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Short communication

Radionuclide biological half-life values for terrestrial and aquatic wildlife

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ABSTRACT

The equilibrium concentration ratio is typically the parameter used to estimate organism activity concentrations within wildlife dose assessment tools. Whilst this is assumed to be fit for purpose, there are scenarios such as accidental or irregular, fluctuating, releases from licensed facilities when this might not be the case. In such circumstances, the concentration ratio approach may under- or over-estimate radiation exposure depending upon the time since the release. To carrying out assessments for such releases, a dynamic approach is needed. The simplest and most practical option is representing the uptake and turnover processes by first-order kinetics, for which organism- and element-specific biological half-life data are required. In this paper we describe the development of a freely available international database of radionuclide biological half-life values. The database includes 1907 entries for terrestrial, freshwater, riparian and marine organisms. Biological half-life values are reported for 52 elements across a range of wildlife groups (marine = 9, freshwater = 10, terrestrial = 7 and riparian = 3 groups). Potential applications and limitations of the database are discussed.

1. Introduction

To estimate the uptake of radionuclides by wildlife, the whole organism[1] concentration ratio ($CR_{wo\text{-}media}$) is most commonly used (e.g. Beresford et al., 2008a; Hosseini et al., 2008; Strand et al., 2009; Yankovich et al., 2013; Howard et al., 2013; IAEA, 2014). This is defined as the ratio of radionuclide activity concentration in the whole organism to that in the surrounding medium:

$$CR_{wo-media} = \frac{Activity\ concentration\ in\ whole\ organism\ (Bq\ kg^{-1})fresh\ mass}{Activity\ concentration\ in\ media}$$

where, media maybe soil (Bq kg^{-1} dry mass), water (Bq L^{-1}) or air (Bq m^{-3}) dependent upon ecosystem and radionuclide.

The concentration ratio is an aggregated transfer parameter, incorporating within it the physical, chemical and biological factors affecting the uptake of radioelements by biota in an empirical way. The turnover of elements differs depending on, for instance,

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[1] Organism less both gastrointestinal tract contents and fur/feathers.

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ingestion or sorption processes, their chemical and biochemical behaviour and the requirements of the organism for the element or its analogue. Instantaneous equilibrium between the organism and the media activity concentrations is assumed in all models that use the $CR_{wo\text{-}media}$ concept (e.g. USDOE, 2002; Brown et al., 2008; Beresford et al., 2008b).

Although some organisms may equilibrate relatively rapidly with radionuclides present in the surrounding media (timescales in the order of days to a few months), there are scenarios whereby equilibrium cannot be assumed. For example, after a short-term pulsed release of ^{99}Tc activity into the marine environment, the activity concentration in lobsters along the dispersion path begins to increase gradually with time. This is because lobsters have a biological half-life for technetium in the range of 60–300 days (Pentreath, 1981). Technetium is soluble in seawater and the pulsed release will clear quickly from the area of sea where lobsters live. Therefore, its concentration in seawater will decrease sharply within a few days after a pulse discharge. Lobster specimens sampled from the area within days of the discharge, when water concentrations have declined, may appear to have an anomalously high $CR_{wo\text{-}media}$ value because they retain the technetium that they absorbed whilst seawater concentrations were high. Conversely, if sampled on the day of discharge $CR_{wo\text{-}media}$ would be low as little uptake would have occurred but seawater concentrations would be high.

If the timeframe of interest is long (e.g. years or decades of planned authorised discharges, involving continuous releases or gradual changes in discharge concentrations) then the $CR_{wo\text{-}media}$ approach is currently considered to be sufficient (Strand et al., 2009; IAEA, 2014). However, if unplanned release scenarios involving abrupt changes in discharge concentrations are being modelled then the $CR_{wo\text{-}media}$ approach may be inadequate and dynamic models of radionuclide transfer to biota may be a better assessment tool. This is especially true for organisms that respond slowly to a change in ambient radioactivity concentration (Vives i Batlle, 2012), and this has been highlighted in the post-accident assessment of the Fukushima accident (e.g. Kryshev and Sazykina, 2011; Buesseler et al., 2011). Such dynamic models need to have rate constants, or biological half-life values ($T_{1/2b}$), describing the loss of radionuclides from organisms. Whilst the biological half-life is typically defined to described the rate of loss of radionuclide from an organism, it is also often used in the estimation of uptake (e.g. Whicker and Schultz, 1982; Vives i Batlle et al., 2008).

