A new IAEA Technical Report Series Handbook on Radionuclide Transfer to Wildlife

B.J. Howard[1], N.A. Beresford [1], D.Copplestone[2], D. Telleria[3], G. Proehl[3], S. Fesenko[3], R. Jeffree[3], T. Yankovich[4], J. Brown[5], K. Higley[6], M. Johansen[7], H. Mulye[8], H. Vandenhove[9], S. Gashchak[10], M. Wood[11], H. Takata[12], P. Anderson[13], P. Dale[14], J. Ryan[15], A. Bollhöfer[16], C. Doering[17], C. Barnett[1] and C. Wells[1].

[1]Centre for Ecology and Hydrology, UK
[2]Stirling University, UK
[3]International Atomic Energy Agency
[4]Saskatchewan Research Council, Canada
[5]Norwegian Radiation Protection Authority, Norway
[6]Oregon State University, USA
[7]Australian Nuclear Science and Technology Organisation, Australia
[8]Canadian Nuclear Safety Commission, Canada
[9]Belgian Nuclear Research Centre
[10]Chernobyl Centre for Nuclear Safety, Ukraine,
[11]Manchester Metropolitan University, UK
[12] National Institute of Radiological Sciences, Japan
[13]Swedish Radiation Safety Authority, Sweden
[14]Scottish Environment Protection Agency, Scotland
[15]Candu owners group, Canada
[16] Supervising Scientist Division, Department of Sustainability, Environment, Water, Population and Communities, Australia
[17]Australian Radiation Protection Nuclear Safety Agency, Australia

1. INTRODUCTION

The IAEA Technical Report Series (TRS) handbook on transfer of radionuclides to human foodstuffs from terrestrial and freshwater systems has recently been revised during the EMRAS I programme [1]. The document updates the previous handbook (TRS 364) and constitutes an important source of information for transfer parameters for the human foodchain. Quantification of the rates of transfer of radionuclides through foodchains to humans has long been a key focus of radiation protection. More recently, there has been a move away from radiation protection being solely anthropogenic to one which also considers protection of the environment as recognised by both the IAEA [2] and the ICRP [3] in their Fundamental Safety Principles and revised Recommendations, respectively, both of which now include the need to protect the environment. To address these recommendations and safety principles, the consequences of radiological releases need to be considered in part by estimating an internal dose. To do this, the transfer of radionuclides to wildlife of interest needs to be quantified.

In response to the need for a reference source of information on radionuclide transfer to wildlife, the IAEA initiated the development of a TRS handbook, which has been supported by interaction with the EMRAS II Working Group 5, (http://www-ns.iaea.org/projects/emras/emras2/working-groups/working-group-five.asp). The TRS handbook has been finalised and is currently going through the IAEA approval process. The TRS handbook provides equilibrium concentration ratio values for wildlife groups in terrestrial, freshwater, marine and estuarine environments. Wildlife is considered to include all non-domesticated plants, animals and other organisms including feral species (i.e. non-native self-sustaining populations). The TRS handbook provides IAEA Member States with transfer data for use in the radiological assessment of wildlife as a consequence of planned and existing exposure situations [3]. As an equilibrium approach is presented, these data are not directly applicable to emergency situations.

2. QUANTIFICATION OF TRANSFER

Currently, in most of the available assessment tools, transfer of radionuclides is quantified using concentration ratios relating activity concentrations in wildlife to those in media and the TRS handbook has therefore focused on providing such data. The TRS handbook provides equilibrium concentration ratio values for wildlife groups in terrestrial, freshwater, marine and estuarine environments.

In the TRS handbook tables of $CR_{wo\text{-}media}$, defined as the ratio at equilibrium between the radionuclide activity concentration in the whole organism (fresh weight) to that in media (dry soil, water or air) are presented. The $CR_{wo\text{-}media}$ values are given for a range of broad wildlife groups (such as tree, fish), which have been divided into subcategories, where possible, for instance, coniferous tree, decidious tree; forage fish, piscivorous fish. Such simplistic ratios clearly do not take into account the many environmental variables which can affect transfer to wildlife. However, the approach has merit because of: (i) its simplicity, transparency and user-friendliness; (ii) the relatively large amount of relevant information available for organisms, elements and ecosystems compared with other methods of quantifying transfer; (iii) the common use of (and therefore need for) this parameter in the existing environmental exposure assessment models, and (iv) it is consistent with the approach being used by the ICRP in its developing framework for non-human biota [3,4] and tools used for human exposure assessments [1].

