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Australian Radiation Protection and Nuclear Safety Agency

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Gillian Hirth

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Executive Summary

It is now generally accepted that there is a need to demonstrate, rather than assume, that non-human biota (e.g. animals and plants) living in natural habitats are protected against ionising radiation risks from radionuclides released to the environment by human activities (ARPANSA, 2014). Uranium mining and milling activities have been conducted in Australia since the 1950s and have the potential to release radionuclides to the environment. Consequently this may result in exposures of non-human biota in natural habitats to ionising radiation at levels above the natural background.

Following a previous report by the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) (Doering, 2010), the Department of Industry (DI) and ARPANSA agreed that in order to support the implementation of international best practice standards in environmental radiological assessment in Australia, an evaluation of existing data relating to non-human biota inhabiting Australian uranium mining environments should be undertaken. In August 2011 DI (then Department of Resources, Energy and Tourism) and ARPANSA signed a Memorandum of Understanding to undertake the project *Concentration ratios in non-human biota inhabiting Australian uranium mining and milling environments*. This project was to identify any shortcomings, including biota types and environmental conditions for which data is most lacking, taking into account the location of current and prospective uranium mines in Australia. Data were to be evaluated for their suitability for use in calculating whole-organism concentration ratios which are used to estimate the transfer of radionuclides from the environment to non-human biota and are an important data requirement when conducting environmental radiological assessments.

This report provides a summary and evaluation of existing radionuclide concentration data in non-human biota common to Australian uranium mining environments that have been collected by a range of organisations over the past 40 years. Where possible, whole-organism concentration ratios for terrestrial and freshwater non-human biota common to Australian uranium mining and milling and uranium deposit regions have been calculated. This has resulted in an increase in the number of wildlife groups for which whole-organism concentration ratios can be reported for Australian uranium mining environments. For terrestrial habitats (predominantly arid/desert mining areas) concentration ratios for two wildlife groups (mammal and reptile) have currently been included in the international Wildlife Transfer Parameters database, additional concentration ratios have now been determined for birds, grasses and herbs, shrubs and trees. For freshwater habitats (predominantly tropical mining areas) additional concentration ratios have been identified for most of the wildlife groups currently included in the international database, and one additional wildlife group (algae).

In relation to data gaps there are a number of topics that should be considered and discussed within the environmental radiation protection/radioecology community and could form the basis of further work. These include:

- Developing Australian specific ash to fresh and dry to fresh weight ratios for terrestrial plants, particularly for those existing in arid/desert areas and for trees including *Eucalyptus* and *Melaleuca* species.

- Investigating the distribution coefficient (K_d) values for Australian aquatic environments (i.e. the relationship between sediment values and activity concentration in filtered water) and whether these should be applied to estimating media concentrations in the absence of data.
- Establishing the approach to be taken for the inclusion/exclusion of values reported as less than the limit of detection in datasets when determining concentration ratios for Australian non-human biota.

Whilst less relevant to the uranium mining industry, the development of thorium tissue to whole-organism conversion factors may be relevant to other industries (i.e. mineral sands) and could be investigated by examining the Australian datasets in more detail.

Recommendations

From the analysis and conclusions of this report ARPANSA recommends that:

1. The terminology to be used in Australia in the future, and how data on domesticated species is incorporated, should be considered as national guidance is developed for radiation protection of the environment in Australia. This guidance should also include recommended sampling and analysis regimes to ensure consistency across the industry sector.
2. The cooperative relationship with industry undertaken during this project is further developed to establish a non-human biota dataset relevant to uranium environments that includes any additional industry data. This is particularly relevant for those extensive datasets that have not yet been paired with media data.
3. The data that have been collated during this project should be published. Publication of this data will benefit the Australian uranium mining industry by consolidating the existing datasets, enabling a comparison to the international values, and assisting in supporting more robust radiological assessments, particular in the screening phase of assessments for long term exposure scenarios for equilibrium situations.
4. Discrepancies in the current Australian dataset incorporated into the international Wildlife Transfer Parameters Database should be reconciled; the approach to be taken with Australian data when including/excluding limit of detection values should be discussed and agreed within the radioecology/radiation protection research community; additional information that may be available from the Environmental Research Institute of the Supervising Scientist (ERISS) should be incorporated.
5. This information should be incorporated into the international Wildlife Transfer Parameter Database and a comparison of Australian concentration ratios to the International Atomic Energy Agency (IAEA) and the International Commission on Radiation Protection (ICRP) summary values should be undertaken. This process should be done in a coordinated manner with industry, research bodies and relevant Commonwealth agencies.

1. Introduction

1.1 Background

The International Commission on Radiological Protection (ICRP) – the primary international body issuing both generic and specific recommendations on protection against ionising radiation – revised its fundamental recommendations in 2007 (ICRP, 2007) to include a framework for assessment and protection of non-human species. The framework (ICRP, 2009) uses a generically defined group of organisms (usually at the taxonomic level of Family) referred to as Reference Animals and Plants (RAPs) to establish datasets that allow assessors to relate the transfer of radionuclides from the environment to organisms, radiation exposure to dose, and dose to effect. In addition to the ICRP, the International Atomic Energy Agency (IAEA) in their Fundamental Safety Principles (IAEA, 2006) and International Basic Safety Standards (IAEA, 2011) now also include the need to demonstrate that the environment is protected from the harmful effects of ionising radiation.

The ICRP RAPs serve as a *reference* for further assessments, and can be used as default *representative organisms* in a particular assessment context. The RAP dataset can also be used to derive, as best as possible, appropriate datasets that better suit the organisms (the *representative organisms*) in the actual environment being assessed. For the purpose of this report, the term *reference organisms* is being used as being equal to representative organisms, using available data sources including those that have been generated by the ICRP for the RAPs. The science underpinning the RAP approach has been developed over the last ten years through several multi-national research efforts which have been focussed on the development of modelling approaches specifically to assess ionising radiation exposures to biota living in its natural habitat (e.g. Beresford et al., 2008a; Howard and Larsson, 2008; IAEA, 2010). A number of countries are now using the approach in a regulatory context for nuclear and other sites releasing radionuclides to the environment to show compliance with environmental protection aims as laid out in relevant legislation (Howard et al., 2012).

Uranium mining and milling actions have been conducted in Australia since the 1950s and have the potential to release radionuclides to the environment. This may result in exposures of non-human species (i.e. animals and plants) in natural habitats to ionising radiation. This in turn may cause deleterious effects in individuals and populations of species. The *Environment Protection and Biodiversity Conservation (EPBC) Act 1999* – Australia's national environmental protection legislation – explicitly recognises mining or milling uranium ore as a nuclear action. Where decided by the Minister, the Act requires the proponent of a uranium mining or milling action to undertake an environmental assessment and address the relevant impacts of the action through the environmental impact statement process. It is implicit that the environmental assessment should include an assessment of the potential radiological impacts of the mining or milling action on the surrounding environment, including non-human biota. It is also Australian Government policy that uranium mining and milling should be based on international best practice standards and on extensive continuing research on environmental impacts.

Doering (2010) provided a detailed overview of the ICRP framework and the Environmental Risk from Ionising Contaminants Assessment (ERICA) Integrated Approach (as one method of implementing the framework) for radiological assessment and protection of non-human species in Australia. This report discussed in some detail the principles and data requirements underlying the methodology for radiological risk assessments using the ERICA Integrated Approach and the ERICA Tool and their applicability to the Australian uranium mining context. This current report will not discuss these frameworks further in any detail.

The RAP approach uses equilibrium concentration ratio – the ratio of radionuclide activity concentration in biota to that in environmental media (e.g. soil, sediment or water) – to estimate the transfer of radionuclides from the environment to non-human biota. The magnitude of the concentration ratio can vary between different radionuclides, biota types and environmental conditions. This means that concentration ratios appropriate to assess biota in one environment type (such as temperate European) may not be appropriate to assess biota in other, dissimilar environments such as desert, arid or wet-dry tropical regions which are more frequently observed in Australian uranium mining areas.

