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Short communication

A new version of the ERICA tool to facilitate impact assessments of radioactivity on wild plants and animals

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ABSTRACT

A new version of the ERICA Tool (version 1.2) was released in November 2014; this constitutes the first major update of the Tool since release in 2007. The key features of the update are presented in this article. Of particular note are new transfer databases extracted from an international compilation of concentration ratios ($CR_{wo\text{-}media}$) and the modification of 'extrapolation' approaches used to select transfer data in cases where information is not available. Bayesian updating approaches have been used in some cases to draw on relevant information that would otherwise have been excluded in the process of deriving $CR_{wo\text{-}media}$ statistics. All of these efforts have in turn led to the requirement to update Environmental Media Concentration Limits (EMCLs) used in Tier 1 assessments. Some of the significant changes with regard to EMCLs are highlighted.

1. Introduction

The shift in focus from a radiological protection framework based solely on humans to one encompassing impacts on the environment (ICRP, 2007) provided the impetus for the development of The ERICA Integrated Approach (Larsson, 2008). A key component of the approach is the quantification of environmental risk involving, as an initial step, the combination of data on environmental transfer and dosimetry to provide a measure of wildlife exposure. These values, in the form of dose rates, or corresponding activity concentrations for screening purposes, can then be compared with benchmarks, derived from exposure levels at which detrimental effects are known to occur, for the estimation of risk. The key (radionuclide-specific) parameters used in deriving dose rates from measured or modelled activity concentrations of radionuclides in soil or water are concentration ratios, $CR_{wo\text{-}media}$ (i.e. ratio of activity concentration in the whole body of an organism to that in media), distribution coefficients, K_ds, (i.e. ratio of activity concentration in sediment to that in water) and dose conversion coefficients, DCCs (i.e. dose rate per unit activity concentration in the organism or media). The ERICA approach is based around the concept of reference organisms, ROs, defined as "*a series of entities that provide a basis for the estimation of radiation dose rate to a range of organisms which are typical, or representative, of a contaminated environment. These estimates, in turn, would provide a basis for assessing the likelihood and degree of radiation effects*". In view of the large data sets underpinning the assessment approach and the potential to introduce errors when performing numerous calculations by hand, a supporting computer-based tool, the ERICA Tool, was developed as described in Brown et al. (2008). The software was made freely available for download (http://www.erica-tool.com and http://www.erica-tool.eu/ [1]). The Tool has been designed to provide robust prognoses over a wide range of applications, although particular emphasis has been placed upon planned, routine discharges of radionuclides, and it gives the option to cover a comprehensive list of radioisotopes and organism types.

The ERICA Tool adopts a tiered structure. Tiered approaches have become a standard means of structuring risk assessments for chemicals (e.g. European Food Safety Authority, 2013) and radioactivity (e.g. USDoE, 2002). For the particular approach used in the ERICA Tool, there are two generic screening tiers and a third site-

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[1] Note this is an additional, new web-address for downloading the tool.

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specific tier. The first Tier is very simple, based around Environmental Media Concentration Limits, EMCLs, defined as the activity concentration of a given radionuclide in media (soil, sediment water) that will result in a dose-rate to the most exposed reference organism equal to the screening dose-rate. The first Tier requires minimal input from the assessor. The generation of EMCL values also has a prerequisite that complete coverage of $CR_{wo\text{-}media}$ values (and DCCs) exist for all possible combinations of ROs and radionuclides. The second Tier, although still a screening tier, is used to calculate dose rates explicitly and requires more detailed input from the assessor allowing for scrutiny and editing of default parameters in the process. A key procedural element of Tier 2 involves the application of Uncertainty Factors, UFs. Such factors reflect knowledge concerning probability distribution functions and provide a way of incorporating conservatism into the assessment by allowing the consideration of high percentile values in underlying parameters.

