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Australian Radiation Protection and Nuclear Safety Agency

SAFETY GUIDE

Radiation Protection of the Environment

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The mission of ARPANSA is to assure the protection of people and the environment from the harmful effects of radiation.

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FOREWORD

To be provided

Carl-Magnus Larsson
CEO of ARPANSA

CONTENTS

1. INTRODUCTION

1.1 Citation

This Safety Guide may be cited as the *Safety Guide for Radiation Protection of the Environment (2014).*

1.2 Background

Australia's system for managing radiation risks[1] from **ionising radiation** is closely aligned with international best practice as laid out by the International Commission on Radiological Protection (**ICRP**), the International Atomic Energy Agency's (**IAEA**) Safety and Security Series and Codes of Conduct, and in relevant Conventions to which Australia is a party. Following the publication of the *Fundamentals for Protection Against Ionising Radiation (2014)*, the Australian system now includes recommendations for demonstrating protection of the **environment**.

Protection of the environment from the harmful effects of ionising radiation is an issue that has evolved over recent decades. Up until the publication of ICRP 103 (ICRP, 2007) the recommended radiation protection framework was designed for the purposes of protecting humans from exposures to ionising radiation, with the implicit assumption that if humans were adequately protected, you would, as a consequence, provide an adequate level of protection for non-human **species** or '**wildlife'**. As modern societies have developed, an increased awareness of the potential impact that human activities can have on the environment has grown and society has come to expect a better understanding of the possible radiological harm to the environment. These expectations have included that radiation protection of the environment is not just assumed, but is clearly demonstrated.

This Safety Guide describes what is meant by 'Radiation Protection of the Environment' and outlines the environmental protection framework and practical aspects of the assessment process through which protection could be demonstrated.

1.3 Purpose

The purpose of the Safety Guide is to provide best practice guidance on how to assess **environmental exposures** and demonstrate protection of the environment from the human activities that give rise to such exposures. This guidance is for use by industry, regulators and others, and will assist in promoting a nationally uniform approach and understanding of what is meant by protection of the environment from the harmful effects of ionising radiation.

1 Radiation risk, as described in the *Fundamentals for Protection Against Ionising Radiation* (ARPANSA, 2014), refers to the likelihood of detrimental human health effects occurring as a result of exposure to ionising radiation, and includes consideration of environmental risks that might arise from such exposure. Exposure may be due to the presence of radioactive material (including radioactive waste) or its release to the environment; or a loss of control over a nuclear reactor core, a nuclear chain reaction, a radioactive source or any other source of radiation; alone or in combination.

1.4 Scope

This Safety Guide specifically focuses on environmental radiological protection (i.e. protection of the biological diversity of wildlife living in their natural environment) under **planned, existing and emergency exposure situations**, noting that protection of the environment is an integral part of any environmental assessment of the potential impact of radiation practices at all stages of development.

Guidance on human radiological protection in relation to exposures from **contaminated** environments is outside the scope of this Safety Guide. However, assessments and decisions relating to all situations involving contaminated environments should always consider human radiological protection in conjunction with protection of the environment. Efforts to reduce exposures of wildlife should, to the extent practicable, complement those to reduce human exposure, and vice-versa.

1.5 Interpretation

The Safety Guide is explanatory and descriptive in nature and is not required to be complied with *per se*; hence the use of the word 'must' in this document should not be understood as a regulatory requirement. Material in the Annexes provides further clarification and guidance on issues discussed in the Safety Guide.

1.6 Structure

This document consists of four sections and three annexes.

Section 1 describes the background, purpose and scope of the Safety Guide.

Section 2 describes the objectives of protection of the environment.

Section 3 describes the framework for demonstrating protection of the environment from exposure to ionising radiation.

Section 4 provides guidance on how to perform a radiological risk assessment as a consequence of exposures of wildlife to ionising radiation and how to demonstrate the level of protection.

Annex A provides more detailed information on assessment considerations.

Annex B describes considerations for environmental sampling and data collection.

Annex C provides specific considerations for environmental assessments under different exposure situations.

The meanings of technical terms used in this Safety Guide are defined in the *Glossary*. Terms defined in the Glossary appear in bold type on first occurrence in the text.

The *References* section provides some high-level references to international frameworks as well as to some other relevant or explanatory scientific publications cited in the document.

2. THE OBJECTIVES OF RADIATION PROTECTION OF THE ENVIRONMENT FROM IONISING RADIATION

The objectives of radiation protection of the environment are to ensure that radiation doses to organisms have a negligible impact on the maintenance of biological diversity, the conservation of species, or on the health and status of natural habitats, communities, and **ecosystems**.

Any considered environment, whether terrestrial or aquatic, may contain many forms of wildlife coexisting within a more or less complex ecosystem. Hence, protection of any specific environment may be defined as the protection of the exposed plants and animals (i.e. wildlife) to ensure minimisation of the impact to the ecosystem under threat as a whole.

2.1 Determining radiological effects on the environment

The main mechanism for determining the possibility of radiological effects on the environment is in the estimation of **dose rates** to wildlife through a radiological assessment (see Section 4). These estimates are then compared to observed effects levels in plants and animals in order to demonstrate protection.

For wildlife, four endpoints are generally utilised to capture the range of ways that a **population** can potentially be affected by radiation. These are:

- Mortality (leading to changes in age distribution, death rate and population density);
- Morbidity (reducing 'fitness' of individuals, making it more difficult for them to survive in a natural environment);
- Reproduction (by either reduced fertility or fecundity); and,
- Cytogenetic (by the induction of chromosomal damage).

All of these should be considered when applying appropriate protection strategies for wildlife.

2.2 Demonstrating protection of the environment

For radiation protection of people (individually or as populations), limits and reference levels can be set in terms of the quantities **equivalent dose** and **effective dose**, usually in **milliSieverts (mSv)** per year. These limits and reference levels are derived from knowledge on the effects of ionising radiation on human tissues, organs, individuals and populations. The values are defined so that **acute** or late tissue reactions will, in principle, not occur, other than as a result of accidents or acts with malicious intent (the use of radiotherapy in cancer treatment being a separate issue). Nominal probability coefficients for cancer and heritable effects (so-called stochastic effects) applied to the effective dose will provide guidance and reassurance of protection against detrimental effects of ionising radiation in the long term.

Similarly, fulfilment of the objectives of protection of the environment against detrimental effects of ionising radiation (as outlined in Section 2.1), can be demonstrated through comparison of measured or projected dose rates in wildlife against predefined dose rate benchmarks. Such benchmarks (further elaborated in Sections 3.6 and 3.7) are intended to guide users (e.g. proponents of a project, regulators and the public) in providing reasonable assurance that both acute and long-term detrimental effects of ionising radiation on the environment are avoided. The dose rate benchmarks for environmental protection are defined using the quantity **absorbed dose**, usually given in micro**Gray** (µGy) per hour.

3. FRAMEWORK FOR RADIATION PROTECTION OF THE ENVIRONMENT

3.1 Introduction

The framework for radiation protection of the environment described in this Safety Guide is based on work undertaken through international collaboration to develop an environmental protection framework within the system of radiological protection (ICRP, 2007; ICRP, 2008; ICRP, 2009; ICRP, 2013; ICRP, 2014). Application of the framework is generally considered as a best practice approach to assess environmental impacts from ionising radiation associated with releases of radionuclides, though this does not preclude the use of other methods to make such assessments.

The framework for radiological protection of the environment (Figure 1) is broadly consistent with that for the radiological protection of humans. The framework incorporates conceptual and numerical models ('**reference organisms**'[2]) for assessing exposure-dose and dose-effect relationships for different types of fauna and flora in a systematic way using radioecological and other information. It also incorporates numerical indices ('environmental **reference values**[3]') for guiding judgements on the acceptability of assessed dose rates and optimisation.