At higher (more detailed) assessment tiers, the USDOE (2002) RESRAD BIOTA approach incorporates some simple foodchain modelling ability using allometric (or mass) expressions; these include allometric biological half-life relationships for a limited number of radionuclides (Higley et al., 2003). Further exploitation of the allometric $T_{1/2b}$ approach to other radionuclides was not possible because of a lack of $T_{1/2b}$ data from which to derive the relationships.

Commonly used assessment tools exploit the $CR_{wo\text{-}media}$ model with the tacit assumption that this is generally likely to be conservative. However, it has been noted that wildlife assessment models do not include direct deposition of radionuclides to vegetation surfaces and that under conditions of continuous aerial discharge this may contribute a significant proportion of radioactivity entering food chains (Copplestone et al., 2010). At the time of writing this paper we are aware that the IAEA is working on an assessment approach for wildlife which does include this deposition pathway (see Beresford et al., 2015a), but, which as a consequence, requires some knowledge of the biological half-life of radionuclides in wildlife. Similarly, reported $CR_{wo\text{-}media}$ values are, in theory at least, equilibrium values and an increasing number of radioecological studies utilise inductively coupled plasma mass spectrometry (ICP-MS) analyses to derive $CR_{wo\text{-}media}$ values from stable element data which should be at equilibrium (e.g. Barnett et al., 2011, 2014; Higley, 2010; Tagami and Uchida, 2010; Takata et al., 2010; Sheppard, 2013). Application of an equilibrium $CR_{wo\text{-}media}$ value to a short-lived radionuclide will over-estimate the resultant whole organism activity concentrations and dose rate. IAEA (2010) propose an approach whereby equilibrium activity concentrations could be corrected (to $CR_{wo\text{-}corrected}$) for application to short-lived radionuclides, but this again requires some knowledge of biological half-life:

$$CR_{wo-corrected} = CR_{wo-media} \times K \quad (2)$$

where:

$$K = \frac{T_{1/2p}}{T_{1/2b} + T_{1/2p}} \quad (3)$$

where, $T_{1/2p}$ is the physical half-life of the radionuclide under assessment.

There are, as demonstrated here, a number of requirements for a comprehensive database of wildlife radionuclide $T_{1/2b}$ values. However, such a database has to date not been available. In this paper we describe the development of a $T_{1/2b}$ database for wildlife.

2. Methods

The work described here was conducted by an international working group under the auspices of the International Atomic Energy Agency's MODARIA programme (see: http://www-ns.iaea.org/projects/modaria/). The review and compilation of $T_{1/2b}$ values was divided amongst the group members depending upon their prior expertise (i.e. by ecosystem and/or organism).

Prior to beginning the review a recording sheet, in MS Excel™, was designed to allow easy collation of the various components into the final database. The recording sheet entry fields are listed in Table 1. The wildlife group categorisations were broadly compatible with those used in the Wildlife Transfer Database (as described by

Table 1
Parameters included in the database template.

Parameter
Entry ID
Common name (English)
Latin name
Wildlife group
Ecosystem (Marine, Freshwater, Terrestrial or Riparian)
Radionuclide
Live weight (kg)
Developmental stage (e.g. adult, tadpole etc.)
Compartment (whole organism or specific tissue)
Experiment type
Length of study (d)
Temperature (°C)
Biological half-life (d) (four columns were included to enable recordings of multiple loss components)
Fraction released (four columns, one for each component of loss)
Number of measurements (made in study) to determine $T_{1/2b}$
Measurement interval (d)
Changeover time (d) (repeated for multiple loss components)
Percentage left at time (t)
Time (t) (d) (referring to the above percentage left)
Organism dimensions (length, width, depth) (m)
Sex
Elimination rate (i.e. k; d^{-1})
Reference
Notes
Comment on if the value has been independently quality controlled