Following its release, the ERICA Tool has been widely employed in various applications worldwide. Examples include: consideration of potential environmental impacts from deep geological disposal facilities in various European countries (Smith and Robinson, 2008; Robinson et al., 2010; Posiva, 2014; Torudd, 2010; Jaeschke et al., 2013); scoping analyses in line with newly introduced environmental regulations (Hosseini et al., 2011); quantifying environmental impacts from operating and planned nuclear power stations (Nedveckaite et al., 2011; Vandenhove et al., 2013; Li et al., 2015); to derive radiological quality guidelines for Australian U mining sites (Doering and Bollhöfer, 2016); assessments of the impact of near-surface radioactive waste repositories in Europe and Australia (Nedveckaite et al., 2013;ANSTO, 2014); U-mining impact assessments (ERA, 2014); assessing releases from medical facilities (Carolan et al., 2011) and for exposure estimates for biota following accidents (Garnier-Laplace et al., 2011; Fuma et al., 2015). The ERICA Tool has also been used in model intercomparison and scenario application under the auspices of International Atomic Energy Agency, IAEA, programmes (Vives i Batlle et al., 2007, 2011; Beresford et al., 2008a, b, 2010; Johansen et al., 2012; Stark et al., 2015; Yankovich et al., 2010). The ERICA Tool generally compared well to other approaches in these intercomparison exercises. Components of the approach were also adopted by the United Nation's Scientific Committee on the Effects of Atomic Radiation in their recent analysis of the impacts of radiation on the environment following the 2011 accident at the Fukushima Dai-ichi nuclear power plant (UNSCEAR, 2014; Strand et al., 2014; Vives i Batlle et al., 2014). Training in the use of the Tool has been relatively comprehensive (see: https://wiki.ceh.ac.uk/x/dIPJBg) with a bespoke 'Questions & Answers' webpage having been developed (see: https://wiki.ceh.ac.uk/x/r48ZBw).

During the period from its launch in 2007 to the present time, there have been several versions released of the tool where various 'bugs', that were identified by the developers and users, have been resolved. The one major addition to the functionality introduced post release has been the option (at Tiers 2 and 3) to select which activity concentration values from empirically based datasets are used in the derivation of missing data values. For example, in a case where you have values for organism A and B and wish to derive activity concentration data for environmental media and an organism C, the option now exists to either use data for organism A or organism B or a combination of the two.

In the years since 2007, there have been significant developments on technical subjects that have ramifications for components of the ERICA integrated approach. Furthermore, the need to provide modifications to the ERICA Tool have been driven by the establishment of updated $CR_{wo\text{-}media}$ databases (Copplestone et al., 2013), the desire to provide consistency with IAEA (2014) and ICRP (2008, 2009) approaches, user feedback, participation in various IAEA intercomparison exercises (as noted above) and further evaluation of the ERICA Tool (e.g. Brown et al., 2013). This has led to the major update and release of a new version of the ERICA Tool (Version 1.2 released in November 2014). A further minor interim update (Version 1.21) has also been planned for January 2016 to make further amendments to $CR_{wo\text{-}media}$ values and hence EMCLs (see Appendix to this paper). This paper provides an overview and justification of the major changes that have been made to the software in its latest edition.

2. Version 1.2 of the ERICA tool

The latest version of the ERICA Tool (Version 1.2) incorporates a number of substantial modifications.

2.1. Default radionuclides

To be consistent with the ICRPs developing environmental protection framework (ICRP, 2008; 2009) the following radionuclides have been added to the default list available from all Tool tiers: ^{140}Ba, ^{45}Ca, ^{51}Cr, ^{252}Cf, ^{192}Ir, ^{140}La, ^{231}Pa and ^{65}Zn. This has required the generation of corresponding values for CRs, K_ds and DCCs for each of the new default radionuclides.

2.2. Default reference organism list

There have been a few changes made to the default reference organism list (Table 1). A freshwater reptile has been added to reflect the observation that there are European protected freshwater reptile species (the original ERICA Tool was stated to have reference organism compatible to all European protected species). Conversely, "bird egg" has been removed primarily because there were no empirical $CR_{wo\text{-}media}$ values available but also to be consistent with other organisms for which life stages were not considered. Other changes were to bring nomenclature more inline with that used in IAEA (2014) and Copplestone et al. (2013); a few further changes are required to improve compatibility in future releases of the Tool (e.g. polychaete worm will be changed to annelid).

2.3. $CR_{wo\text{-}media}$ values

When first released in 2007, the ERICA Tool (Brown et al., 2008) contained the most comprehensive and well documented $CR_{wo\text{-}media}$ database available for wildlife (Beresford et al., 2008c; Hosseini et al., 2008).