Doering (2010) identified that there is currently no consolidation of existing Australian data on concentration ratio to support non-human biota radiological assessments in the Australian uranium mining context and this impedes the ability of the industry to undertake assessments. The report recommended that further research was required to collect and assemble data on fauna and flora common to major Australian environments in order to establish a set of Australian reference organisms and to facilitate the implementation of the ICRP framework in an Australian context. The report also aimed to promote discussion which may eventually lead to the development of specific national guidance in Australia related to the radiological protection of non-human species, including guidance on specific assessment methods.

The justification for the work detailed in this report arose from the need of the Australian uranium mining industry to demonstrate international best practice standards in environmental assessment, as well as from the current lack of consolidated concentration ratio data to support resonant and technically robust application of a reference animal and plant approach in the Australian uranium mining context.

In August 2011 a Memorandum of Understanding (No. 002097) was signed by the then Department of Resources, Energy and Tourism (DRET) (now DI) and ARPANSA to jointly undertake the project *Concentration Ratios for Non-Human Biota inhabiting Australian Uranium Mining Environments*. It was agreed that in order to support the implementation of international best practice standards in environmental radiological assessment in Australia, an evaluation of existing data relating to non-human biota inhabiting Australian uranium mining environments should be undertaken, to identify any shortcomings, including biota types and environmental conditions for which data is most lacking, taking into account the location of current and prospective uranium mines in Australia. The report was to include an evaluation of the data and provide recommendations to guide decisions on future work directions.

A Steering Committee (SC) was established in November 2011 to provide strategic direction to the project and to facilitate effective communication with the uranium mining and milling sector and other key stakeholders. This committee was comprised of representatives from DRET and ARPANSA, one invited technical expert from the Environmental Research Institute of the Supervising Scientist (ERISS) and three industry members, nominated by the Australian Uranium Association (AUA) who assisted with facilitating communication with industry and provision of data.

1.2 Purpose and Scope

This report provides a summary and evaluation of existing Australian radionuclide activity concentration data in non-human biota common to Australian uranium mining and milling environments. Sources reviewed include data published in peer-reviewed journals, internal government agency reports, data from uranium mining companies and other consultant's reports that have been produced by a range of organisations over the past 40 years.

Data was evaluated for its suitability for use in calculating whole-organism concentration ratios. Where possible, in the timeframes available to this project, a number of these whole-organism concentration ratios for terrestrial and freshwater wildlife groups have been calculated. An overview of these will be provided.

Any significant data gaps or issues are discussed in order to assist with moving towards establishing a collection of Australian whole-organism concentration ratios. This will also assist with identification of appropriate Australian reference organisms and the implementation of a framework for assessment and protection of the environment, in an Australian context, which is compatible with international best practice.

1.3 Structure

This report consists of four sections and four appendices. Following this introduction, Section 2 describes the concepts and approach taken in conducting this review. Section 3 outlines the data collection, review and evaluation process. Section 4 provides the conclusions and makes some recommendations for future work.

2. Concepts and Approach

2.1 Terminologies

2.1.1 Non-human biota, non-human species or wildlife?

The term used to refer to species other than humans has varied over the past 20 years. The ICRP use the term 'non-human species', the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) use non-human biota, and the International Atomic Energy Agency (IAEA) have used a range of terms including, plants and animals (IAEA, 1992); non-human species (IAEA, 2010) and in their most recent document, which is still to be published (IAEA, in press), the IAEA will use the term 'wildlife' which relates to living species that are not domesticated and exist in natural habitats. In other publications 'non-human biota' has been used but this term is rarely used in ecotoxicology and other areas of environmental protection. It is noted that ARPANSA discussed non-human species in their previous publication on this topic (Doering, 2010) however in this current report the term non-human biota will be used, as agreed between DI and ARPANSA in 2011. Non-human biota includes any flora or fauna, endemic or introduced, that exists in natural habitats, and specifically in this report, Australian uranium mining or milling environments. This includes domesticated species such as sheep that graze on extensive areas of pastoral lease near uranium deposits or mining areas. Following the finalisation of this report it has been agreed that in the future environmental exposures of wildlife in the natural environment will be the terminology applied in the Australian radiation protection framework (ARPANSA, 2014).

How data on domesticated species such as sheep are utilised when conducting environmental assessments in the future should be considered by the working group that is currently preparing the ARPANSA *Safety Guide for Radiation Protection of the Environment* under the direction of the Radiation Health Committee.

2.1.2 Equilibrium concentration ratios

When undertaking radiological risk assessments one of the data components that is essential for such assessments are the organism-to-media concentration ratio (CR) values that are used to estimate whole-organism radionuclide activity concentrations in biota from those in environmental media. The CR values discussed in this report are all assumed to be in equilibrium in the environment between exposed biota and the environmental media which they inhabit. These CR values are particularly appropriate for assessments of long-term exposure scenarios. They are not appropriate for circumstances where there is variation in the radiological conditions (e.g. pulsed inputs of radionuclides or accidents) and alternative methods of quantifying transfer, including dynamic models should be considered.

Given the aim of this project was to review existing Australian datasets for radionuclide activity concentrations in non-human biota inhabiting uranium mining environments and assess their use for calculating whole-organism CRs, it is important to understand the common approaches utilised within the international community to estimate whole-organism concentration ratios for non-human biota from a range of data sources.

2.1.2.1 Whole-organism concentration ratios

The whole-organism concentration ratio ($CR_{WO\text{-}media}$) is a value used to quantify the equilibrium activity concentration between an environmental medium and the whole living organism. This may previously have been referred to as concentration factor or bioaccumulation factor. It generally does not include parts of the organism which might be contaminated by environmental media (soil, silt) such as the gut or pelt (IAEA, in press).

The definitions of $CR_{WO\text{-}media}$ are as follows:

For terrestrial biota:

$$CR = \frac{Activity\ concentration\ in\ biota\ whole - body\ (Bq/kg\ fresh\ weight)}{Activity\ concentration\ in\ soil\ (Bq/kg\ dry\ weight)}$$

Exceptions for terrestrial biota exist for chronic atmospheric releases of H-3, C-14, S-35 and radioisotopes of P, where:

$$CR = \frac{Activity\ concentration\ in\ biota\ whole - body\ (Bq/kg\ fresh\ weight)}{Activity\ concentration\ in\ air\ (Bq/m^3)}$$

For aquatic biota:

$$CR = \frac{Activity\ concentration\ in\ biota\ whole - body\ (Bq/kg\ fresh\ weight)}{Activity\ concentration\ in\ filtered\ water\ (Bq/L)}$$

Additionally, in aquatic ecosystems, the distribution coefficient (K_d) describes the relative activity concentrations of radionuclides in sediment and water, where:

$$\frac{K_d\ (I/kg) = Activity\ concentration\ in\ sediment\ (Bq/kg\ dry\ weight)}{Activity\ concentration\ in\ filtered\ water\ (Bq/L)}$$

The distribution coefficient can be used to predict radionuclide activity concentration in sediment from that in water, or vice versa, if data for either is lacking.

During the course of this data review the relationship between sediment values and activity concentration in filtered water was not examined, nor applied to estimate radionuclide activity concentrations in either media if data was lacking. A summary of K_d values for Australian aquatic environments and their application to estimating media concentrations in the absence of data should be considered in the future.

2.1.2.2 Tissue concentration ratios

The tissue-media concentration ratio ($CR_{tissue\text{-}media}$) is a value used to quantify the equilibrium activity concentration between an environmental medium and a specific biota tissue. Tissue-to-media CR should not be used in biota dose assessments in lieu of organism-to-media data. This is because radionuclide activity concentration (and thereby CR) for a specific tissue may be substantially less than, or greater than, that for the whole-body of the organism due to preferential uptake of certain radionuclides by certain tissues.

Doering (2010) provided a short summary of existing CR data for Australian biota. These CRs were at the tissue-to-media level and came from a limited number of geographic regions, including the Alligator Rivers Region (Martin et al., 1998; Martin & Ryan 2004; Ryan et al., 2008; Bollhöfer et al., 2011), Maralinga (Giles et al., 1990) and some semi-arid regions of Australia (Johansen & Twining, 2010).