For C and H, specific activity approaches are provided in the TRS handbook which are consistent with the approach used for human foodchain modelling [1].

As the $CR_{wo\text{-}media}$ values are presented for whole organism they are not appropriate for assessing the transfer of radionuclides to humans for which the reader should refer to IAEA [1, 5, 6].

3. DATA COLLATION AND MANIPULATION

To facilitate the collection of data for the TRS handbook an online database has been established (www.wildlifetransferdatabase.org). This provides a structured way to collate data from the scientific community on the transfer of radionuclides to wildlife. This has been a joint development with the ICRP so that the same database is being used to provide CR values for their developing framework [4].

The database compiles data on organism-media concentration ratios and does not include recommended values from previous publications. Data for stable elements are included and most data are derived from field studies rather than laboratory studies (simple aquatic organisms being the exception). Data used to derive $CR_{wo\text{-}media}$ values are mostly for wildlife and media activity concentrations measured at the same sites. However, some $CR_{wo\text{-}media}$ values for marine organisms have been calculated using observed stable element concentrations in organisms and generic global seawater concentrations. Detailed information is provided in the TRS handbook on the methods of data collation and, where required, manipulation was used to derive the $CR_{wo\text{-}media}$ values.

Data often had to be transformed to the format required in the database. The most common problems were: (i) wildlife activity concentrations given on a dry or ash weight basis (when fresh weight $CR_{wo\text{-}media}$ values are required); (ii) data available for specific tissues (i.e. not whole organism); and (iii) soil activity concentrations given as Bq m^{-2}. Where information was not given within the source publications to enable manipulation of the data into the format required a set of standard assumptions were followed. The conversion data used for the online database were based on those used for the ERICA tool and are given in an Appendix. For instance, to enable conversion of edible tissues to whole organism values for wildlife assessment, the TRS handbook provides tables of conversion values to enable tissue specific activity concentrations (or concentration ratios) to be converted to whole organism values.

The CR data compilations used to parameterise the ERICA Tool [7, 8] were used (following additional quality control) to initially populate the online database as these represented the most comprehensive database available when the work began.

4. THE $CR_{WO\text{-}MEDIA}$ TABLES

In the TRS handbook concentration ratio values for adult life stages are provided for terrestrial, freshwater, marine and estuarine ecosystems. The reference sources for the $CR_{wo\text{-}media}$ values are provided in an Appendix. To provide the information, which may be required for different assessment approaches and purposes, the $CR_{wo\text{-}media}$ data tables give weighted geometric and arithmetic means for different wildlife groups together with associated standard deviation estimates and ranges in observed values. These values may not be appropriate for detailed site specific assessments for which the collection of bespoke data would be required.

For assessments, there is a need to provide $CR_{wo\text{-}media}$ values for many different radionuclide and wildlife groups. The $CR_{wo\text{-}media}$ tables in the TRS handbook only provide values where there are sufficient relevant data in the database. Guidance is provided on different methods that can be used to derive missing $CR_{wo\text{-}media}$ values.

Where possible, $CR_{wo\text{-}media}$ values are presented by wildlife subcategory. Subcategories were not considered for inclusion, if the number of data were <10; if the number of data were in the range 10-20 but originated from only one or two source references, the data were evaluated and the subcategory values excluded from the summary tables if they represented a small proportion (typically <10%) of the overall dataset for a wildlife group. Subcategories have not been considered in estuarine ecosystems because there are relatively few data which originate from only two areas (Japanese estuaries or the Baltic Sea).

4.1 Comparison with ERICA CR values

Clearly, it is not possible to report all the $CR_{wo\text{-}media}$ values in the TRS handbook in this overview since this comprises >800 element – wildlife group combinations. However, in Table 1 we compare the values with those currently in the ERICA Tool for a selection of radionuclides and for those organism-radionuclide combinations for which values have changed by more than an order of magnitude; however most values are similar to those in the ERICA Tool. Note not all organisms are the same in the ERICA Tool and the TRS handbook, in the Table where organism groupings are not the same we use the generic wildlife group from the TRS. The TRS includes additional $CR_{wo\text{-}media}$ values for elements and wildlife groups which are not included in the ERICA Tool.

In Figures 1 and 2 we show, as examples, the $CR_{wo\text{-}soil}$ values for Cs to the terrestrial wildlife groups and the $CR_{wo\text{-}water}$ values for Po for marine wildlife groups. Subcategories are shown where available.