Evaluation of the various models (including the ERICA Tool) available to conduct environmental radiological assessments identified that the transfer component contributed significantly to the uncertainty of assessments (e.g. Beresford et al., 2008b). Consequently, the wildlife transfer database (WTD; www.wildlifetransferdatabase.org/) (Copplestone et al., 2013) was established to collate $CR_{wo\text{-}media}$ values and assist the IAEA and ICRP in the production of reports on recommended transfer parameter values (IAEA, 2014; ICRP, 2009). The WTD was initially populated using the ERICA Tool database. Many additional data were subsequently input including, a review of Russian language literature, and data from Canadian monitoring programmes associated with nuclear power plants, U-mining and related industries (Copplestone et al., 2013).

In 2011, data in the WTD were summarised and used by the ICRP to produce a report on recommended transfer parameters for its Reference Animals and Plants (RAPs) (ICRP, 2009). Concurrently, summaries of the WTD were used by the IAEA to produce a

Table 1
Reference organisms for which changes have been made (Ecosystem: F = Freshwater; M = marine; T = Terrestrial).

Original	Revised	Reason for change
Bivalve mollusc (F)	Mollusc – bivalve	Internal consistency (Gastropod is also a mollusc)
Gastropod (F)	Mollusc – gastropod	Internal consistency
Missing (F)	Reptile (F)	Protected species in some parts of Europe - a requirement to include
(Wading) bird (M)	Bird (M)	The word 'Wading' was redundant (many seabirds considered not just waders)
Bivalve mollusc (M)	Mollusc – bivalve (M)	Internal consistency
Sea anemone or true coral – polyp (M)	Sea anemone/true coral (M)	Unnecessary to have 2 two 'Sea anemone or true coral categories' – most exposed 'geometry' selected
Sea anemone or true coral – colony (M)	Removed	Unnecessary to have 2 two 'Sea anemone or true coral categories' – most exposed 'geometry' selected
Bird egg (T)	Removed	Conspicuous as only non-adult terrestrial form and lack of $CR_{wo\text{-}media}$ data rendered inclusion untenable
Gastropod (T)	Mollusc – gastropod	Internal consistency
Mammal (Deer) (T)	Mammal – large	Since mammal $CR_{wo\text{-}media}$s are generic it was more informative (and does not lead to misinterpretation) to relate the RO name to 'geometry' as this actually affects the dose rate for the RO
Mammal (Rat) (T)	Mammal – small-burrowing	Since mammal $CR_{wo\text{-}media}$ s are generic it was more informative (and does not lead to misinterpretation) to relate the RO name to 'geometry' as this actually affects the dose rate for the RO
Soil invertebrate (worm) (T)	Annelid	Revised version is taxonomically correct

handbook of transfer parameters for wildlife (IAEA, 2014; Howard et al., 2013; Yankovich et al., 2013).

At the time the WTD was used to prepare the IAEA and ICRP reports, it contained information from 523 references. There were more than 50,000 lines of data entered into the WTD representing 86,979 CR values for 1438 species and 71 elements. Of these, 24,884 were $CR_{wo\text{-}sediment}$ values for freshwater organisms; these were used by neither the ICRP nor IAEA as they were likely to be highly site-specific given that they incorporate transfer processes from sediment-to-water and from water-to-biota.

Between 2011, when the WTD was used to provide values for the ICRP and IAEA reports, and the end of 2013 (when the ERICA Tool database was updated), about 17,000 additional $CR_{wo\text{-}media}$ values were added (Beresford et al., 2014). These new inputs include data for: representative species of the ICRPs RAPs from a UK forest; monitoring data from Finland and Japanese estuaries; Canadian wildlife; Pu from US weapons testing programme sites; wild plants and invertebrates from north western USA; and an *ad-hoc* review of refereed literature published after 2011. Additionally, data already in the WTD from Australia were reviewed with reference to original source reports not previously considered and amended where required (see Hirth et al., 2014). Amongst the additional entries were the first reported transfer data applicable to the ICRP RAP bee (Barnett et al., 2014; Sheppard et al., 2010). The number of elements included in December 2013 totalled 80.