It was expected during this review that much of the additional data would also be at the tissue-to-media level as the data was originally collected for the purpose of assessing ingestion dose to the 'representative person' consuming certain plant and animal tissues. Over recent years, at the international level, there has been a significant amount of work undertaken to assist in 'unlocking' some of this tissue data in order to facilitate the estimation of whole-organism-to-media CRs.

2.2 International Initiatives

Since the mid-1980s there have been ongoing initiatives and programs of work within the international community to improve the capabilities in the field of environmental radiation dose assessment and modelling. These have included, but are not limited to, BIOMOVS (BIOspheric Model Validation Study) and BIOMOVS II, initiated by the Swedish Radiation Protection Authority in 1985, and the programs sponsored by the IAEA: VAMP (Validation of Model Predictions, 1988-1996); BIOMASS (BIOsphere Modelling and ASSessment, 1996-2001); EMRAS (Environmental Modelling for Radiation Safety, 2003-2006); EMRAS II (2007-2011) and MODARIA (Modelling and Data for Radiological Impact Assessments, 2012-2015).

These programs have built on previous work and the outputs of the EMRAS II program (and specifically Working Group 5), have provided guidance for the approach taken in reviewing and processing of data that has been collated.

The focus of Working Group 5 was "*to contribute to the development and implementation of an online Wildlife Transfer Parameter Database to be applied in the production of a Technical Reports Series (TRS) Handbook on Wildlife Transfer Coefficients. In parallel a core group was established by the IAEA in cooperation with International Union of Radioecology (IUR) to develop an online concentration ratio database, initially populated with the ERICA data, to provide data tables for the Handbook. A further objective of the Working Group was to provide a peer review of the text of the above mentioned Handbook.*"

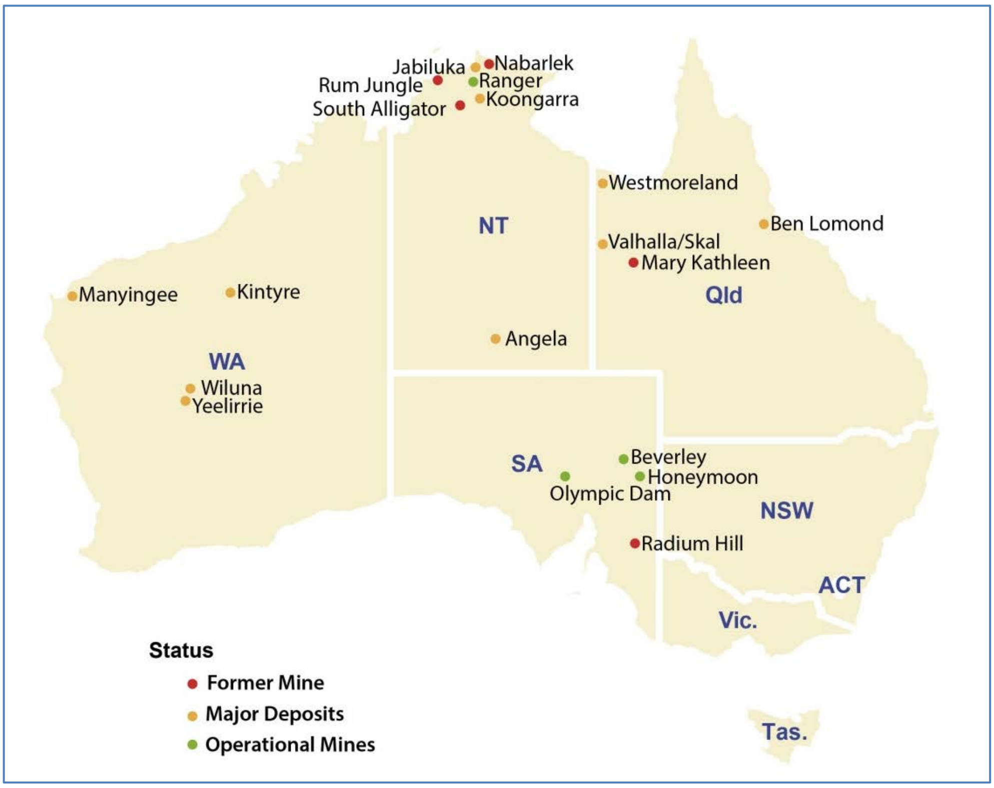
2.2.1 Wildlife Transfer Parameter Database

The Wildlife Transfer Parameter Database (WTD) has been established for use in environmental radiological assessments to estimate the transfer of radionuclides to non-human biota (i.e. 'wildlife'). In addition to aiding the IAEA in the production of a TRS handbook on wildlife transfer coefficients (Howard et al., 2012) the WTD is also providing data for derivation of transfer parameter values for the ICRP's list of RAPs. As noted above the database was initially populated with the default CR values from the ERICA Tool. During the course of the EMRAS II program a significant amount of additional data has also been contributed by numerous organisations and individuals. The summarised data that were extracted from the database in February 2011 for both the IAEA and ICRP reports are available at the WTD website. In the future these summaries will be updated when sufficient additional data are available, hopefully on an annual basis. The data manipulation process detailed in the yet to be published IAEA handbook (IAEA, in press) is applied to data collated in the WTD and has been followed when accessing data during this work.

2.3 Australian Uranium Mining Environments

Australia is one the world's major producers and exporters of uranium. In terms of resource abundance it has approximately 33% of the world's reasonably assured resources of uranium (IAEA, 2012). The locations of most major deposits, operational mines and former mining operations are shown in Figure 1. South Australia (SA) has approximately three-quarters of the known resources in Australia with Olympic Dam being the world's largest deposit. Other known significant resources are located in the Northern Territory (NT), Queensland (QLD) and Western Australia (WA).

Figure 1: Major uranium deposits, operational mines and former mining operations in Australia



Data that have been reviewed during this project have been sourced from journal publications, reports on former mining areas (i.e. Alligator Rivers Region, NT; Rum Jungle, NT), major deposits that have been the subject of some form of baseline assessment and/or draft Environment Impact Assessment (i.e. Yeelirrie, WA; Lake Way/Wiluna, WA; Manyingee, WA) and data from regions that now have operational mines (Ranger, NT; Olympic Dam, SA; Beverley, SA; Honeymoon, SA).

Given that the magnitude of the concentration ratio can vary between different environmental conditions and biota types it has been important to take into account the different climate classifications as the data has been collated. The Australian uranium mines/major deposits were classified with reference to the Bureau of Meteorology modified Köppen classification system (Figure 2) and the major seasonal rainfall zones (Figure 3).

This enabled comparison with international datasets, which generally have a bias towards temperate European climates and also a comparison between Australian climates i.e. desert/arid versus tropical summer dominant, which tend to be the two dominant environmental conditions for the Australian data. A summary of the environmental classification of Australian uranium mines/major deposits is provided in Table 1.

This comparison may also provide additional information to assist in better understanding the consequences and/or appropriateness of utilising:

- generic concentration ratios derived from international datasets in Australian assessments where quite different environmental conditions and species may exist; and
- generic parameter values derived from international datasets, such as dry:fresh or ash:fresh weight conversion factors that can be utilised to determine fresh weight whole-organism concentration ratios in Australian non-human biota in the absence of data.