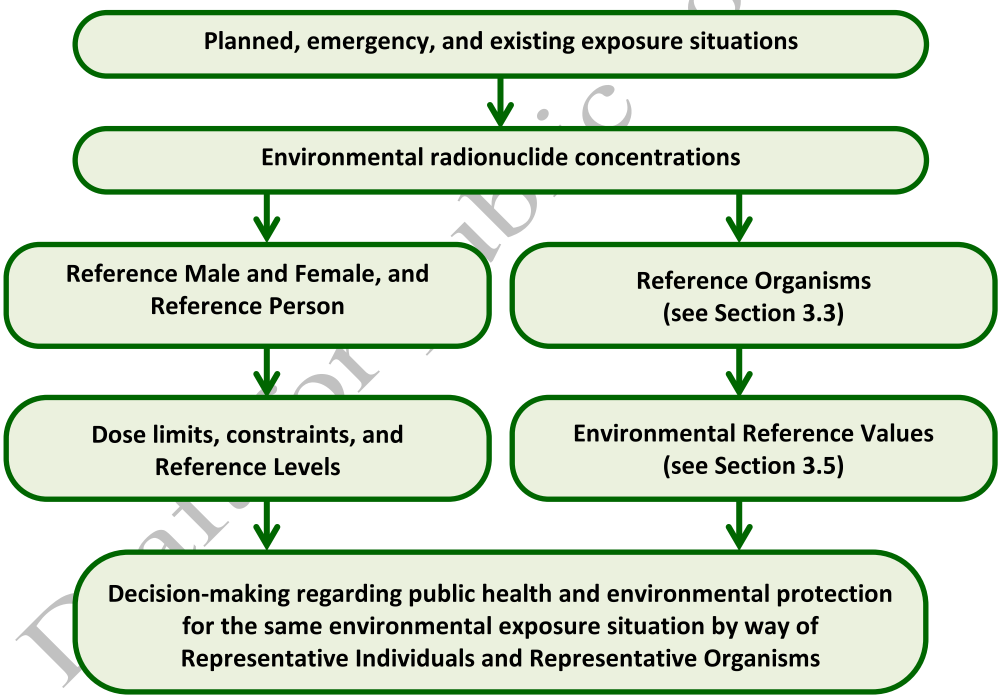

Figure 1: Framework for radiological protection of people (left) and the environment (right) in relation to all exposure situations.

2 Various compatible terms are used to describe the conceptual and numerical model used to describe an organism type, or **Representative Organism** (see Section 3.3 and Annex A.2). These include '**Reference Animals and Plants**' (**RAP**) (ICRP, 2009) and the ERICA Integrated Approach use of 'Reference Organisms' (Larsson, 2008; Howard and Larsson, 2008). The latter tem is generally used in this Guide.

3 Environmental Reference Values (ICRP, 2014) have been used as a reference point for environmental protection in this Guide (see Section 3.6). These can be based on the ICRP's **Derived Consideration Reference Levels (DCRL)** (ICRP, 2009) (see Section 3.6).

3.2 Applying the framework in an assessment context

Application of the framework for radiological protection of the environment may be helpful in assessing environmental impacts from radiation associated with different exposure situations and scenarios. It may assist at:

- the conceptual level for:
  - planning environmental assessments;
  - identifying sources of radionuclides;
  - identifying key receptor organisms, exposure pathways and endpoints;
  - identifying assessment tools (tiered approaches) that are fit for purpose; and
  - identifying and organising data that are fit for purpose.
- the operational level for:
  - providing an indication of the potential environmental impacts from radiation associated with an operation or facility;
  - developing a flexible environmental monitoring program, including ongoing comparison of assessment predictions with potential outcomes; and
  - optimising the level of effort expended on environmental protection.
- the regulatory level for:
  - assessing/demonstrating compliance with environmental protection objectives of relevant legislation or other adopted standards or codes of practice ; and
  - demonstrating that stakeholder expectations for radiological protection of the environment have been adequately addressed;
  - Expanding knowledge to improve future risk assessments by merging acquired information into the existing databases on the environmental impacts of ionising radiation.

Appropriate scientific rigour in applying the framework in an assessment context is required to properly address environmental protection objectives.

The questions to consider regarding environmental **exposure scenarios** typically include:

- *What is the natural **background**?* All organisms exist in a natural radiation environment and only the incremental human-derived dose above this (baseline) background needs to be considered in relation to assessing potential detriment to the environment
- *What is the source of the radioactivity?* This determines the type of radioactive materials released to the environment, their quantities, half-lives, and the means by which they enter the broader environment. Typical releases are atmospheric (gases or dusts from stacks or less controlled processes), aquatic (via pipes to rivers, lakes or oceans or through sewerage systems) and/or, potentially, via groundwater (from mines, processing or storage facilities). The nature of the source will determine the types of monitoring and assessment required.

- *Is the assessed release controlled or accidental?* Planned and unplanned releases have different characteristics and are assessed differently. Routine or regular releases into the environment are best assessed as **chronic**, long-term releases (**equilibrium** situation). Accidental releases can be assessed using either chronic or acute response data or both.
- *How does the material move through and disperse into the environment?* What are the transport mechanisms and vectors? How long does it take for the process to progress? What is the geographical context (i.e. an area of $2m^2$ around a discharge point or an entire County or State)? Is the material fully dispersed to negligible activity concentrations or are there sinks (e.g. sediments in lakes or oceans, surface soils downwind of stacks, etc.) where the material concentrates? How spatially and temporally homogeneous is the dispersion at the point of assessment?
- *What is eventually affected, and to what extent?* Which ecosystems or organisms are affected (either in situ or in transit)? What habits of wildlife could increase uptake of radionuclides? Where does the radioactivity finally end up (i.e. what are the endpoints)?

For humans, the three main issues that determine external dose from exposure to radioactive materials are time, distance and shielding. These issues also pertain to environmental dose. Animals can move into and out of exposure (e.g. animals coming to a river for water or to a contaminated pasture to graze) or they may be fully immersed (e.g. fish in a contaminated river or stygofauna in a groundwater plume).

Internal dose will depend on how (and in what form) radionuclides enter the organism. The concepts of bioaccessibility and bioavailability need to be considered. Bioaccessibility determines whether the plant or animal can access the environmental radioactivity (e.g. deposited materials on a soil surface will be more accessible to shallow rooted grasses than deep rooted trees). Bioavailability determines whether the material is in a form that the organism can bioaccumulate (e.g. complexation or chemical speciation strongly influences bioavailability and subsequent toxicology) and, for animals, digestibility also has a significant influence with indigestible components passing rapidly through the gut whilst adsorbed materials are retained longer and are more dispersed throughout the body.

A walk-through of aspects that should be considered in the assessments process is provided in Section 4.

3.3 Reference organisms

Reference Organisms are hypothetical representations of plants and animals that are simplified (to ellipsoids) for the purposes of determining dose and effects parameters.

One of their key practical purposes is to provide a basis for the estimation of radiation dose rates to a range of living organisms that are representative of a potentially **impacted** environment, or necessary for the structural or functional integrity for any radiation exposed ecosystem (i.e. keystone species). These estimates, in turn, provide a basis for assessing the likelihood and degree of radiation effects (Larsson, 2004).

Reference organisms are not real or living organisms themselves. They are instead simplified conceptual and numerical models used for estimating external and internal doses of the selected **representative organisms** (Figure 2). This simplification is based on the fact that radiation damage arises from the ionisation that follows the path or track that radioactive particles follow as they pass through tissues. Hence the dimensions of the organisms have an effect on the degree of radiation damage that may occur.