The revised WTD was quality checked by considering the degree of variation in the data for each organism-element combination and the change between WTD versions. This identified a number of errors (e.g. double entry of data, unit conversion errors and entries based on a dry matter rather than the required fresh weight basis) all of which were rectified. Revised summary values were generated from the WTD in December 2013 (available from: www.wildlifetransferdatabase.org/). Fig. 1 presents changes in $CR_{wo\text{-}media}$ values from the ERICA database through the IAEA report to the WTD as of December 2013 using terrestrial reptiles as an example. This demonstrates the amount of additional data added (in this case mostly from the review of Wood et al., 2010) and quality control (e.g. the change in the ERICA Cs and Sr values is largely the consequences of errors noted by Barnett et al. (2009) whilst the change in natural radionuclide values from 'IAEA TRS' to 'WTD 2013' is mostly the consequence of the re-evaluation of Australian data (Hirth et al., 2014).

The December 2013 version of the WTD was used to revise the ERICA Tool. A decision was made to use data at a broad wildlife group level rather than at the sub-category level, e.g. marine fish $CR_{wo\text{-}media}$ data selected as opposed to benthic fish and pelagic fish. Analyses of the current WTD has suggested that the use of the sub-categories is currently not justified (Beresford et al., 2013; Wood et al., 2013, 2014).

2.3.1. Extrapolation approaches for transfer in the ERICA tool

In total, about 1500 CR values were required in the process of populating underlying default databases and hence deriving EMCL values for version 1.2 of the Tool. From this number, approximately 50%, compared to less than 40% in v1.0 of the Tool (which considered fewer elements), could be derived from empirical data alone. The remaining values required the application of extrapolation or guidance approaches to provide missing data building on the method first applied in the original release of the ERICA Tool (Beresford et al., 2008c). This included the consideration of analogue radionuclides not present on the revised ERICA default list but available through the more comprehensive WTD data collation (e.g. application of Cu data to provide Ag parameters). However, amendments to the approach were made reflecting experience gained in the application of the Tool. In a study comparing $CR_{wo\text{-}media}$ values in the ERICA Tool derived using extrapolation approaches with more recently available empirical data from the WTD, Brown et al. (2013) provided an assessment of how well the original ERICA Tool extrapolation approaches had worked. Consequently, a recommendation was made that there should be some simplification of the various options (e.g. simply use 'similar reference organism' rather than the original dichotomy of 'similar taxonomy' and 'similar reference organism'). Furthermore, that selecting a $CR_{wo\text{-}media}$ value for a 'similar reference organism' should be used as a preferred approach to select $CR_{wo\text{-}media}$ values for screening level assessments. Advice was given against the application of data from the marine to freshwater ecosystem (an approach used in the initial Tool version). However, it was noted that the WTD contains data for (comparatively highly saline) estuarine environments and that these may be appropriate surrogates for marine systems and *vice-versa*.

Further refinement of the application of extrapolation approaches to derive surrogate values through a more elaborate consideration of probability distribution functions (PDFs) was also

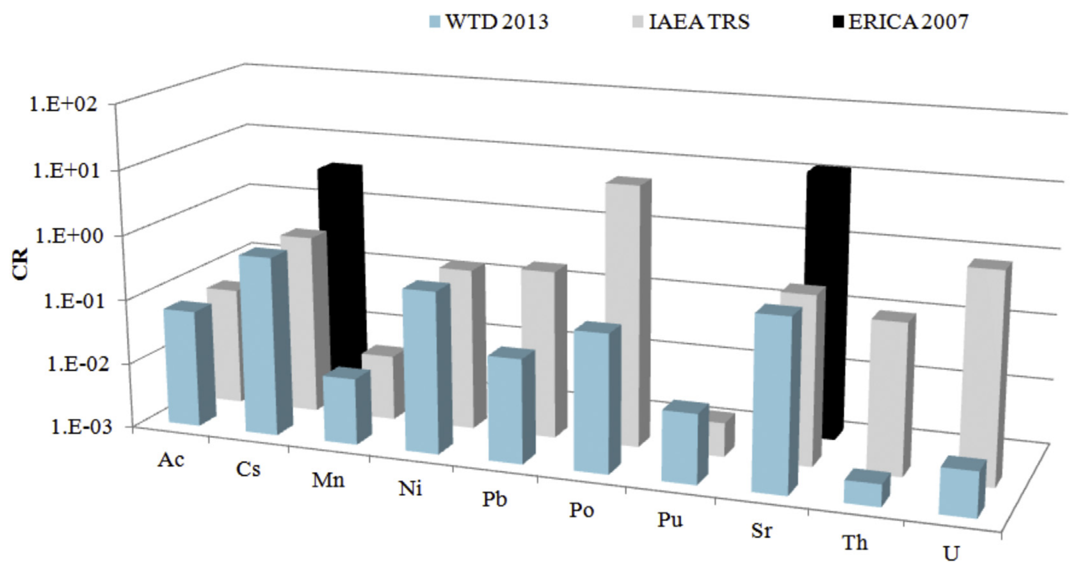

Fig. 1. A comparison of $CR_{wo\text{-}soil}$ values for terrestrial reptiles from the ERICA database (*ERICA 2007*), IAEA technical report series handbook (*IAEA TRS*) and WTD in December 2013 (*WTD 2013*).