Figure 2: Climate Classification – based on the Köppen classification system modified by the Bureau of Meteorology

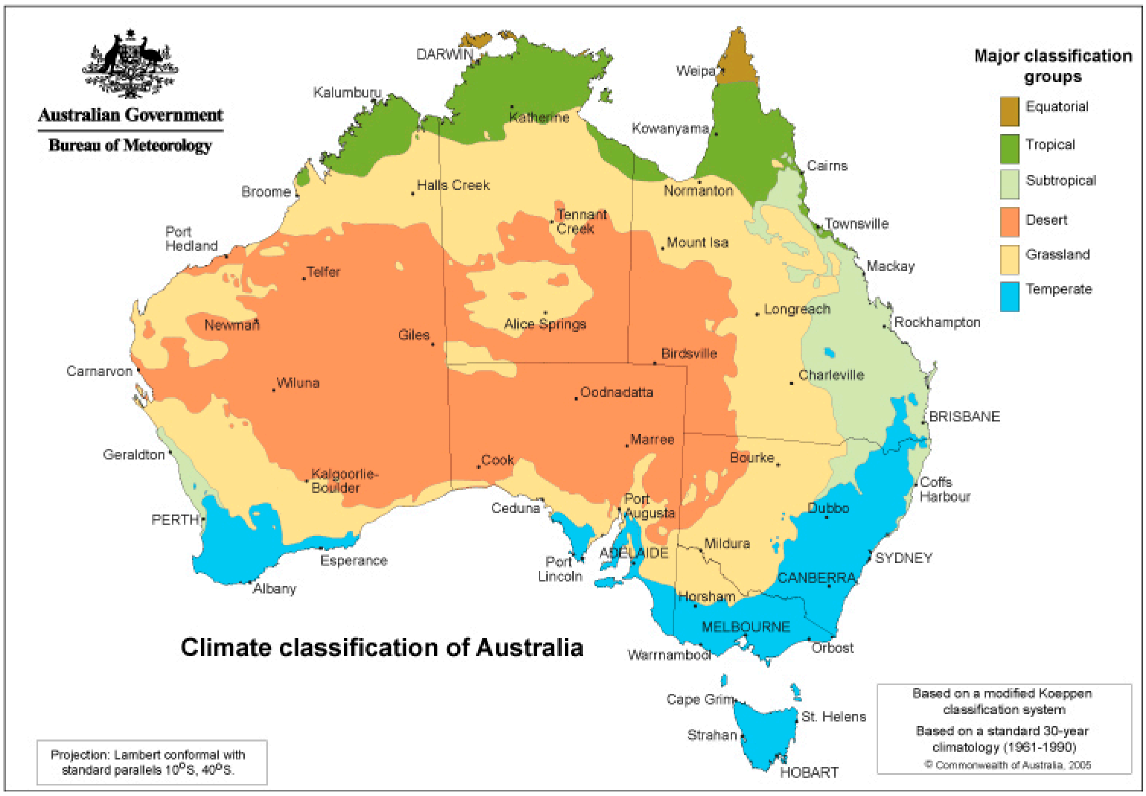


Image courtesy of the Bureau of Meterology (www.bom.gov.au)

Figure 3: Major seasonal rainfall zones of Australia

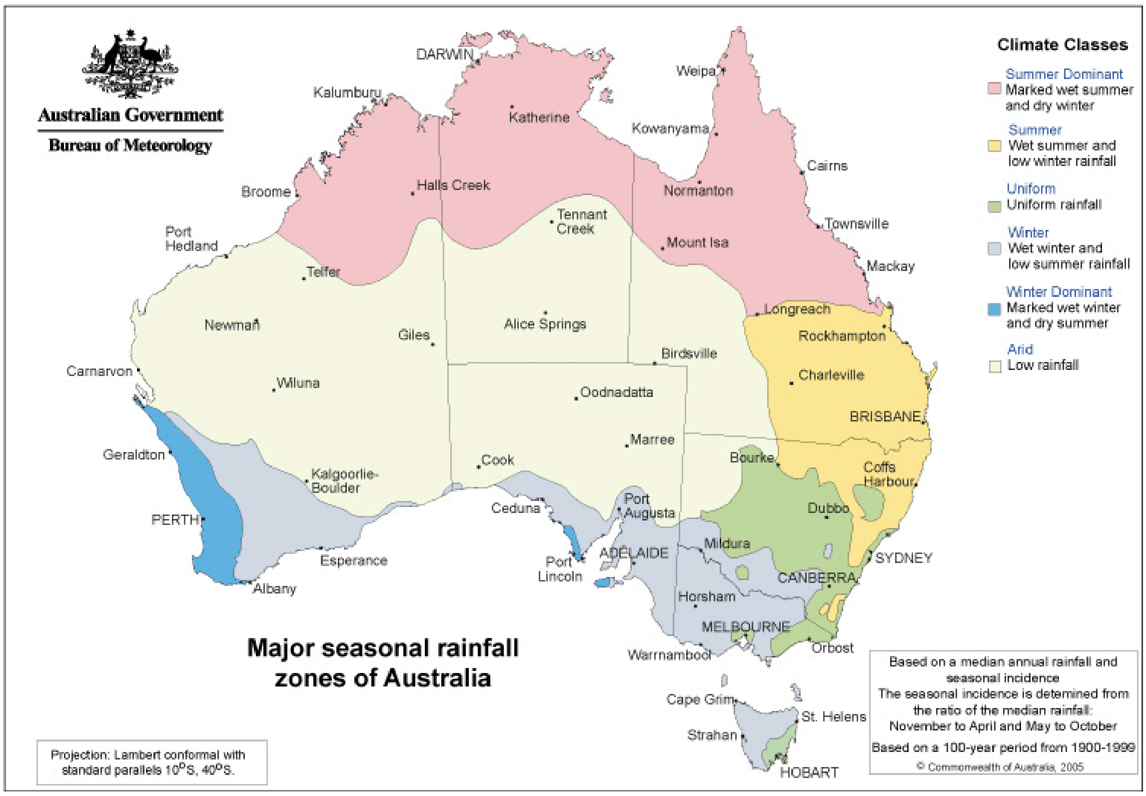


Image courtesy of the Bureau of Meterology (www.bom.gov.au)

Table 1: Summary of environmental classification of Australian uranium mining (past and present) and major deposit regions. See Figure 1 for locations.

Uranium deposit / mine area	Köppen Classification	Rainfall zone
Radium Hill	Desert/Grassland	Arid
Honeymoon, Beverley, Olympic Dam	Desert/Grassland	Arid
Manyingee	Grassland	Arid
Kintyre, Yeelirrie, Wiluna, Lake Way	Desert	Arid
Rum Jungle, Nabarlek, South Alligator, Ranger, Jabiluka, Koongarra	Tropical / Grassland	Summer dominant
Mary Kathleen	Desert/Grassland	Arid or summer dominant
Valhalla	Desert/Grassland	Arid or summer dominant
Westmoreland	Grassland	Summer dominant
Ben Lomond	Subtropical/grassland	Summer dominant

3. Data Collection, Review and Evaluation

3.1 Data Collection

3.1.1 Australian input to the Wildlife Transfer Parameter Database

As a starting point for this review the data that had been provided by Australian participants to the WTD during the EMRAS II program was sought. Data had been provided by both ANSTO and ERISS participants and was kindly shared with ARPANSA for this project.

The ERISS data was reported to the WTD as whole-organism CRs that they had calculated using the common approach outlined in this report. The ANSTO data were reported as a mixture of tissue and whole-organism CRs. Tissue CRs were then converted by the managers of the WTD to whole-organism CRs. It should be noted that the ANSTO data were supplied included data on sheep and these are not included in the WTD as they do not meet the WTD definition of 'wildlife'. These data will be included in Appendix 3 of this report for comparative purposes. The ANSTO data also included Maralinga data for Cs-137, Am-241 and Pu isotopes, and these will not be discussed in this report. In addition to the data provided by ANSTO and ERISS there was a limited amount of additional Australian data that had been included in the WTD from other sources. These were also provided to ARPANSA during this review by Dr Nick Beresford of the Centre for Ecology & Hydrology (CEH), United Kingdom.

The data manipulations to calculate whole-organism CRs undertaken by ERISS, ANSTO and the managers of the WTD for all the Australian data currently in the WTD were reviewed during this project. This was to ensure that the process utilised was clearly understood and recorded for reference, to ensure consistency in approach for future data manipulations. It also provided an extra level of quality assurance for data submitted to the WTD and identified some inconsistencies and duplication of data that will need to be addressed in the future.

3.1.2 Library searches

An extensive review of publications and library collections at both ARPANSA and ANSTO were conducted. During a visit to the ANSTO library it was identified that the AUA had sent their library to ANSTO in recent years. The AUA collection was also reviewed for potential data.

3.1.3 Uranium industry

Data were requested from the uranium industry through the Australian Uranium Industry (AUA). Feedback from a number of companies was received through the steering committee industry members. A number of companies were able to provide access to valuable datasets that have been evaluated as appropriate for use in calculating whole-organism concentration ratios.