Currently, the simplifications in the models include:

- the representation of living organisms by simple shapes (e.g. ellipsoids); and
- an assumption of homogeneous radionuclide distribution in the tissues of the organism (internal **dosimetry**) and in environmental media (external dosimetry).

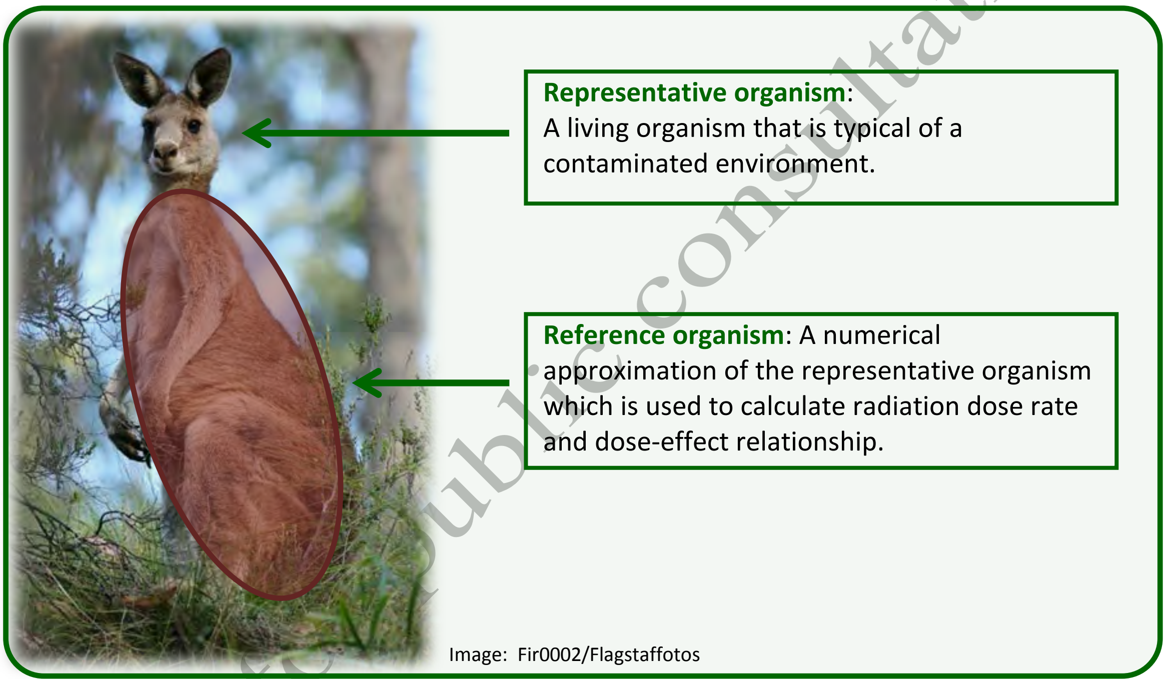

Figure 2: Simplification of a representative organism (a kangaroo) to a reference organism (such as ICRP's *Reference Animal Deer* or ERICA's *Mammal (deer)*) for dosimetry **modelling**.

Future improvements in biota dosimetry modelling, such as those proposed by the ICRP (ICRP, 2008) or under development within the IAEA **MODARIA** program (IAEA, 2012), may enable more realistic geometries and radionuclide distributions to be investigated, including uptake by and doses to specific tissues and recognition of the temporal nature of environmental exposure and biological response. However, the current situation is that for practical reasons assessment methods and tools are generally limited to the simple geometries and assumptions on radionuclide distribution and equilibrium conditions described above. This is sufficient for screening the environment at the ecosystem level.

Reference organisms also serve as points of reference for organising data for dosimetry modelling and effects analysis. Radioecological and other data for reference organisms may sometimes be pooled across several species and/or non-connected studies to obtain sufficient data for use in any assessment. This means that data for reference organisms may not necessarily relate to an individual species, specific site or geographical region. The use of pooled (i.e. generic) versus species or site specific data is an important assessment consideration and one that is likely to influence the assessment result. This is particularly the case for choice of radionuclide transfer factor (concentration ratio – see Section 3.4), which has been shown to be the most sensitive parameter affecting biota assessment results (Beresford et al., 2008). Annex A of this Safety Guide provides advice on selecting reference organisms and data for assessment.

3.4 Estimating radionuclide transfer to biota

If known, activity concentrations in plants and animals can be used directly in subsequent dose-rate calculations. However, most of the time the only data readily available are likely to be the activity concentrations in the environmental media that surrounds the biota. In these cases, activity concentrations in plants and animals will need to be derived from measured or estimated activity concentrations of radionuclides in environmental media such as the soil, water and/or sediments in which the plant or animal lives, in order to undertake a radiological risk assessment.

Concentration ratio (CR)

In order to estimate the activity concentration in a plant or animal it is essential to have an appropriate organism-to-media concentration ratio (CR) for those environmental media. These CR values are normally assumed to reflect an equilibrium situation between the exposed biota and the environmental media in which they inhabit. The CR values are particularly appropriate for assessments of constant long-term exposure scenarios. Equilibrium approaches have limited applicability in dynamic situations where environmental concentrations are changing rapidly with time (Coughtrey and Thorne, 1983; Brown et al. 2008). Application of CRs in these situations has a tendency to produce an over-estimation in the initial phase, when activity concentration in media is increasing (Psaltaki et al. 2012). Alternately, it may produce an under-estimate if the environmental media concentrations have declined at the time of sampling but within the biological half-life of the radioactive material. Dynamic modelling may be applied to a more limited number of key species and a limited number of main dose-forming radionuclides.

Tissue-media concentration ratio

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 (e.g., muscle, bone, etc.). These values may have been derived previously during efforts to assess human dose via the consumption of particular foods, such as meat or milk. Tissue-to-media CR should not be used in biota dose assessments in lieu of organism-to-media data. This is because radionuclide activity concentrations (and thereby CR) for a specific tissues 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. In cases where only tissue data are available, it can be used to estimate whole-organism concentrations using the ratios provided in Yankovich et al. (2010).

Whole-organism concentration ratio

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 (Johansen et al. 2013).

The definitions of $CR_{WO\text{-}media}$ are as follows (Howard et al., 2013):

For terrestrial biota:

CR = 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 ^{3}H, ^{14}C, ^{35}S and radioisotopes of P[4], where:

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

For aquatic biota:

CR = Activity concentration in biota whole-body (Bq/kg fresh weight) / Activity concentration in filtered water (Bq/l)

Distribution coefficient (K_d)

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

K_d (l/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 are lacking (see Annex A). However, it is much preferred to use site-specific water and sediment data as the published (model default) K_d values can have large uncertainty ranges and literature values often do not match well with site-specific conditions.

3.5 Screening levels and tiered approaches

The general approach recommended when making an assessment of environmental radiological impact is to consider an as-complex-as-necessary but as-simple-as-possible approach, thus minimising unnecessary work. To reflect this, the protection of wildlife should be addressed using a tiered (or graded) approach.

4 Atmospheric release of ^{222}Rn (radon) and progeny could also apply here where such releases are enhanced by human activities.

It has been suggested (for the use of the ERICA tool) that a **screening level**[5] of 10 µGy/h above natural background should be appropriate in most circumstances to effectively distinguish situations that are below concern from those which may require a more considered evaluation (Andersson et al., 2009; Garnier-Laplace et al., 2008; Garnier-Laplace et al., 2010). This screening level value has been derived from statistical analysis of radiation effects data using an accepted methodology for the derivation of benchmark values for other chemical stressors on the environment. It represents the dose rate at which 95% of the species in the ecosystem are expected to be protected, with an additional safety factor incorporated to account for limitations in the initial data[6].