used to improve the approach. In this regard, an alternative to using a best estimate and exponential PDF, as originally employed in the ERICA Tool, is to use, more expansively, the statistics provided by a surrogate dataset. By way of example, this might include the arithmetic mean, standard deviation and actual (or assumed) distribution of the biochemical analogue or similar organism dataset being used to provide surrogate information. This also facilitates the avoidance of exponential distributions that tend not to reflect the distributions observed for (ratio-based) transfer parameters characterising natural systems. Such parameters are often better described by log-normal distributions (Sheppard, 2005). The requirement to adopt this approach has been further promoted through dialogue between the ERICA Tool developers and end users (see Thorne, 2013; Avila et al., 2014). In the latest release of the ERICA Tool, efforts have been made to apply log-normal distributions to surrogate datasets as far as practicable/justifiable.

The refined extrapolation approach used to derive the default $CR_{wo\text{-}media}$ values in v1.2 of the Tool are outlined in Table 2.

Some additional words of explanation are required in relation to Approach 10 “Combined method”. This code not only covered cases where the various methods tabulated (i.e. 1–9 in Table 2) were combined but also instances where the variance of underlying datasets was poorly characterised. Hosseini et al. (2013) promoted the use of Bayesian statistics in radioecology by considering various cases where relevant but, indirectly applicable, datasets were available to the situation in hand. Of particular interest was a case wherein relevant external data were available, but no concomitant information about the variance could be derived, or wherein other (qualitative) information rather than data was available for the variance. In such a situation, the prior distributions of mean and variance can be specified independently. If no prior information is available for the variance, a so called non-informative prior for the variance can be used. With these prior distributions the *conditional* posterior distributions of the mean and variance attain the same functional form as the prior, but the joint conjugate posterior does not. Therefore, these prior distributions are often referred to as *semi-conjugate* prior distributions. To improve the situation for the ERICA $CR_{wo\text{-}media}$ database in terms of deriving more robust parameter estimates various methods, including a Bayesian updating approach, were applied. A decision was made to look more closely at cases where the number of available data were equal to, or less than, five. An assumption was made that any parameter derived in these cases suffered from a lack of credibility as they were based on few data points. After the identification of such cases, the updated gap-filling options were accessed to discern which analogues would have been used if no data had been available. In this way a surrogate organism or radionuclide was assigned for each case where possible. Hence, depending on the availability of a surrogate dataset as well as statistical information, different situations were dealt with as covered in Table 3.

The full catalogue of $CR_{wo\text{-}media}$ values as used in v1.2 of the Tool is provided in Appendices I–III.

Table 2
Revised extrapolation approaches used in the ERICA Tool for deriving $CR_{wo\text{-}media}$.

Ref code (Preferred?)	Descriptor
1 (Preferred)	Similar reference organism
2 (Preferred)	From published review
3 (Preferred)	Modelling approaches
4 (Preferred)	Element of similar biogeochemistry for reference organism
5	Element of similar biogeochemistry for similar reference organism
6	Highest available value
7	Estuarine data
8	Highest animal value
9 (Least preferred)	Highest plant/algae value
10 (Least preferred)	Combined method[a]

[a] using one or more of the above approaches and/or methods to derive a missing SD value.

Table 3
An overview of categorisation of cases where N ≤ 5 in updating the ERICA $CR_{wo\text{-}media}$ databases.

Statistical data for organism of interest		Surrogate dataset	Approach
Mean	SD		
A*	A	A	*Semi – conjugate (non-informative)*
A	A	NA**	*Using data as it is (assume lognormal PDF)*
A	NA	A	*Using ratio of SD to mean for the surrogate to derive the missing SD from the data mean*
A	NA	NA	*Using mean and assume exponential PDF*

*A – available; **NA - not available.