A number of mining companies advised that they held no data or limited data that would be useful for the purposes of this project. Other companies do hold data for radionuclide activity concentrations in non-human biota which had largely been collected for the purposes of human food-chain ingestion exposure assessments. During the course of the data collection phase these were not able to be adequately matched with appropriate media data to enable concentration ratios to be calculated. Additionally, there is a significant body of data that were collected during the 1970s and 1980s in preparing baseline environmental surveys and assessing mining impacts, predominantly by the Australian Atomic Energy Commission (AAEC) (now ANSTO). Some tissue CRs have already been reported in the literature from these AAEC reports (Johansen & Twining, 2010) and many of these reports contain significant amounts of flora data which have not previously been summarised and can be utilised to calculate CRs.

It is recommended that a cooperative relationship with industry is built upon to establish a robust non-human biota dataset and additional industry data is pursued. This is particularly relevant for those unpublished datasets that are known to exist but have not yet been paired with media data.

3.2 Data Review and Evaluation

When initiating data evaluation it was important to establish whether the data was appropriate for estimating $CR_{WO\text{-}media}$. Data sourced from the original research/analysis reports was targeted for collection. Original data were included in calculating the $CR_{WO\text{-}media}$ values when the following criteria were met:

- documentation of sample collection, preparation, and analysis methods were described and conformed to generally accepted practice
- non-human biota were not constrained to laboratory enclosures or mesocosms
- sampling of media (water, soil, sediment) was representative of the natural environment from which the biota was collected
- the period of time of biota exposure to radionuclides was generally consistent with the equilibrium assumption
- pooled samples were for the same or closely related species.

When reviewing the datasets against these criteria there were some datasets that could not be adequately matched with media and were excluded from further analysis. This does not mean media data does not exist, but further investigation may be required to adequately pair biota with a media activity concentration representative of the biota's natural environment. A summary of the reports, publications and other unpublished data reviewed and evaluated during the course of this project is provided in Appendix 1.

3.3 Data Manipulation

When reviewing original data few reports had information in directly useable formats (Bq/kg fresh weight for biota; Bq/kg dry weight for soils and sediments; and Bq/L for filtered water). Most reports prior to approximately 1980 reported activity concentrations in pico-curies (pCi) requiring, at a minimum, conversion to the S.I. unit of becquerels (Bq). A significant amount of data required activity concentrations to be converted to fresh weights as they were often reported as dry or ash weights. Finally, when CRs were reported they were often reported as tissue-to-media CRs rather than whole-organism CRs and subsequently required further manipulation to obtain $CR_{WO\text{-}media}$.

In these cases, to determine whole-organism $CR_{WO\text{-}media}$ values from reported activity concentrations the following data manipulation process was followed:

1. Data reported in pico-curies were converted to becquerels.
2. Data reported on a dry- or ash- mass basis instead of fresh-mass basis were converted to a fresh-mass basis using conversion factors selected in the following order of priority:
   (a) ash or dry weight to fresh weight ratios as reported in original source
   (b) ash or dry weight to fresh weight ratios (generic) as reported in Beresford et al. (2008b) for terrestrial ecosystems, or Hosseini et al., (2008) for aquatic ecosystems (see Appendix 2)
   (c) ash or dry weight to fresh weight ratios as reported in other available publications as noted.
3. When data were reported for specific tissues, instead of whole-organism, a conversion was made to a whole-organism on the following priority basis:
   (a) whole-organism:tissue concentration ratios from study data were used when reported
   (b) whole-organism:tissue concentration ratios were calculated using conversion factors from Yankovich et al. (2010), Hosseini et al. (2008) or Wood et al. (2010); If a number of tissue CRs are given for the same organism (e.g muscle, liver & kidney) then the $CR_{WO\text{-}media}$ calculated for each tissue is then averaged to determine one $CR_{WO\text{-}media}$ for that sample
   (c) whole organism:tissue conversion factors reported in other publications as noted.

A table of the IAEA summary $CR_{WO\text{-}media}$ and Australian $CR_{WO\text{-}media}$ that are relevant to the uranium mining and milling industry is provided in Appendix 3. The Australian $CR_{WO\text{-}media}$ included in this table have been reported to the WTD and are therefore taken into account when deriving the IAEA summary $CR_{WO\text{-}media}$ values. These are provided for information and no detailed analysis or conclusions have been reached in regard to how they the Australian values compare to the IAEA summary values. It should be noted that during the course of this review it was identified that there are some corrections required to the Australian datasets currently within the WTD. These values will be modified in the future and corrections made to the WTD. This process has already been discussed with the WTD and the relevant contributors.

In addition to reviewing the existing $CR_{WO\text{-}media}$ significant progress was made during the course of this project in calculating new $CR_{WO\text{-}media}$ for non-human biota relevant to the uranium mining and milling habitats. The datasets assessed have enabled $CR_{WO\text{-}media}$ to be calculated for uranium decay series radionuclides for a number of additional wildlife groups that had not been previously included in the WTD. This included the wildlife groups of grasses, shrubs and trees, more limited amounts of information have been identified for birds and algae. The review will also increase the amount of data for the wildlife groups of terrestrial mammals and reptiles, and freshwater reptiles, molluscs, fish and vascular plants. A summary of the wildlife groups identified during this project where whole-organism CRs can be calculated, species within those groups and their habitats is provided in Appendix 4.

Concurrent to this project ERISS has also been reviewing its database of bushfoods and media activity concentrations that can potentially be used to calculate whole-organism CRs. This process is building on the CRs that ERISS have already provided to the WTD. Additional data may be available in the future after publication by ERISS.

It is recommended that the new $CR_{WO\text{-}media}$ values from this project be collated with the current WTD CRs and the additional ERISS CRs and once assembled this information should be made available through publication as an ARPANSA technical report or an alternative format. Once published this information should be incorporated into the WTD and a comparison of Australian CRs to the IAEA and ICRP summary values should then be undertaken.

3.4 Issues Arising

3.4.1 Limit of Detection (LOD) values

In many of the datasets that were examined the activity concentrations were often reported as less than the limit of detection (LOD). Substituting LOD data with a value to enable inclusion into a larger dataset has been applied in a number of reviews and the approach adopted varies. One approach that has been utilised in the development of some databases on radionuclide transfer to wildlife is LOD/2 substitution that is applied to datasets where no more than 20% of the values are below the LOD (Beresford et al., 2011; Hosseini et al., 2008). Although this approach can be justified on the grounds of simplicity or pragmatism it is best if it is only applied when it has a negligible effect on the end result (Wood et al., 2010). It should also be noted that there is little, if any, statistical rationale behind the substitution method and the approach performs worst in situations where there are multiple detection limits (Helsel, 2005). This is a situation often encountered in radioecological datasets and especially those obtained from gamma spectrometry.

Wood et al. (2010), when assembling data on radionuclide transfer to reptiles, applied survival analysis techniques to handle datasets that included <LOD values. The Kaplan-Meier method, a non-parametric technique, was used to estimate the mean and standard deviation when summarising reptile CR datasets that included up to 50% LOD values.

Johansen & Twining, (2010) included 'less than minimum detectable activity' (MDA) values (in this case MDA's are meant as the same as LOD) only when the MDA's were less than the average value of the dataset with the intent being that the <MDA value represents a valid non-detection useful for descriptive statistics.

ERISS has chosen to only include data that provides a measurement that is equal to or greater than the LOD, i.e. it is an actual measurement of the activity contained within a sample. The approach used by ERISS has also been adopted for the purposes of this work and any CR values calculated are based on data that was reported as being equal to or greater than the limit of detection. All data that was reported as <LOD was excluded from this initial analysis.

Given that some of the source data that was considered during this review was the same as that analysed by Johansen & Twining (2010) and Wood et al. (2010) there may be some variation in both the sample sizes (n values) and also the resultant concentration ratios. That noted, the variation in CR values is generally within the same magnitude.

It is recommended that these variations be reconciled in the future and discussed more widely within the Australian radioecology community to ensure a consistent approach is taken when <LOD values are utilised to estimate concentration ratios for Australian non-human biota. Prior to final publication of an Australian whole-organism CR dataset this issue should be discussed and any decision should ensure that there is a negligible effect on the resultant concentration ratios.