4.2 Application of the $CR_{wo\text{-}media}$ values

The $CR_{wo\text{-}media}$ values can be used to calculate the whole organism activity concentration of wildlife in environmental risk assessments in three ways depending upon the requirements of the assessment:

a) generic average value using either the geometric or arithmetic mean;
b) conservative estimate using either the maximum value or apply the SD to derive an upper percentile to be decided by the assessor (e.g. 95th percentile);
c) probabilistic assessment using the mean and associated standard deviation.

4.3 Limitations of the existing database

The limitations of available data are discussed in the TRS handbook and include: (i) limited geographical coverage of data (ii) many data for some radionuclides (e.g. Cs, Sr) but few for others (e.g. Tc) (iii) relevance of stable element data (iv) effect of dominance of data sources for some $CR_{wo\text{-}media}$ values (v) the dominance of data for adult life stages (vi) the exclusion of roots from CRwo-soil values and (vii) impact of the exclusion of gut contents, pelt and fur etc., especially on foodchain modelling

Table. 1. Comparison of selected ERICA Tool CR values with $CR_{wo\text{-}soil}$ values in the IAEA TRS handbook where the difference is an order of magnitude.

Element	Ecosystem	ERICA Tool Database				TRS Data				Ratio
		Reference organism	AM	SD	n	Wildlife group	AM	SD	n	TRS/ERICA
Co	Terrestrial	Shrub	7.5E-1	5.4E+	11	Shrub	7.2E-2	8.5E-2	128	0.10
Co		Tree	1.8E-1	1.5E-2	3	Tree	8.7E-3	1.3E-2	7	0.05
Sr		Reptile	1.2E+1	2.4E+1	4	Reptile	3.8E-1	6.1E-1	74	0.03
Po		Shrub	9.9E-2	6.2E-2	14	Shrub	1.3E+0	1.2E+0	448	13.01
Po		Mammal	2.8E-3	1.6E-3	36	Mammal	8.6E-2	2.1E-1	67	31.11
Pb		Soil invertebrate (worm)	2.9E-2	4.4E-2	264	Annelid	5.2E-1	7.5E-1	647	18.15
U		Shrub	7.1E-3	1.4E-2	496	Shrub	2.3E-1	6.4E-1	970	33.29
U		Lichen & bryophytes	7.1E-2		-	Lichen & bryophytes	2.5E+0	4.4E+0	237	35.84
U		Mammal	1.1E-4	1.3E-4	2	Mammal	5.8E-3	6.8E-3	22	54.56
Am		Grasses & Herbs	5.0E-3	5.0E-3	40	Grasses & Herbs	1.0E-1	2.9E-1	65	20.55
Ra		Shrub	2.4E-2	9.0E-3	10	Shrub	1.0E+0	1.6E+0	504	42.24
Th		Shrub	1.6E-2		-	Shrub	2.5E-1	5.6E-1	403	15.42
Cs	Freshwater	Phytoplankton	2.3E+3	5.5E+2	2	Phytoplankton	1.4E+2	1.9E+2	50	0.06
Cs		Zooplankton	1.6E+3	1.9E+3	4	Zooplankton	9.0E+1	6.4E+1	41	0.06
Cs		Gastropod	2.8E+3	3.3E+3	2	Mollusc - Gastropod	1.4E+2	1.2E+2	50	0.05
Sr		Zooplankton	6.0E+1		1	Zooplankton	3.7E+3	7.4E+2	10	61.67
Sr		Benthic fish	1.7E+1	2.3E+1	14	Fish	8.9E+2	5.2E+3	789	52.12
Sr		Pelagic fish	1.7E+1	2.3E+1	14	Fish	8.9E+2	5.2E+3	789	52.12
Cm		Vascular plant	3.0E+2	4.5E+2	3	Vascular plant	2.3E+0	8.0E+0	26	0.01
Cd		Bivalve mollusc	1.0E+4		1	Mollusc - Bivalve	2.8E+5	2.4E+5	3	27.56
Zr		Vascular plant	1.9E+3		2	Vascular plant	4.1E+1	3.5E+1	6	0.02
Ce		Vascular plant	3.0E+3	4.5E+3	4	Vascular plant	1.2E+2	1.0E+2	6	0.04
Ce		Pelagic fish	1.5E+1	1.3E+1	8	Fish	1.60E+2	3.6E+3	276	10.67
Ra		Bivalve mollusc	1.5E+3	1.6E+3	2	Mollusc - Bivalve	2.4E+4	3.4E+4	43	16.00
Am		Insect larvae	2.0E+4		1	Insect larvae	1.8E+3		15	0.09
Am		Gastropod	1.8E+2	2.9E+1	4	Mollusc - Gastropod	6.3E+3	9.4E+3	50	34.97
Am		Pelagic fish	1.8E+		1	Fish	7.6E+1	6.7E+2	17	422.12
Th		Vascular plant	1.3E+3	7.4E+2	5	Vascular plant	1.1E+5	3.6E+5	84	85.71
Sr	Marine	Mammal	1.6E+1	4.3E+1	23	Mammal	1.6E+2	3.6E+2	33	10.25
Ce		Crustacean	3.4E+3	5.7E+3	3	Crustacean	1.0E+2		2	0.03