2.4. Distribution coefficients in the ERICA tool

Distribution coefficients, K_ds, have received less attention than $CR_{wo\text{-}media}$ values in the development of the revised ERICA Tool databases with heavy reliance being placed upon the values reported in IAEA compendia (IAEA, 2004; IAEA, 2010). Nonetheless, in-line with the descriptions given above an attempt was made to minimise the, previously ubiquitous, use of marine K_ds in freshwater ecosystems. Only a single value (for iridium) still relies on this approach.

For marine K_ds, with values entirely taken from IAEA (2004), some additional statistical manipulations were required reflecting limitations within the original dataset. The values reported in TRS-422 are 'recommended values' but a note is made to the effect that when minimum and maximum values are required, such data can be assumed to be within one order of magnitude of the recommended value. The approach used in deriving the supporting database for the revised ERICA Tool has been to assign these lower and upper bounds as 5th and 95th percentiles and then to derive concomitant means and standard deviations from these values as shown below:

$$Min = \frac{recommended\ value}{10} = 5^{th} percentile \quad (1)$$

$$Max = recommended\ value \times 10 = 95^{th} percentile \quad (2)$$

Mean (μ) and standard deviation (σ) were then derived assuming a log-normal distribution such that:

$$\mu = \frac{[\ln(Max) + \ln(Min)]}{2} \quad (3)$$

$$\sigma = \frac{[\ln(Max) - \ln(Min)]}{2 \times 1.6449} \quad (4)$$

and, for a lognormal distribution, the arithmetic mean (expected value) and standard deviation can be derived by the following equations:

$$\text{Mean} = e^{\mu + 0.5\sigma^2} \quad (5)$$

$$\text{Standard deviation} = \sqrt{\left(e^{\sigma^2} - 1\right) \cdot e^{2\mu + \sigma^2}} \quad (6)$$

2.5. Dosimetric parameters in the ERICA tool

Some changes to dosimetric parameters have been required. The marine macroalgae DCC has been updated using a geometry consistent with ICRP (2008) (increase in mass from 0.0065 kg to 0.652 kg). This rectifies the inconsistency identified by Amato and Italiano (2014). Furthermore, corrections were made to the 'Lichen & bryophytes' external DCCs. The original external (on soil beta-gamma) DCCs were found to be orders of magnitude lower than the corrected values derived using the 'Add organism' module in the Tool for the relevant 'Lichen & bryophytes' geometry. A correction has also been made for terrestrial amphibian and reptile where the original default occupancy factors were considered to lack conservatism and to be inconsistent with respect to other Reference Organisms when allowance is made for the life history of these biota types. Default occupancy factors have now been set to 100% 'in soil' for both organism groups.

An anomaly has also been recognised in the original version of the ERICA Tool concerning the application of certain dose-rate benchmarks in aquatic ecosystems. The application of a benchmark of 400 $\mu Gy\ h^{-1}$ for all aquatic organisms based on an interpretation of previous collations about the effects of ionising radiation on (populations of) wildlife (IAEA, 1992; UNSCEAR, 1996) was considered to be lacking the more nuanced understanding we, in fact, have with regards to radiosensitivity in marine and freshwater systems. A dose-rate benchmark of 40 $\mu Gy\ h^{-1}$ now applies to aquatic mammals and birds, retaining 400 $\mu Gy\ h^{-1}$ for all other aquatic organisms; this is now more consistent with the approach adopted in USDoE (2002).

2.6. Environmental media concentration limits in the ERICA tool

EMCLs are defined as the activity concentration in the selected media: soil or air (H, C, S and P only) in terrestrial environments, water or sediment in aquatic environments that would result in a dose-rate to the most exposed organism equal to that of the selected screening dose-rate. The first stage in the EMCL derivation involves the calculation of intermediate EMCL values for all reference organisms for a selected radionuclide and media (Equation (7)). The minimum intermediate EMCL value across all organisms is then selected to define the final EMCL value for a particular radionuclide. The limiting organism may be different for different radionuclides.

$$\text{EMCL} = \frac{SDR}{\text{F}} \quad (7)$$

where: F = the maximum dose rate that an organism will receive for a unit activity concentration of a given radionuclide in an environmental medium ($\mu Gy\ h^{-1}$ per $Bq\ l^{-1}$ (water) or per $Bq\ kg^{-1}$ dry weight (soil) or per $Bq\ m^{-3}$ (air) of medium); SDR = the screening dose rate ($\mu Gy\ h^{-1}$) selected by the assessor at the assessment context stage (10 $\mu Gy\ h^{-1}$ is used as the default value in the ERICA approach (Andersson et al., 2009).