If a simple (or screening) assessment of the situation identifies incremental dose rates to animals and plants above ***10 µGy/h***, depending on the scenarios applied and demonstrated conservatism, then a more complex assessment should be made. This assessment could use, for example, less conservative assumptions or site-specific data obtained from an environmental monitoring program.

Dose rates below the value 10 µGy/h for a conservative scenario and application of a relevant screening tool can be considered to be below concern. If more realistic assumptions are made, potentially supported by site specific data, the dose rate criterion may have to be reconsidered, and may be either higher or lower than 10 uGy/h for the particular scenario under assessment.

If a more complex assessment of the situation still identifies incremental dose rates to animals and plants above the screening level, then an assessment could be made of the probability, magnitude and distribution (spatially and temporally) of radiation exposures and possible adverse effects. This could involve an optimisation process based on Environmental Reference Values (see Section 3.6).

As the complexity of the assessment increases, so too do the effort and data requirements.

Finally, it is important to note that screening levels should not be applied as regulatory limits but, rather, as levels beyond which further investigations are highly recommended.

3.6 Reference values for environmental protection

Reference values are levels of absorbed dose rate to living organisms at which a more considered level of evaluation of the situation might be reasonably expected (see Figure 3).

5 Screening tools should be applied using the precautionary principle (Jordan & O'Riordan, 2004), whereby doses are over-estimated where available data is less precise.

6 Garnier-Laplace et al. (2010) derived screening benchmarks, namely the predicted no-effect dose rates (PNEDR), at the ecosystem level. They used radiotoxicity EDR_{10} data (dose rates giving a 10% effect in comparison with control) to fit a species sensitivity distribution (SSD) and estimate the HDR_5 (the hazardous dose rate affecting 5% of species with a 10% effect). An assessment factor (AF) was applied to the HDR_5 to estimate a PNEDR value (justified by a multi-criteria approach). The suggested generic screening value of 10 µGy/h was derived using the lowest available EDR_{10} value per species, an unweighted SSD, and an AF of 2 applied to the estimated HDR_5.

These reference values can be based on the ICRP's Derived Consideration Reference Levels (DCRLs)[7] for each reference organism (ICRP 2009; ICRP 2013), or other derived effects levels (see Table 1). They are not intended to be regarded as dose limits or 'substitute' values for them, and do not imply that higher dose rates are environmentally damaging, or that lower dose rates are in some way 'safe' or non-damaging. Rather, they can be considered as:

- a dose rate increment to living organisms above the natural background level that might incur deleterious radiation effects in the environment; and
- a point of reference to optimise the level of effort expended on environmental protection, dependent on the overall management objectives and relevant exposure situation.

Reference values should be derived from knowledge of defined expected biological effects in living organisms, such as the ICRP's Derived Consideration Reference Levels (DCRLs) (ICRP, 2008). They therefore provide a point of reference to evaluate assessment results in the context of known radiation effects levels for living organisms and in doing so provide a scientific basis for guiding decisions on environmental protection.

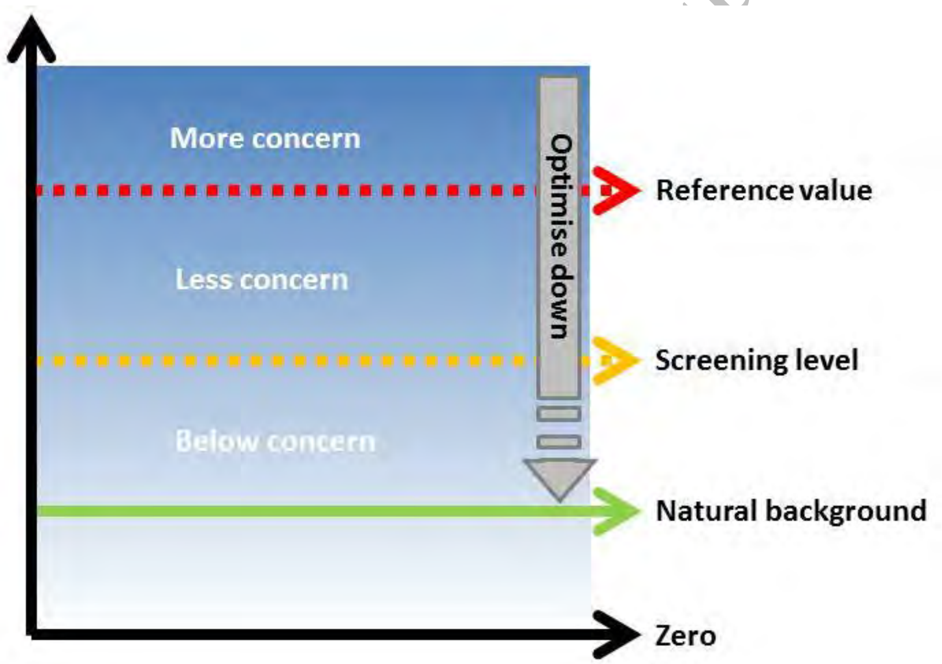

Figure 3: Use of reference value based on organism-specific expected biological effects for protection of the environment.

7 A review of all known radiation effects data relevant to reference animals and plants (RAPs) was undertaken and compiled as bands of dose rate spanning one order of magnitude (ICRP, 2008). These are called *Derived Consideration Reference Levels (DCRLs)*, and are "… a band of dose rate within which there is some chance of deleterious effect from ionizing radiation occurring to individuals of that type of Reference Animal or Plant (derived from a knowledge of defined expected biological effects for that type of organism) that, when considered together with other relevant information, can be used as a point of reference to optimize the level of effort expended on environmental protection, dependent upon the overall management objectives and the relevant exposure situation" (ICRP, 2008).

Table 1: Summary of derived effects levels (µGy/h) below which population level effects are not expected to occur. Different values have been derived for similar organisms due to the use of alternate data and/or application of differing levels of concern.

Organism	IAEA (1992)	UNSCEAR (2011)	ICRP (2008)
Terrestrial			
Plants	400	100	
Reference pine tree*			4–40
Reference wild grass			40–400
Animals	40	100	
Reference bee			400–4000
Reference earthworm			400–4000
Reference duck			4–40
Reference deer			4–40
Reference rat			4–40
Aquatic			
Freshwater organisms	400	400	
Reference frog			40–400
Reference trout			40–400
Marine organisms		400	
Reference crab			400–4000
Reference flatfish			40–400
Reference brown seaweed			40-400

*Reference 'organism type' refers to the ICRPs Reference Animals and Plants.

3.7 Selecting environmental reference values

The purpose of reference values is to provide:

- an indication of the possibility of occurrence of deleterious radiation effects in the environment; and
- a point of reference to optimise the level of effort expended on environmental protection.

Reference values should be evidence-based and principally derived from review or analysis of the radiation effects literature and other relevant data. Review or analysis of the radiation effects literature should consider the biological effects associated with a reported exposure and their relevance in an environmental context. It is important to assess whether each biological effect is likely to impact only an exposed individual (or small group of individuals) or whether it is likely to manifest as a population level effect within a potentially impacted environment. Generally it is the latter which is currently considered when assessing doses.

Biological effects to individuals that could have a consequence at the population level include:

- early mortality (leading to changes in age distribution, death rate and population density);
- some forms of morbidity (that could reduce 'fitness' of the individuals, making it more difficult for them to survive in a natural environment);
- impairment of reproductive capacity by either reduced fertility or fecundity (affecting birth rate, age distribution, number and density); and
- the induction of chromosomal damage which potentially manifests adverse effects in subsequent generations.