3.4.2 Terrestrial plants from arid and desert regions

When initially applying the data manipulation process to terrestrial plants from arid/desert regions of Australia the data was mostly reported as a dry weight activity concentration. This required the use of dry:fresh weight ratios to convert to a fresh weight activity concentration. In some of the earlier reports reviewed there were no dry:fresh weight ratios reported, so the assumed dry:fresh weight ratio of 0.1 for shrub (other parts) reported in Beresford et al. (2008b) was utilised in the absence of anything more appropriate. Subsequently, when reviewing later datasets dry:fresh weight ratios were reported for similar species from arid/desert regions of Australia. These ratios were consistently and substantially different (average dry:fresh weight ratios in shrub/grass foliage of 0.6) to the assumed values reported in Beresford et al. (2008b). The decision was therefore made to recalculate the earlier plant data and apply the dry:fresh weight ratio of 0.6 to estimate the fresh weight activity concentrations in these plants.

Noting this difference in the dry:fresh weight ratios for the plants from arid/desert regions, and that many of these plants exhibit xerophytic or halophytic characteristics to assist them to deal with the arid, sometimes saline and often extreme heat conditions, it is recommended that development of a set of Australian specific ash:fresh and dry:fresh weight ratios, particularly for terrestrial plants from arid and desert regions of Australia be considered for future work.

In the absence of any appropriate dry:fresh weight ratios being identified during the data review some CRs have only been calculated on a dry weight basis. For example, activity concentration data was identified in a number of reports for leaves of trees from the *Eucalyptus* and *Melaleuca* species. It is recommended that further research is undertaken to confirm an appropriate dry:fresh weight ratio for these leaves prior to conversion of this data to a fresh weight concentration.

3.4.3 Duplication of data and access to data

During the review of the Australian data that had been submitted to the WTD there was one occurrence of data being included twice (from different sources) and one occurrence of data from a summary journal publication being included, that would have had a different CR for polonium and N (number of samples) value had the data been drawn from the original research report (n=1 from the summary journal publication; n=7 from the original research report). Whilst these occurrences are ultimately not avoidable and once identified can be rectified, it is recommended that a more coordinated approach is taken when collating and submitting future Australian non-human biota concentration to the WTD. This initiative could potentially be led by ARPANSA in cooperation with ERISS and ANSTO, and possibly others.

A strict process for quality assurance and review of data is important. An essential key to these processes is having access to original research/analysis reports. The original source data or reports often provide more detailed information on sampling, sample size, analysis techniques and raw data that may not be available in more easily accessible formats such as journal publications or publically available environmental impact statements (EIS). Some journal publications and particularly EIS documents present data in a more summarised format, and in some cases this lacks information such as whether activity concentrations are on a dry weight or wet weight basis. Establishing a cooperative working group across a range of organisations within Australia would enhance the quality and consistency in the data collated on Australian non-human biota.

3.4.4 Absence of conversion factors

The use of appropriate conversion factors was discussed above in regard to dry:fresh and ash:fresh weight ratios. Similarly, in some instances there are no conversion factors available for some data manipulations. For example, tissue concentration ratios for thorium have been calculated for Australian mammals. However, suitable whole-organism to tissue CRs such as those presented in Yankovich et al. (2010) have not yet been established to convert tissue CRs to whole-organism CRs for thorium in mammals. Whilst less relevant to the uranium mining industry, this may be one data gap that is relevant to other industries (i.e. mineral sands) and by examining the Australian datasets in more detail suitable thorium conversion factors could be developed.

3.4.5 Data gaps, Maralinga, and other environments

3.4.5.1 Data gaps

The tables below summarise the broad IAEA wildlife groups for terrestrial (Table 2) and freshwater (Table 3) habitats relevant to uranium mining for which data is available for Australian non-human biota. These tables identify wildlife groups for which whole-organism CRs for Australian biota are available and the groups for which additional information was confirmed during this review. For terrestrial habitats (predominantly arid/desert mining areas) there is an increase in data from two (mammal and reptile) to six wildlife groups with new CRs available for bird, grasses and herbs, shrubs and trees. For freshwater habitats (predominantly tropical mining areas) there has been an increase from five to six groups. Additional data have been identified for most of the five groups, and limited new data identified for algae. Once published, this data will benefit the Australian uranium mining industry by consolidating datasets, providing a comparison to the international values, and will assist in supporting more robust radiological assessments, particularly in the screening phase of assessments.

These two tables provide a snapshot of potential data gaps. Whether or not data is required for additional wildlife groups is something that should be considered in a strategic manner or on a case by case basis, given the variation in species that can be seen in the wide range of Australian environments. Additionally, ongoing involvement in international research programs (such as the IAEA program MODARIA: Modelling and Data for Radiological Impact Assessments, that will run from 2012-2015) will be important to ensure a continuing involvement and understanding of the evolution of international databases such as the WTD. Other information may also be available for additional wildlife groups by examining datasets for stable isotope measurements that may have been captured within the ecotoxicology research community. These alternative data sources may provide information that can be used to estimate CRs for some radionuclides.

3.4.5.2 Maralinga

Maralinga is located in central South Australia. Between 1956 and 1963 the Maralinga lands were used by the British to conduct nuclear weapons testing, including both critical and non-critical nuclear test trials. From a climatic perspective Maralinga is in an arid desert area which is a common environment to many uranium deposits in Australia. However, in relation to Maralinga data, the isotopes reported were the anthropogenic radionuclides Cs-137, Am-241 and Pu-239/240 which are not relevant to the uranium mining and milling industry. For the purposes of this review the Maralinga data was not included or reviewed further.

3.4.5.3 Other environments

There are a wide range of practices that release radioactivity to the environment. Whilst this review only considered data for non-human biota inhabiting uranium mining and milling environments it is recommended that any future publication of Australian CRs, including those from this project, be incorporated with all available data for Australian environments.

Table 2: IAEA Broad Terrestrial Wildlife groups and relationship to ICRP RAPs and Australian data for uranium mining areas

IAEA Broad Terrestrial Wildlife Groups	Potential appropriate ICRP RAP	Australian data (Yes/No)	
		Currently in WTD	Identified during project
Amphibian	Frog	No	No
Arachnid	–	No	No
Arthropod	Bee	No	No
Bird	Duck	No	**Yes**
Annelid	Earthworm	No	No
Fern	–	No	No
Fungi	-	No	No
Grasses and herbs	Wild Grass	No	**Yes**
Lichens and Bryophytes	–	No	No
Mammal	Rat or Deer	**Yes**	**Yes**
Mollusc - gastropod	–	No	No
Reptile	–	**Yes**	**Yes**
Shrub	–	No	**Yes**
Tree	Pine Tree	No	**Yes**

Table 3: IAEA Broad Freshwater Wildlife groups and relationship to ICRP RAPs and Australian data for uranium mining areas

IAEA Broad Freshwater Wildlife Groups	Potential appropriate ICRP RAP	Australian data (Yes / No)	
		Currently in WTD	Identified during project
Algae	–	No	**Yes**
Amphibian	Frog	No	No
Bird	Duck	No	No
Crustacean	–	**Yes**	No
Fish	Salmonid	**Yes**	**Yes**
Insect	–	No	No
Insect larvae	–	No	No
Mammal	–	No	No
Mollusc	–	**Yes**	**Yes**
Phytoplankton	–	No	No
Reptile	–	**Yes**	**Yes**
Vascular Plant	Wild Grass	**Yes**	**Yes**
Zooplankton	–	No	No

4. Conclusions

The aim of this project was to review and evaluate existing Australian radionuclide activity concentration data in non-human biota common to Australian uranium mining and milling environments. A wide range of data sources were reviewed, and a substantial amount of data were identified that can be utilised for estimating whole-organism concentration ratios (CRs). It has also identified that there is still additional information available which should be pursued. For terrestrial habitats (predominantly arid/desert mining areas) there is an increase in data from two (mammal and reptile) to six wildlife groups with new CRs available for birds, grasses and herbs, shrubs and trees. For freshwater habitats (predominantly tropical mining areas) there has been an increase from five to six groups. Additional data has been identified for most of the five groups and data identified for algae.