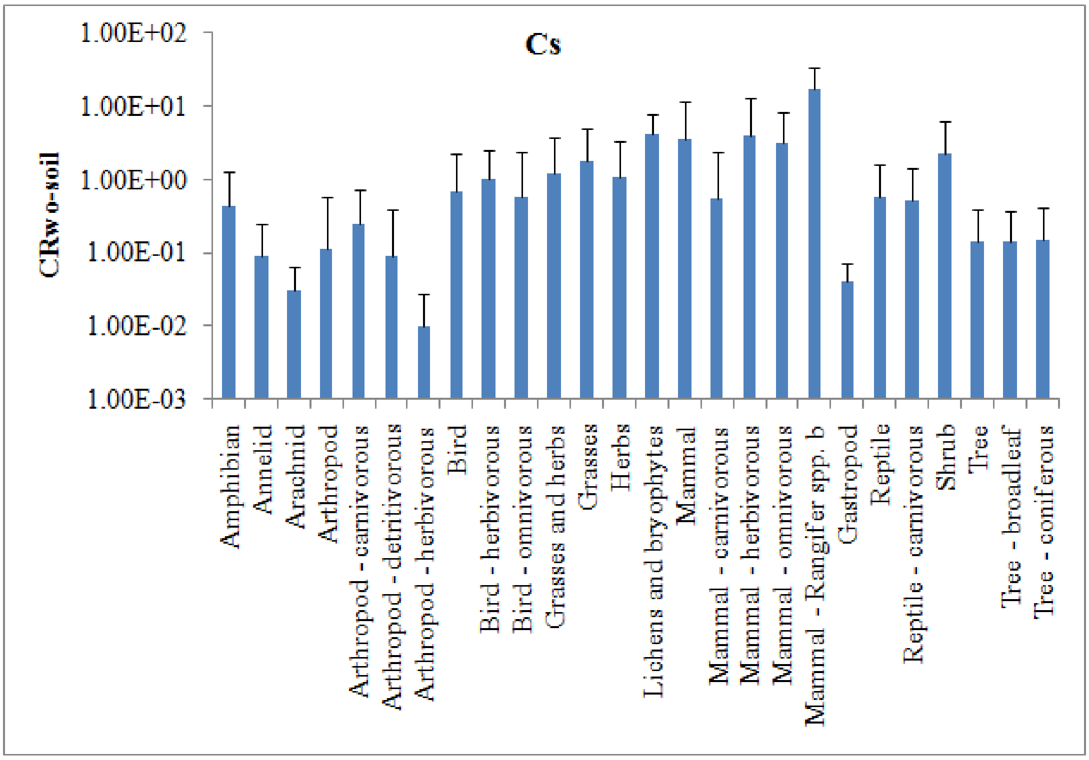

Figure 1 $CR_{wo\text{-}soil}$ values for Cs and terrestrial wildlife groups with sub categories (arithmetic mean with SD). Note log scale.