In deriving F, the selection of the default location within the habitat is based on the configuration that will result in maximum exposure of the reference organism (and this is also the default occupancy within the Tool). For example, for the terrestrial burrowing mammal, the assumption is made that the organism spends 100% of its time underground, when in reality it will also spend much of its time at the soil surface. As an example of the equations used to estimate F, the case for a burrowing mammal is provided in Equation (8), below.

$$F = \left[DCC_{\mathrm{int},bm} \cdot CR_{bm} + DCC_{ext,bm}\right] \tag{8}$$

where: $DCC_{int,bm}$ = internal dose conversion coefficient for a burrowing mammal; CR_{bm} = concentration ratio for burrowing mammal; $DCC_{ext,bm}$ = external DCC for in-soil.

The full set of equations, covering all ecosystems and reference organisms, is provided in the 'Help' function for the ERICA Tool. F values were calculated using all available information, which included probability density functions of parameters for which these were available (namely CR values and sediment-water distribution coefficients for aquatic ecosystems). Calculations were performed probabilistically using a Monte Carlo approach resulting in a PDF for the F value from which any percentile of the F value can be selected. As the default, the 95th percentile F value has been selected for use in the calculations (i.e. this value is entered into Equation (7)) to yield a 5th percentile EMCL.

For the new release of the Tool, new EMCL values had to be generated to account for the modifications to underlying parameter values as described above.

By way of example the newly generated EMCL values have been compared with the old values for the terrestrial ecosystem (Fig. 2).

Substantial differences are noted for isotopes of iodine where new terrestrial EMCL values are two orders of magnitude higher than the old terrestrial EMCLs. This undoubtedly reflects the removal of bird egg as a reference organism category (for reasons noted above) for which the assumed CR was likely overly conservative (see Beresford et al., 2008c), resulting in an EMCL value which was correspondingly low. Other notable examples where differences are large can be found for isotopes of uranium, where the new EMCL values are at least one order of magnitude lower than the old EMCLs. Although no changes have been made in the limiting organisms, namely lichen and bryophyte, a more robust characterisation of concentration ratios for this organism group explains the change. Corrections to the external DCCs, as noted above, would have had little effect because these coefficients are (whether old or new) relatively insubstantial for U isotopes. The new lichen and bryophyte CR value is based on 250 measurements, whereas the number of data upon which the old value was based was unknown.

2.7. Uncertainty factors in the ERICA tool

In Avila et al. (2014) we argued that since in Tier 2 we only obtain expected values, then from the Maximum Entropy Method, we can only assume that RQs follow an exponential distribution when estimating UFs. We acknowledge that other approaches may be applied. In particular, we are aware of the arguments of Thorne (2013) that concern the fact that we often know more than just the expected value and that parameters like CRs are bounded by 0 at one end of the distribution and by a physical constraint at the upper end and hence do not fit comfortably with an exponential distribution. Nonetheless, the UFs generated for 95th percentiles using the exponential distribution assumption are similar to the values obtained for a lognormal distribution with a geometric standard deviation of 3 (a value that might be considered a typical variance for a well-defined parameter) for the same percentile. The current approach is therefore considered to be reasonably robust for application under generic conditions bearing in mind that were the assessor to be overly concerned that uncertainty is not being captured appropriately they have the possibility to derive and enter their own bespoke UF value or move to a fully probabilistic Tier 3 assessment. Nonetheless, further consideration will be given to the requirement to adjust default UFs in future releases of the Tool.