In relation to data gaps there are a number of topics that should be considered and discussed within the environmental radiation protection/radioecology community and could be further researched. These include:

- developing Australian specific ash:fresh and dry:fresh weight ratios for terrestrial plants, particularly for those existing in arid/desert areas and for trees including *Eucalyptus* and *Melaleuca* species
- distribution coefficient (K_d) values for Australian aquatic environments (i.e. the relationship between sediment values and activity concentration in filtered water) and whether these should be applied to estimating media concentrations in the absence of data
- the approach to be taken for the inclusion/exclusion of as less than the limit of detection values in datasets when determining CRs for Australian non-human biota

Whilst less relevant to the uranium mining industry, the development of thorium tissue to whole-organism conversion factors may be relevant to other industries (i.e. mineral sands) and could be investigated by examining the Australian datasets in more detail.

Finally, this report has only dealt with equilibrium CRs that are used to support radiological assessments, particularly in the screening phase of assessments for long term exposure scenarios for equilibrium situations. Equilibrium whole-organism CRs discussed in this report are not appropriate for use in circumstances where there is variation in the radiological conditions (e.g. pulsed inputs of radionuclides or accidents). Alternative methods of quantifying transfer, including dynamic models should be considered in these situations.

4.1 Recommendations

From the analysis and conclusions of this report ARPANSA recommends that:

- The terminology to be used in Australia in the future, and how data on domesticated species is incorporated should be considered as national guidance is developed for radiation protection of the environment in Australia. This guidance should also include recommended sampling and analysis regimes to ensure consistency across the industry sector.

- The cooperative relationship with industry undertaken during this project is built upon to establish a non-human biota dataset relevant to uranium environments and that additional industry data is pursued. This is particularly relevant for those datasets that are known to be quite extensive but have not yet been paired with media data.
- The data that have been collated during this project should be published. Publication of this data will benefit the Australian uranium mining industry by consolidating datasets, enabling a comparison to the international values, and will assist in supporting more robust radiological assessments, particularly in the screening phase of assessments for long term exposure scenarios for equilibrium situations.
- Discrepancies in the current Australian dataset incorporated into the WTD should be reconciled; the approach to be taken with Australian data when including/excluding limit of detection values should be discussed and agreed within the radioecology/radiation protection research community; additional information that may be available from ERISS should be incorporated.
- This information should be incorporated into the international Wildlife Transfer Parameter Database and a comparison of Australian CRs to the IAEA and ICRP summary values undertaken. This process should be done in a coordinated manner with industry, research bodies and relevant Commonwealth agencies.

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Appendix 2 Conversion Factors

Table A2-1: Assumed ash or dry weight conversion factors (expressed as ash or dry weight as a fraction of fresh weight) taken from Beresford et al. 2008b

Terrestrial Organism	Dry weight fraction	Ash weight fraction
Grass/herb	0.25	-
Shrub (wood)	0.5	0.013
Shrub (other parts)*	0.1	0.003
Tree (wood)	0.5	0.013
Tree (other parts)*	0.1	0.003
Small mammals (whole organism)	0.3	-
Mammal (bone)	0.8	0.5
Mammal (muscle)	0.25	-
Bird (whole organism)	0.3	-

* These were not considered to be appropriate for application to shrubs/trees from the arid/desert regions of Australia. A dry weight:fresh weight fraction of 0.6 was applied to shrubs from arid/desert. This was based on data presented in references 12 and 26 (Appendix 1).

Table A2-2: Assumed dry weight to fresh weight conversion factors (expressed dry weight as a fraction of fresh weight) for aquatic organisms taken from Hosseini et al. 2008.

Aquatic Organisms	Dry weight fraction
Freshwater	
Phytoplankton	0.2
Vascular plant	0.25
Bivalve mollusc, crustacean, insect larvae	0.25
Amphibian (whole organism) Fish	0.21 0.18

Appendix 3 Australian Whole-organism CR – Current

Table A3-1: Concentration ratio ($CR_{wo\text{-}soil}$) values for mammals inhabiting Australian terrestrial ecosystems included in the WTD compared to IAEA summary values (www.wildlifetransferdatabase.org)

Wildlife Group (Terrestrial)	$CR_{wo\text{-}soil}$ ($Bq\ kg^{-1}$ fw whole organism/$Bq\ kg^{-1}$ dw soil)		**N**	**Reference (Appendix 1)**
	AM	**AMSD**		
IAEA Mammal-Uranium	**5.78×10^{-3}**	**6.83×10^{-3}**	**22**	**44**
Red-kangaroo (arid)	2.12×10^{-2}	3.76×10^{-3}	2	12
Red-kangaroo (arid)	7.99×10^{-4}	7.52×10^{-4}	4	26
Eastern grey kangaroo (arid)	8.53×10^{-3}		3	27
Red fox (arid)	1.6×10^{-2}		2	27
Rabbit (arid)	1.22×10^{-2}	2.59×10^{-3}	3	27
Mouse (arid)	6.5×10^{-4}		1	18
Wallaby (tropical)	1.25×10^{-3}	1.68×10^{-3}	3	14
Wild boar (tropical)	8.93×10^{-4}		1	15
Water Buffalo (tropical)	3.42×10^{-4}		1	15
IAEA Mammal-Radium	**0.047×10^{-3}**	**1.21×10^{-1}**	**84**	**44**
Red-kangaroo (arid)	7.6×10^{-1}	2.43×10^{-1}	2	12
Red-kangaroo (arid)	5.38×10^{-2}		4	26
Wallaby (tropical)	5.49×10^{-3}	4.10×10^{-3}	3	14
Wild boar (tropical)	1.63×10^{-2}		1	15
Water Buffalo (tropical)	1.35×10^{-2}		1	15
IAEA Mammal-Lead	**3.8×10^{-2}**	**3.6×10^{-2}**	**515**	**44**
Red-kangaroo (arid)	2.22×10^{-2}		4	26
Wild boar (tropical)	2.73×10^{-4}		1	15
Water Buffalo (tropical)	1.91×10^{-3}		1	15
IAEA Mammal-Polonium	**8.6×10^{-2}**	**2.10×10^{-1}**	**67**	**44**
Red-kangaroo (arid)	1.06×10^{0}	5.8×10^{-1}	2	12
Eastern grey kangaroo (arid)	2.9×10^{-2}		3	27
Red fox (arid)	1.9×10^{-2}	4.8×10^{-3}	2	27
Mouse (arid)	7.5×10^{-4}		1	18
Wallaby (tropical)	2.99×10^{-2}	2.41×10^{-2}	3	14
Wild boar (tropical)	9.8×10^{-2}		1	15
Water Buffalo (tropical)	9.49×10^{-3}			15

__AM__ = Arithmetic Mean; __AMSD__ = AM standard deviation; __N__=Number of samples contributing to the mean biota concentration

Table A3-2: Concentration ratio ($CR_{wo\text{-}soil}$) values for reptiles inhabiting Australian terrestrial ecosystems included in the WTD compared to IAEA summary values (www.wildlifetransferdatabase.org)

Wildlife Group (Terrestrial)	$CR_{wo\text{-}soil}$ (Bq kg^{-1} fw whole organism/Bq kg^{-1} dw soil)		N	Reference (Appendix 1)
	AM	AMSD		
IAEA Reptile-Uranium	**1.5**	**3.1**	**21**	**44**
Reptile (arid)	2.5	3.7	13	18
IAEA Reptile-Thorium	**0.20**	**0.5**	**18**	**44**
Reptile (arid)	0.27	0.55	13	18
IAEA Reptile-Lead	**0.37**	**1.0**	**45**	**44**
Reptile (arid)	1.2	1.6	13	18
IAEA Reptile-Polonium	**9.5**	**23**	**15**	**44**
Reptile (arid)	11	24	13	18

***AM** = Arithmetic Mean; **AMSD** = AM standard deviation; **N**=Number of samples contributing to the mean biota concentration*