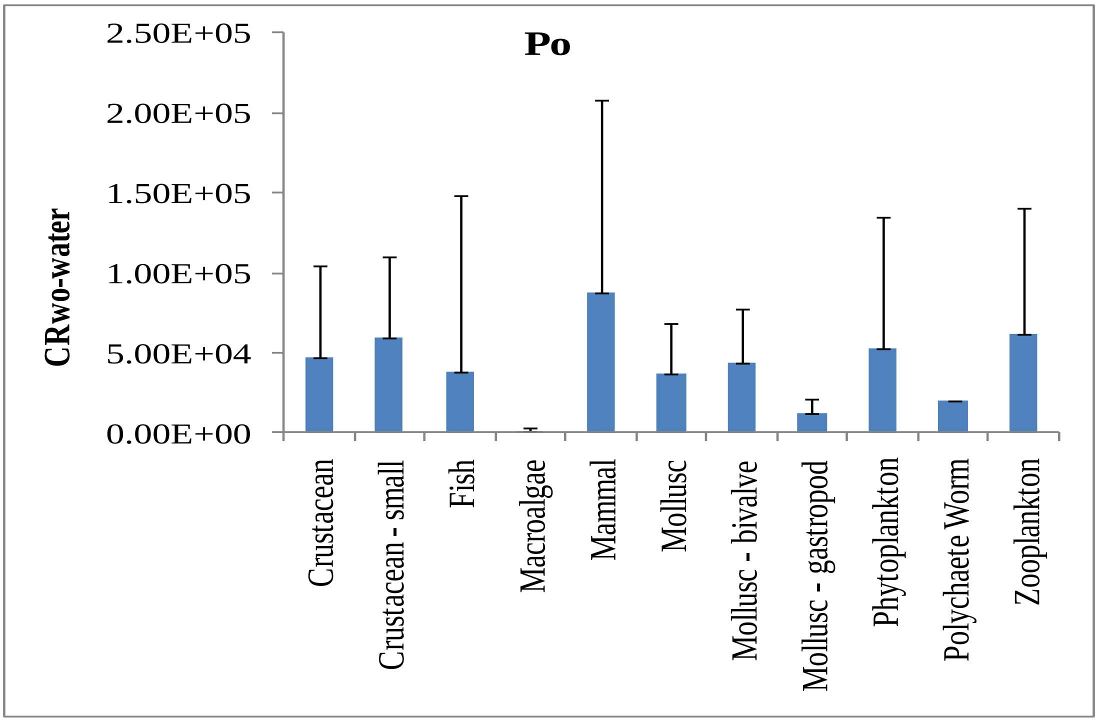

Figure 2 $CR_{wo\text{-}water}$ values for Po and marine wildlife groups with sub categories (arithmetic mean with SD).

5 APPROACHES FOR FILLING DATA GAPS

There are no $CR_{wo\text{-}media}$ values for a wide range of wildlife groups and radionuclide combinations in the tables, therefore the TRS handbook does not contain all the $CR_{wo\text{-}media}$ values which may be required in generic assessments. If the relevant data needed are not available in the $CR_{wo\text{-}media}$ tables then the first response should be to consider whether appropriate sampling should be conducted to provide the required $CR_{wo\text{-}media}$ values (or site specific whole organism activity concentrations). Such data collection also needs to take account of the ethical justification for sampling of each wildlife group.

Existing models use a number of approaches to overcome the lack of $CR_{wo\text{-}media}$ values. Approaches considered to be the most appropriate for deriving missing $CR_{wo\text{-}media}$ values are described in the TRS handbook and include: (i) surrogate organisms including the application of phylogenetic relationships; (ii) biogeochemical analogues and including consideration of the ionic potential of the element of interest and possible analogues; (iv) allometric models; and (v) data from a different ecosystem (specifically only suggested for marine-estuarine ecosystems).

Acknowledgements

We would like to thank the many other contributors, acknowledged in the TRS handbook, in addition to the drafting group and major contributors listed here as authors, notably EMRAS WG5 participants.

References

[1] International Atomic Energy Agency, Handbook of Parameter Values for the Prediction of Radionuclide Transfer in Terrestrial and Freshwater Environments. IAEA-TRS-472, IAEA: Vienna. (2010).

[2] International Atomic Energy Agency, Fundamental safety principles: safety fundamentals. IAEA safety standards series No. SF-1, IAEA, Vienna (2006).

[3] International Commission on Radiation Protection, Recommendations of the International Commission on Radiological Protection Publication 103 Annals of the ICRP 37 2-3 (2007).

[4] International Commission on Radiation Protection, Environmental Protection: the Concept and Use of Reference Animals and Plants. Annals of the ICRP, 108, Pergamon Press, Oxford (2009).

[5] International Atomic Energy Agency, Sediment distribution coefficients and concentration factors for biota in the marine environment IAEA-TRS-422, IAEA, Vienna (2004).

[6 International Atomic Energy Agency, Quantification of Radionuclide Transfer in Terrestrial and Freshwater Environments for Radiological Assessments. IAEA-TECDOC-1616. IAEA, Vienna (2009).

[7] Beresford, N.A., Barnett, C.L., Howard, B.J., Scott, W.A., Brown, J.E., Copplestone, D. J.. J. Environ. Radioact. **99** (2008c) 1393-1407.

[8] Hosseini, A., Thørring, H., Brown, J. E., Saxén, R. And Ilus, E., J. Environ. Radioact. **99** (2008) 1408-1429.