use this parameter (e.g., Thompson et al., 2005), we have neither summarised these values here, nor are they reported by the Strand et al. (2009) or IAEA (in preparation). This is because such data are extremely site-specific, combining both $CR_{\text{wo-water}}$ and the sediment-water partition coefficient (K_d).

2.1. Freshwater ecosystems and broad wildlife groups

Freshwater data could be categorised as either coming from 'Freshwater – flowing' (i.e. rivers and streams) or 'Freshwater – lake' (i.e. lakes and other static water bodies), although in cases where the water body type was not known, a more generic 'Freshwater' ecosystem category was assigned.

Data were also classified into broad wildlife groups and, where appropriate, a level of subcategory classification was also used (Table 1). This is consistent with, and will provide useful input to, the approaches used in existing models; however, "broad wildlife groups" may be referred to by other terms, such as "reference organism", "representative species", "feature species" or "receptor" in the different approaches that are used internationally (see IAEA, in press) (Table 1). The selected broad freshwater wildlife groups and sub-categories are suitably broad to be applicable worldwide and encompass a range of trophic levels, organisms likely to be sensitive to ionising radiation, protected freshwater species, organism types that are easy to sample (and in many cases, sampled in existing monitoring programmes), and organisms likely to receive relatively