There is unlikely to be any effect at the population level if there are no deleterious effects in any of the individuals of that population. Therefore environmental reference values should be selected commensurate with the minimum dose rate level at which radiation induced biological effects in individuals occur. However, there are a number of additional points that should be considered when deriving reference values for the environment. These are discussed below.

Observed biological effects reported in the radiation effects literature may arise from acute or chronic exposures depending on the particular experiment or study conducted. In an environmental context, chronic low level exposures of organisms are those that are most likely to occur, particularly in planned and existing exposure situations. Thus, it may be appropriate to apply data from the radiation effects literature relevant to the type of exposures expected in the environmental situation being considered.

Not all organisms share common ***radiosensitivity***. Higher order organisms (e.g. mammals, birds, trees) tend to be more sensitive to radiation than lower order organisms (e.g. insects, invertebrates, planktons) (**UNSCEAR**, 2008). This means that higher order organisms will generally experience biological effects at lower dose rates compared to lower order organisms. The implication is that environmental reference values for higher order organisms should be comparatively lower than those for lower order organisms.

Radiation effects data for most organism types are relatively sparse. Consequently, there is likely to be inherent uncertainty in distinguishing the exact minimum dose rate level at which biological effects in organisms actually occur. In order to account for this uncertainty, it may be desirable to express environmental reference values in a banded fashion rather than as a single (discrete) value. The possible combination of small effects on biological endpoints should also be considered.

Review and analysis of the radiation effects literature has been conducted at the international level to derive effects levels below which there is not expected to be significant population level effects for a range of organism types (Table 1). These derived values may be helpful in guiding the selection of environmental reference values for use in assessment. As an example, where the representative organism is sufficiently similar to one of the ICRP Reference Animals or Plants, the corresponding Derived Consideration Reference Level for that Reference Animal or Plant could be used as the environmental reference value. Another example could be to use a more general value, such as those reported by IAEA or UNSCEAR, across the range of representative organisms included in the assessment. No matter the adopted value for the environmental reference value, the rationale for its selection should be clearly documented in the assessment report.

3.8 Interpreting assessment results in the context of environmental reference values

The approach taken to radiological protection of the environment in this safety guide is, by design, conservative. This is in line with both the precautionary principle (Jordan and O'Riordon, 2004) and the paucity of data which exists for the radiological impact on some biota. Because of this, any finding above the environmental reference levels does not necessarily imply any true effect on the environment. However, they do indicate the need for further work to refine the determination of exposure, dose and/or impact. This work may range from more closely aligning the models with the site specific factors through to detailed radiological studies of the impacts. In most cases it would be expected that, simply by using more realistic base assumptions, it would be possible to confirm that the environment is being protected.

A very important concept to remember in assessing environmental impacts on biota is the difference which is inherent between protection of humans and protection of the environment. Human protection is importantly structured around the individual and any detriment to an individual must be justified, limited and optimised. With environmental protection the end points are based on a combination of mortality, morbidity, reproduction and cytotoxicology and the population as a whole is the critical endpoint. For this reason it is important that, when assessing the radiological impact on the environment, the protection of the environment as a whole remains the key aim.

The relative risks of radiation and other pollutants should be characterised and compared, with radiation treated similarly to a range of conventional hazards (earth moving, land disturbance, creek diversion, chemical storage, etc.). Although impacts on individuals should be minimised, individual impacts do not necessarily prevent a facility or operation being justified. Studies conducted in Australia on radiological impacts have shown that the radiological impacts may be several orders of magnitude less than that from other physical or chemical effects and also may be far less than other toxicological effects (Johnston et al., 2003).

4. ASSESSMENT CONSIDERATIONS

4.1 Introduction

The most common and effective way to demonstrate protection of the environment from ionising radiation is by undertaking an environmental radiological assessment. Whilst each assessment varies in its detail and complexity, the Section that follows aims to outline aspects which should to be considered when performing an assessment.

4.2 When to do an environmental radiological assessment

Knowing whether or not an environmental radiological assessment is needed for a particular radiation practice or source will help to ensure that effort and resources are not expended unnecessarily. As a general guide, an environmental radiological assessment should be undertaken when:

- Requested by the regulatory authority to do so. The request could be by written direction, as a licence condition or contained in guidelines for the preparation of an environmental impact statement or licence application.

- The operator has committed to do so. Such a commitment could be made within the environmental or radiation management plan for the practice.

- The practice is a 'nuclear action' under the Environment Protection and Biodiversity Conservation (EPBC) Act 1999. Nuclear actions include, but are not limited to, establishing a nuclear installation, mining or milling uranium ore, establishing a large-scale disposal facility for radioactive waste and de-commissioning or rehabilitating any facility or area in which any of the previously mentioned activities has occurred.

- There is a real, potential or perceived risk of environmental exposures of concern due to the nature of the practice and there is uncertainty about the magnitude and extent[8] of exposure.

4.3 Building a scenario

Building the exposure scenario(s) is fundamentally important in the assessment process. Scenario building should include a description of;

- The radiation practice or source,

- The exposure situation (i.e. planned existing or emergency)

- The physico-chemical properties of the released radioactive material and the means of dispersion,

8 Extent of exposure includes the spatial and temporal scales over which the exposure may occur, as well as the number of species and individuals exposed.

- The impacted environment, including actual or likely contamination levels,
- The characteristics and activity patterns of wildlife populations of concern, including their interaction with the impacted environment,
- The representative organisms selected for the assessment and the rationale for their selection,
- The exposure pathways,
- The features, events and processes that could influence the release of radionuclides from the source into the wider environment,
- The spatial and temporal scales of potential exposure.

Some questions that might be asked when constructing a scenario are given in Section 3.2, with general aspects broken down in Figure 4 and under the subheadings that follow.

The overall effect of radiation exposure in the context of other contaminants could also be considered at this stage; however more data from the outcome of relevant assessments may be required to reach an informed decision.

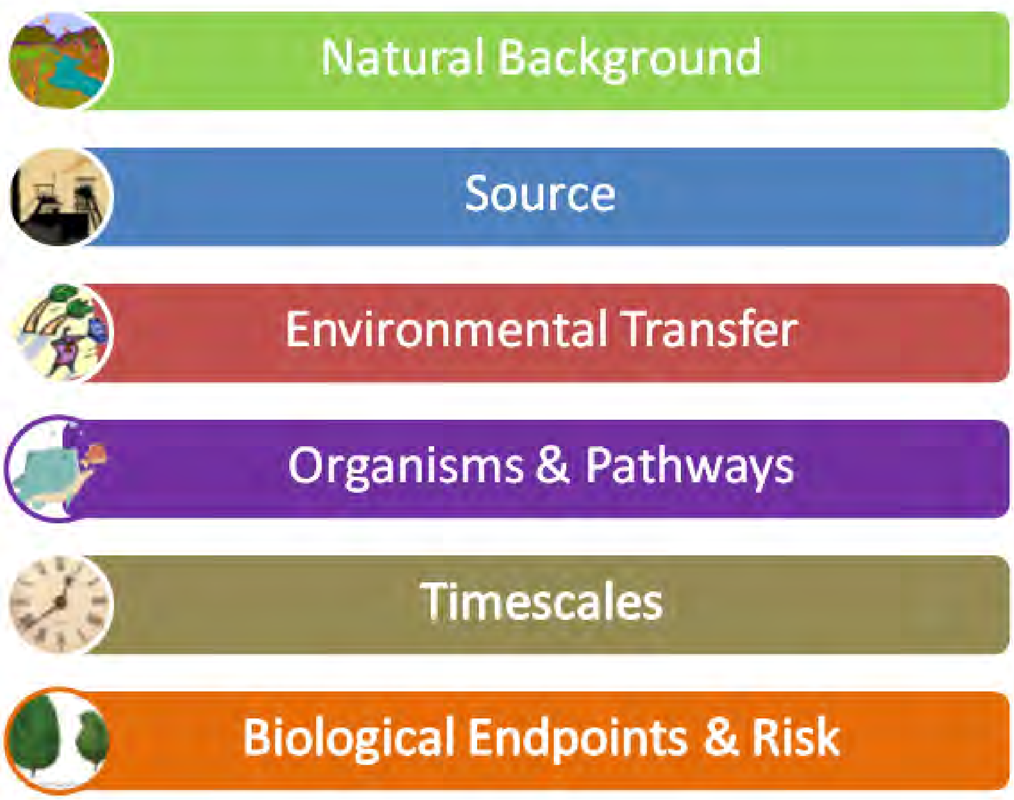

Figure 4: General aspects which need to be considered when building scenarios.