3. Concluding remarks

A number of limitations exist with the Tool which will hopefully be addressed in the future. Some examples are considered below:

For the terrestrial environment, a potential limitation exists with regards to an option to assess impacts from certain radionuclides in gaseous forms. Currently, only ^{3}H, ^{14}C, ^{32}P and ^{35}S are considered this way in the tool. The omission of noble gases may be

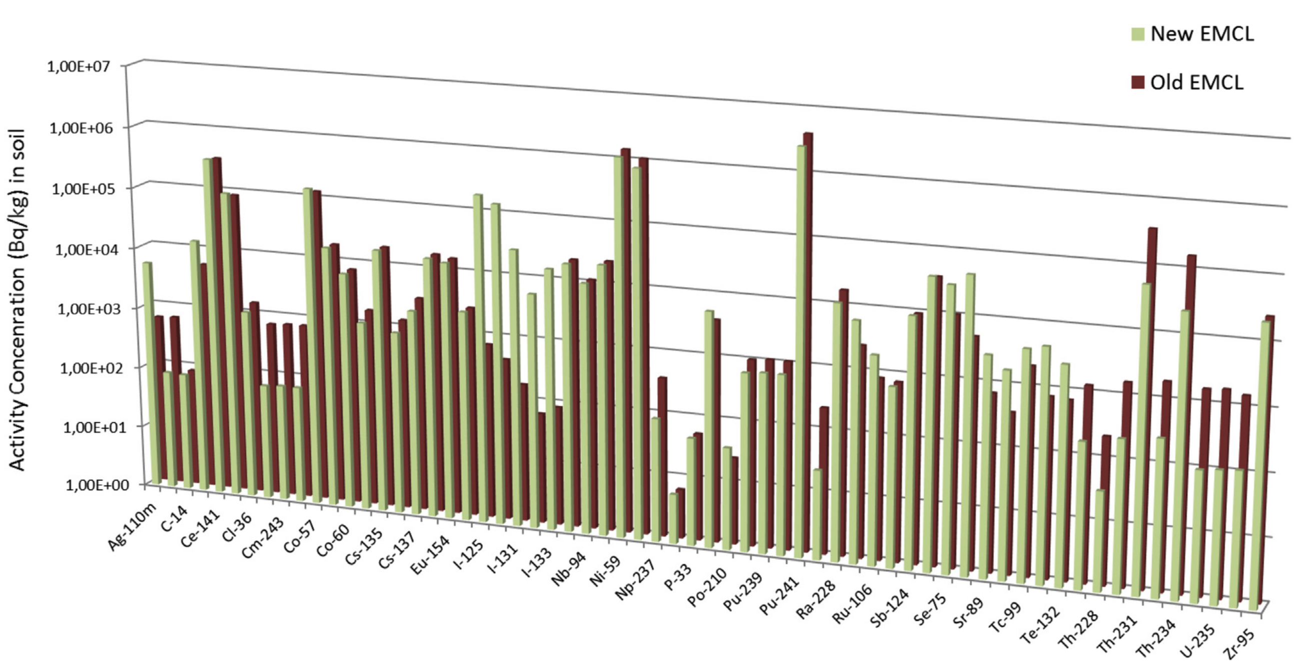

Fig. 2. Old and new EMCL values for terrestrial ecosystem.

a particular issue with this group of radionuclides constituting a large proportion of potential release inventories for some cases (Copplestone et al., 2010). Methods are available for the quantification of environmental exposures from noble gases (e.g. Vives i Batlle et al., 2012) and efforts to provide functions of this type within the Tool will be pursued.

Another key limitation concerns the current set up in the ERICA Tool whereby data entry is limited to a single location in time and space. Recent developmental efforts have focussed on providing an interface to accept time series and location-specific data. A beta version of this software will be tested in 2016.

The current version of the Tool provides a simplified means of dealing with decay series radionuclides, whereby the decay chain is truncated when the physical half-life of a given daughter product exceeds 10 days and the DCCs of all progeny up to that point are combined with the parent radionuclide by assuming that the entire group of radionuclides is in secular equilibrium. However, the system is arguably overly rigid and it is envisaged that the ability to select any relevant dose integration period would be advantageous. This would allow decay and ingrowth of (all) decay chain members (with concomitant dose contributions) to be modelled over periods commensurate with more ecologically relevant factors such as the lifetime of selected organisms (see e.g. Ulanovsky and Pröhl, 2012).

With these and other factors in mind, work continues on the improvement and modification of the ERICA Tool including efforts to maintain consistency with developments originating from the IAEA and ICRP. The ERICA Tool continues to be freely available from the websites: http://www.erica-tool.com/ and http://www.erica-tool.eu/ with regular updates on upcoming courses and news associated with developments etc. also available at: https://wiki.ceh.ac.uk/x/5gHbBg.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.jenvrad.2015.12.011.

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