Table A3-3: Concentration ratio ($CR_{wo\text{-}water}$) values for crustaceans inhabiting Australian freshwater ecosystems included in the WTD compared to IAEA summary values (www.wildlifetransferdatabase.org)

Wildlife Group (Freshwater)	$CR_{wo\text{-}water}$ (Bq kg^{-1} fw whole organism/Bq L^{-1} filtered water)		N	Reference
	AM	AMSD		
IAEA Crustacean - Uranium	**200**	**314**	**5**	**44**
Crustacean (tropical)	200	314	5	15
IAEA Crustacean - Radium	**270**	**444**	**5**	**44**
Crustacean (tropical)	270	444	5	15
IAEA Crustacean - Lead	**39**	**47**	**5**	**44**
Crustacean (tropical)	39	47	5	15
IAEA Crustacean - Polonium	**8293**	**7008**	**12**	**44**
Crustacean (tropical)	1240	500	5	15

***AM** = Arithmetic Mean; **AMSD** = AM standard deviation; **N**=Number of samples contributing to the mean biota concentration*

Table A3-4: Concentration ratio ($CR_{wo\text{-}water}$) values for reptiles inhabiting Australian freshwater ecosystems included in the WTD compared to IAEA summary values (www.wildlifetransferdatabase.org)

Wildlife Group (Freshwater)	$CR_{wo\text{-}soil}$ (Bq kg^{-1} fw whole organism/Bq L^{-1} filtered water) AM	AMSD	N	Reference (Appendix 1)
IAEA Reptile-Uranium	**116**	**96**	**8**	**44**
Goanna (tropical)	50		1	15
File Snake (tropical)	92	8	3	15
Snapping turtle (tropical)	194	197	2	15
Freshwater crocodile (tropical)	45		1	15
IAEA Reptile-Thorium	**1028**	**638**	**7**	**44**
Goanna (tropical)	244		1	15
File Snake (tropical)	1520	621	3	15
Snapping turtle (tropical)	962	96	2	15
Freshwater crocodile (tropical)	470		1	15
IAEA Reptile-Radium	**798**	**1518**	**18**	**44**
Goanna (tropical)	180		1	15
File Snake (tropical)	270	88	3	15
Snapping turtle (tropical)	3990	2520	2	15
Freshwater crocodile (tropical)	3310		1	15
IAEA Reptile-Lead	**440**	**623**	**12**	**44**
Goanna (tropical)	81		1	15
File Snake (tropical)	36	15	3	15
Snapping turtle (tropical)	1100	59	2	15
Freshwater crocodile (tropical)	233		1	15
IAEA Reptile-Polonium	**3634**	**2260**	**7**	**44**
Goanna (tropical)	4720		1	15
File Snake (tropical)	1490	622	3	15
Snapping turtle (tropical)	4470	23	2	15
Freshwater crocodile (tropical)	7310		1	15

***AM** = Arithmetic Mean; **AMSD** = AM standard deviation; **N**=Number of samples contributing to the mean biota concentration*

Table A3-5: Concentration ratio ($CR_{wo-water}$) values for fish inhabiting Australian freshwater ecosystems included in the WTD compared to IAEA summary values (www.wildlifetransferdatabase.org)

Wildlife Group (Freshwater)	CR wo-soil (Bq kg^{-1} fw whole organism/Bq L^{-1} filtered water)		N	Reference (Appendix 1)
	AM	AMSD		
IAEA Fish-Uranium	**31**	**101**	**1294**	**44**
Fish (tropical)	215	266	15	15
IAEA Fish-Thorium	**675**	**4575**	**64**	**44**
Fish (tropical)	157	81	8	15
IAEA Fish-Radium	**171**	**504**	**277**	**44**
Fish (tropical)	1106	1408	23	15
IAEA Fish-Lead	**255**	**697**	**379**	**44**
Fish (tropical)	70	64	20	15
IAEA Fish-Polonium	**2029**	**6636**	**203**	**44**
Fish (tropical)	5577	12250	38	15

***AM** = Arithmetic Mean; **AMSD** = AM standard deviation; **N**=Number of samples contributing to the mean biota concentration*

Table A3-6: Concentration ratio ($CR_{wo-water}$) values for molluscs inhabiting Australian freshwater ecosystems included in the WTD compared to IAEA summary values (www.wildlifetransferdatabase.org)

Wildlife Group (Freshwater)	CR wo-soil (Bq kg^{-1} fw whole organism/Bq L^{-1} filtered water)		N	Reference (Appendix 1)
	AM	AMSD		
IAEA Molluscs-Radium	**24294**	**34785**	**43**	**44**
Mussels (tropical)	70950	41051	14	2, 9, 19
IAEA Molluscs-Lead	**6035**	**14664**	**32**	**44**
Mussels (tropical)	23550		8	9, 19
IAEA Molluscs-Polonium	**123505**	**51896**	**147**	**44**
Mussels (tropical)	22950		8	9, 19

***AM** = Arithmetic Mean; **AMSD** = AM standard deviation; **N**=Number of samples contributing to the mean biota concentration*

Note: Concentration ratio (CRwo-sediment) values for vascular plants inhabiting Australian freshwater ecosystems have been reported to the WTD however these values are not included in this Appendix for comparison to the IAEA summary values as the IAEA values reflect the CRwo-water.

Appendix 4 Summary of Data Identified During Project

Table A4-1: Summary of Wildlife Groups and Habitats for which new CR data has been identified during this project

Habitat - Wildlife Group	CR $_{wo\text{-}soil}$ Available for the following nuclides	References from Appendix 1
Terrestrial: arid/desert – Shrubs These include (but are not limited to the following species: *Rhagodia sp, Acacia sp, Tecticornia sp, Maireana sp, Atriplex sp*) and includes other mixed halophyte shrubs	U, Th-230, Ra-226, Pb-210, Po-210	11, 12, 21, 22, 23, 24, 26, 32-43
Terrestrial: arid/desert – Grasses Mixed species of ephemeral grasses and herbs	U, Th-230, Ra-226, Pb-210, Po-210	11, 12, 26, 27, 28
Terrestrial: tropical wetland – Grasses Sedge and para grasses	Ra-226, Pb-210	3, 4
Terrestrial: arid/desert – Trees *Melaleuca sp, Eucalyptus sp* (dry weight only)	U, Th-230, Ra-226, Po-210	11, 26, 27
Terrestrial: wetland – Trees *Melaleuca sp, Eucalyptus sp* (dry weight only)	Ra-226, Pb-210	3, 4
Terrestrial: arid/desert – Reptile	Th-230, Ra-226, Pb-210, Po-210	21-23
Terrestrial: wetland – Bird	U, Th, Ra-226, Pb-210, Po-210	14, 3
Freshwater: arid/desert hot springs vascular plants	U, Ra-226, Pb-210	26, 27
Freshwater: tropical - vascular plants	U, Ra-226, Pb-210	3, 29
Freshwater: arid hot springs – algae	U, Ra-226,	27
Freshwater: tropical – Reptile	U, Ra-226,	3, 4
Freshwater: tropical – Molluscs	U, Ra-226,	3
Freshwater: tropical – Fish	U, Ra-226, Po-210	1, 3, 4

Table A4-2: Example of new whole-organism CRs for radium in Terrestrial Shrubs from arid/desert regions compared to the IAEA summary CRs

Wildlife Group (Terrestrial)	CR $_{wo-soil}$ (Bq kg^{-1} fw whole organism /Bq kg^{-1} dw soil)		**N**	**Reference**
	AM (GM)	**AMSD (GMSD)**		
IAEA Shrubs - Radium	**1.01 (0.54)**	**1.61 (3.07)**	**504**	**44***
Shrubs - Yeelirrie	0.15 (0.08)	0.27 (3.25)	76	26
Shrubs - Manyingee	0.09	0.06	11	12
Shrub – Lake Way	0.17	0.12	3	11
Shrub – Wiluna (Acacia)	0.05	0.03	12	21-23
Shrub – Wiluna (Samphire)	0.10	0.10	11	21-23

***AM** = Arithmetic Mean; **AMSD** = AM standard deviation; **N**=Number of samples contributing to the mean biota concentration*

*No Australian data included in the estimation of the IAEA summary value