Natural background

A baseline value for natural background should be established. Environmental radiological assessment focuses on dose rates to wildlife *additional* to natural background.

Source

The source of radiation exposure should be quantified. This includes a description of the relevant radionuclide quantities, locations of generation or storage, as well as the release type and duration. Further information on source term considerations for Planned, Existing and Emergency situations is provided in Annex C.

Environmental transport

Mechanisms by which radionuclides physically move through the environment should be identified. These can include migration or dispersion through soil, air or water – also consider that the spatial and temporal scales of radionuclide transfer can vary. An appropriate dispersion model may need to be applied to estimate the transfer of the source material to the environment. In the case of past releases, the impacted environment should be sampled directly to provide reliable activity concentration data.

Organisms and pathways

As defined in Section 3.3, Representative Organisms should be determined via surveys of the affected area. Consideration should be given to relevant organisms or habitats that may be difficult to sample. These can be represented at the assessment stage through use of Reference Organism data (numerical approximations). Detailed information on defining Reference Organisms for Australian wildlife is given in Annex A.

Transfer of radionuclides to animals and plants is discussed in Section 3.4. Relevant pathways of exposure from external and internal sources associated with defined exposure scenarios should be considered. The specific habits of the local wildlife or assumptions associated with these can also be incorporated into the scenario.

Timescales

The duration of source release or exposure time are important aspects to consider during the assessment. Most assessment models generally assume equilibrium conditions, and many standard parameters assume exposure for longer time periods (i.e. in the order of years). Exposure times can usually be related to routine organism habits and behaviours. A short-term assessment (days and months following a release) will require specialised dynamic models (see Section C.3).

The nature of the source materials should also be taken into account. In some cases, where long half-life radionuclides are included in the source term, a long-term assessment (i.e. tens of thousands of years for long-lived radionuclides) of radionuclide transfer should be considered.

Biological Endpoints and Risk

Exposure to radiation can cause a biological outcome. The size of the risk (or estimations of probability) that exposure to radiation will bring about an effect of significance on a population or ecosystem should be discussed in the context of environmental reference values (see Section 3.6). If possible, the discussion can be extended to how significant this effect may be. This encompasses analysis of transfer, uptake and effects of exposure to ionising radiation, including the derivation of dose-effect relationships for various biological endpoints in exposed organisms (Oughton et al., 2004). In rare cases, consideration can also be given to the redundancy of the exposed habitat in relation to the broader regional context and the ability of biota to recruit back into the affected habitats from refugia.

4.4 Undertaking the assessment

Once the scenario has been constructed, various aspects for undertaking the environmental assessment should be stepped through (see Figure 5). Each of these has been included under the four sub-headings that follow.

Figure 5: Aspects which should be considered when performing an environmental radiological assessment (after building the scenario).

Appropriate assessment tool

Various assessment tools are available for radiological assessment of the environment. These can use differing methodologies of calculation, and the user should take care to choose the appropriate tool for their specific application and be aware of assumptions that are applied within.

Some readily-available assessment tools that could be considered are the ERICA tool (Brown et al., 2008) and RESRAD-BIOTA (USDOE, 2004). These two tools have been tested in various inter-comparison exercises to look at model-model differences introduced by user assumptions (Beresford et al., 2008; Beresford et al., 2010; Johansen et al., 2012; Vives i Batlle et al., 2007;

Tiered/graded approach

An assessment tool that includes a tiered or graded approach should be applied (see Section 3.5). This will help to ensure that the assessment is as simple as possible but as complex as necessary.

A pictorial representation of a tiered approach showing screening and a second, more complex tier, is shown in Figure 6. This flow chart shows the steps of building a scenario, applying a screening level and moving on to more complex assessment methodology if required.

The final justification is based upon known biological outcomes, sound reference levels and demonstration of protection – the screening level should not be used as a dose limit.

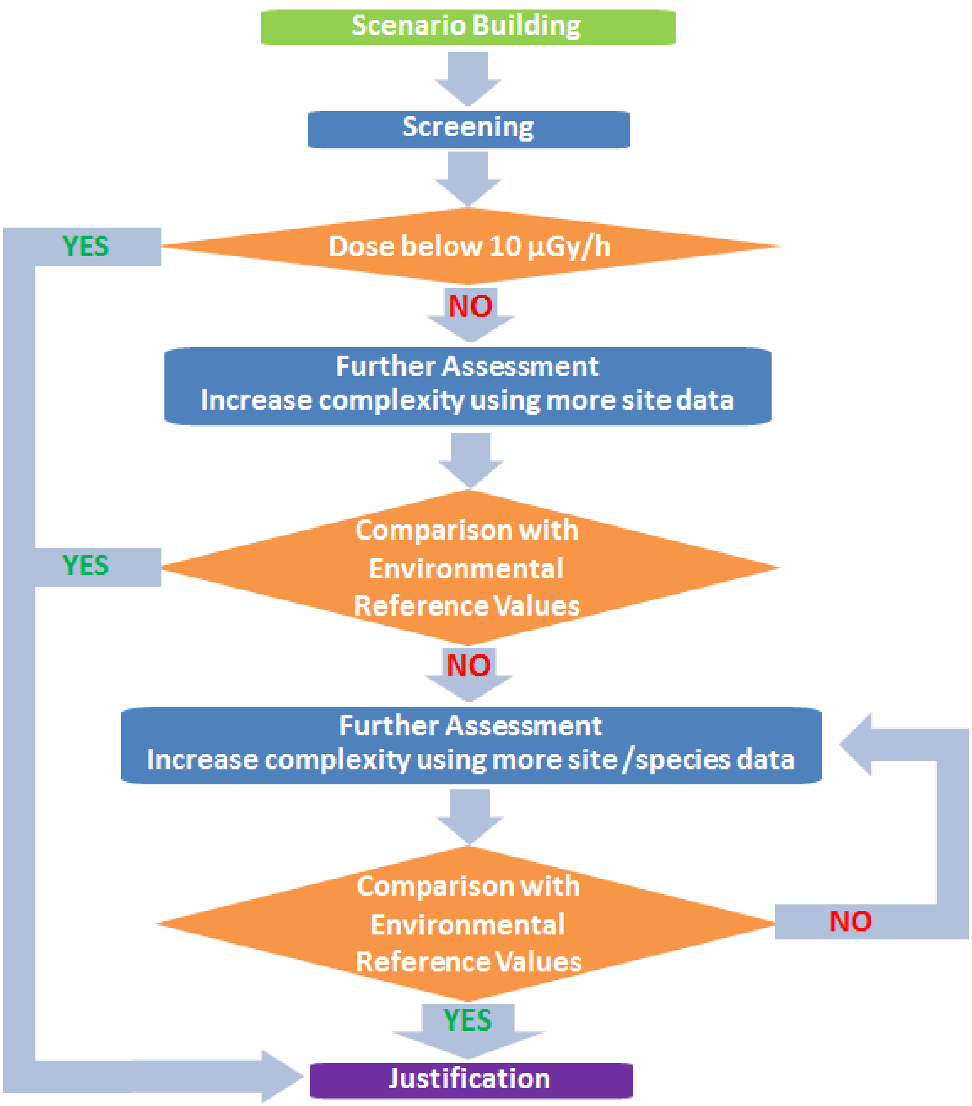

Figure 6: Applying a tiered/graded approach in radiological assessment. Exposures which are not of concern can be identified at the screening stage. If required, further assessment (at a more complex level) can then be applied and justified by comparison with biological effects data (e.g. ICRP DCRL bands).

Screening and reference levels

An initial screening using conservative assumptions applied to a general dose rate of 10 µGy/h provides a reliable way to determine exposures which are not of concern and where no further justification is required (see Section 3.5).

Where the screening has failed, a more complex assessment (where site-specific data is applied) along with less conservative assumptions is strongly recommended. Once calculated, biota dose rates should be compared to environmental reference values (see Sections 3.6 and 3.7), which relate to observed biological effects on reference organisms from ionising radiation.

Protection at population levels

Populations and ecosystems are normally the overall objects of protection (rather than aiming to protect at the individual plant or animal level). This can be incorporated into the information used in the setting of environmental reference values and in the overall justification that protection has been demonstrated. Further information on interpretation of assessment outcomes against reference values can be found in Section 3.8.

4.5 Stakeholder consultation

At all stages of environmental assessment it is recommended that relevant stakeholders are engaged, with the amount of effort depending on the impact of the action being assessed and the level of community concern. The consultation process should demonstrate independence and show transparency and openness, with the aim being to inform stakeholders and earn their trust. The engagement of disparate stakeholders also has the advantage of ensuring that as much information as possible is provided for the assessment.

Stakeholders can include, but are not limited to;

- Public & community groups,
- Local liaison groups (or committees),
- Special interest groups,
- Proponents of the development and industry representatives,
- News and social media,
- Government authorities and decision makers,
- Professional bodies,
- International organisations and national regulatory bodies (and their staff).

4.6 Other considerations

When performing an environmental assessment, human and environmental protection should be considered in parallel. It is also important to note that other contaminants related to human actions can also have an influence on the environment, including, but not limited to;

- Acid or alkaline materials;
- Heavy metals;
- Hydrocarbons;

- Pesticides;
- Thermal pollution;
- Chemical pollution.

The possible effects of these contaminants are not specifically considered in this Safety Guide, due to a focus on radiation protection. However, any deliberations on environmental impacts should include the effects of all possible contaminants and a characterisation of the relative risks that they may pose to populations and ecosystems.

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Annex A Further Assessment Considerations

A.1 Reference organisms in detail

As defined in Section 3.1, Reference Organisms are hypothetical representations of plants and animals that are typically simplified (to ellipsoids) for the purposes of determining dose and effects parameters. One of their key practical purposes is to provide input information (mass, size dimensions, etc.) into the detailed dosimetric modelling necessary to calculate dose.

Establishing reference organisms

The current state-of-practice for dosimetric modelling for biota utilises a series of simplifying assumptions about an organism's shape, density, and position relative to radionuclide contamination in order to perform probabilistic modelling (e.g., Monte Carlo simulations) of absorbed doses. Key outcomes of such modelling include **dose conversion coefficients** (DCCs), which are factors used to relate radionuclide concentrations in soil or water to the internal and external doses of exposed organisms (e.g., dose=DCC x concentration). DCCs are approximated as follows:

$$DCC_{internal} = 5.7672\text{x}10^{-4} \text{ x } E \text{ x } \Phi_E \qquad (1)$$

$$DCC_{external} = 5.7672\text{x}10^{-4} \text{ x } E \text{ x } (1-\Phi_E). \qquad (2)$$

Where:

E is the energy of a mono-energetic radiation source (MeV)

Φ_E is the absorbed fraction for a given energy (based on organism density, size, geometry, etc.)

Equations (1) and (2) are approximations that assume that the organism and surrounding media are of the same density and elemental composition.

Instead of deriving their own DCCs for each case, most practitioners may choose to use DCC reference tables, which are pre-calculated DCCs for a range of organisms (e.g., Ulanovksy and Prohl, 2006), or use available biota dose modeling software (e.g., ERICA-Tool, RESRAD-BIOTA) which rely on these pre-calculated DCCs. In some software codes (e.g., ERICA-Tool) the user may model a 'new organism' (a user-defined organism) by providing the mass, geometry, and other information on an organism of interest. When this 'new organism' function is used, the software codes interpolate or extrapolate from the standard set of reference organisms and therefore the dose results for a 'new organism' may be under- or over protective. It is essential that the dose model parameters used at a particular site are justified as being sufficient and protective for the organisms and conditions of that site.

Guidance on reference organism geometry

Whether using the above equations, the published DCC reference tables, or available software codes, it is required that the dimensions and mass of the Reference Organism be known. Under the current state-of-practice, the Reference Organism is modeled as a three-dimensional ellipsoid (most organisms, see Figure 7), or cylinder (a few organisms). The dimensions are typically entered as centimeters, and are designated as:

- a-major axis (length),
- b-minor axis (width),
- c-second minor axis (height).

As examples, a Reference Organism for the rat family can be described as a=20 cm, b=6 cm, c=5 cm, with a mass of 0.314 kg; a Reference Organism for a freshwater mollusc can be described as a=10 cm, b=4.5 cm, c=3 cm, with a mass of 0.0164 kg.

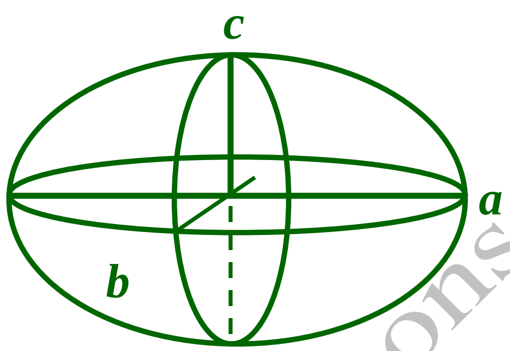

Figure 7: Nomenclature for Reference Organism dimensions.

Published reference organism dimension and mass data

Dimension data for certain terrestrial and aquatic organisms (fresh water and marine) have been published in ICRP (2008) and are provided below for convenience (Table 2). However, the ICRP list is highly general, and may be biased toward organisms inhabiting northern hemisphere ecosystems. Their use in Australia should be accompanied by an evaluation and justification of their applicability to the evaluation area.

Australian-specific data

A process of selecting and performing dosimetric modelling and effects studies on a list of Australian-specific Reference Organisms has not yet been performed. However, as suggested above, the dimensions, masses and radionuclide transfer parameters for Australian plants and animals may be entered into available codes that have ‘new organism’ (user-defined) capability with care to make protective (conservative) representations. The following ellipsoid dimensions and masses are suggested for a range of typical Australian organisms (see Table 3).

Table 2. Some standard reference organism geometries including ICRP reference animals and plants (see Ulanovsky and Prohl, 2008 for additional organisms)

Organism name	Reference organisms (examples)	Reference Animals and Plants	Habitat	Dimensions* (cm)	Mass (kg)
Terrestrial					
Insect, small	Detritivorous invertebrate (woodlouse)		In soil, on soil	$1.74 \times 0.61 \times 0.31$	1.70×10^{-4}
Insect	-	Bee	On soil	$2 \times 0.75 \times 0.75$	5.89×10^{-4}
Lichen	Lichen and bryophytes (bryophyte)		On soil	$4.0 \times 0.23 \times 0.23$	1.10×10^{-4}
Gastropod	Gastropod (snail)		In soil, on soil	$1.88 \times 1.54 \times 0.93$	1.40×10^{-3}
Grass	Grasses and herbs (wild grass)	Wild grass	On soil	$5 \times 1 \times 1$	2.62×10^{-3}
Earthworm	Soil invertebrate (earthworm)	Earthworm	In soil	$10 \times 1 \times 1$	5.24×10^{-3}
Amphibian	Amphibian (frog)	Frog	In water, in soil, on soil	$8 \times 3 \times 2.5$	3.14×10^{-2}
Bird egg	Bird egg (duck egg)	Duck egg	On soil	$6 \times 4 \times 4$	5.03×10^{-2}
Burrowing mammal	Burrowing or small mammal (rat)	Rat	In soil, on soil	$20 \times 6 \times 5$	0.314
Reptile	Reptile (snake)		In soil, on soil	$116 \times 3.5 \times 3.5$	0.744
Wading bird	Wading bird (duck)	Duck	In water, on soil, in air	$30 \times 10 \times 8$	1.26
Large mammal	Large mammal (deer)	Deer	On soil	$130 \times 60 \times 60$	245
Tree	Tree (pine tree)	Pine tree	On soil	$1000 \times 30 \times 30$	471
Shrub	Shrub		On soil	-	-
Aquatic (marine)					
Phytoplankton	Phytoplankton		In water	$0.005 \times 0.005 \times 0.005$	6.54×10^{-11}
Zooplankton	Zooplankton		In water	$0.62 \times 0.61 \times 0.31$	6.14×10^{-5}
Anemone	Sea anemones/true corals		In water	$1.5 \times 1.5 \times 1.5$	1.77×10^{-3}
Algae	Macroalgae	Brown seaweed	In water	$50 \times 0.5 \times 0.5$	6.54×10^{-3}
Mollusc	Benthic mollusc		In water	$5 \times 2.5 \times 2.5$	1.64×10^{-2}
Worm	Polychaete worm		In water	$23 \times 1.2 \times 1.2$	1.73×10^{-2}
Plant	Vascular plant		In water	$9.29 \times 2.32 \times 2.32$	2.62×10^{-2}
Pelagic fish	Pelagic fish		In water	$30 \times 6 \times 6$	0.565
Crab	Crustacean	Crab	In water	$20 \times 12 \times 6$	0.754
Benthic fish	Benthic fish (flatfish)	Flat fish	In water	$40 \times 25 \times 2.5$	1.31
Reptile	Reptile (marine turtle)		In water	$85 \times 39 \times 80$	139
Mammal	Mammal (dolphin)		In water	$180 \times 44 \times 44$	182
Aquatic (freshwater)					
Phytoplankton	Phytoplankton		In water	$0.008 \times 0.0007 \times 0.0007$	2.05×10^{-12}
Zooplankton	Zooplankton		In water	$0.2 \times 0.14 \times 0.16$	2.35×10^{-6}
Crustacean	Crustacean		In water	$1 \times 0.3 \times 0.1$	1.57×10^{-5}
Insect larvae	Insect larvae		In water	$1.5 \times 0.15 \times 0.15$	1.77×10^{-5}
Plant	Vascular plant		In water	$100 \times 0.1 \times 0.2$	1.05×10^{-3}
Gastropod	Gastropod		In water	$3 \times 1.5 \times 1.5$	3.53×10^{-3}
Mollusc	Bivalve mollusc		In water	$10 \times 4.5 \times 3$	7.07×10^{-2}
Pelagic fish	Pelagic fish (trout)	Salmonid/trout	In water	$50 \times 8 \times 6$	1.26
Benthic fish	Benthic fish		In water	$50 \times 8 \times 7$	1.47
Mammal	Mammal (muskrat)		In water	$33 \times 15 \times 15$	3.90

* Dimensions represent the axes of ellipsoids

Table 3. Suggested dimensions and masses of some Australian organisms (a,b,c, in cm; mass in kg). Site-specific data should be used in preference (where possible).

Organism		***a* (cm)**	***b* (cm)**	***c* (cm)**	**Mass (kg)**
Eastern Grey Kangaroo	*Macropus gigantus*	84	40	40	70
short beaked echidna	*Tachyglossus aculeatus*	37	18	13	4.5
lace monitor	*Varanus varius*	70	16	14	8.2
swamp wallaby	*Wallabia bicolor*	60	24	20	15
water buffalo	*Bubalus bubalis*	250	90	90	1060
central netted dragon	*Ctenophorus nuchalis*	11	3	2	0.03
Australian raven	*Corvus coronoides*	21	8	7	0.6
European red fox	*Vulpes vulpes*	58	16	16	7.7
emu	*Dromaius novaehollandiae*	70	36	38	50
brown Snake	*Pseudonaja textilis*	180	2.5	2.5	0.5

A.2 Representative organisms

In evaluating doses to biota at a site, it is usually impractical to calculate dose for each of the numerous diverse plants and animals that may inhabit, or use the site. Instead, a set of Representative Organisms is chosen which have characteristics, and perform ecological functions, that are representative of the range of diverse organisms present. Selection of Representative Organisms is a critical step in a wildlife dose evaluation and consideration should be given to performing consultation with the interested parties prior to progressing through the evaluation, to gain the benefit of their knowledge on the ecological significance of site organisms. Care should also be taken to avoid undue human bias – all affected organisms should be considered, not only those which humans can utilise, see or consider attractive in some way.

Considerations for selecting representative organisms

Prior to selecting Representative Organisms, a sufficient biological survey may be undertaken to document the range of organisms present at a site. Note that sampling difficulty may impart a bias in which species are detected. Survey methods[9] may include:

- camera observation surveys,
- plot, transect surveys,
- capture-release assessments,
- audio call-response surveys,

[9] The appropriate Animal Care/Wildlife Ethics Approvals are required before performing biological survey work. Data collection activities need to take account of the ethical justification for sampling of each wildlife group and meet with all applicable regulations regarding animal care and wildlife study. The use of non-lethal sampling and monitoring strategies are preferred.

- remote imaging vegetation surveys,
- consultation with site residents and workers,
- accessing previous biological surveys.

When selecting a set of Representative Organisms from the plants and animals inhabiting or using a site, special consideration should be given to organisms which:

- live in or pass through the evaluation area and utilise the vegetation, soils, water and other media being considered;
- have higher potential for exposure to radionuclides due to their behaviours (for example, burrowing terrestrial animals may penetrate waste areas, **benthic** aquatic feeders may uptake more radionuclides associated with sediments); rodents may live in the wetlands that receive regular industrial discharges.
- have higher sensitivity to ionising radiation (for example, mammals and other vertebrates are generally more radiosensitive than invertebrates);
- have importance to the function and structure of the ecosystem under consideration;
- have smaller home ranges, which are generally preferred over those which may range or migrate off site;
- have special ecological significance, are threatened or endangered;
- are persistent in the system across the natural range of environmental conditions (e.g. drought/flood, summer/winter).

Consideration should be given as to whether existing information on physical attributes, feeding and sheltering behaviours, etc. is available for an organism. Selection of a particular organism for a radiological-dose study may provide for integration with other studies (e.g., habitat assessment, ecotoxicological evaluation).

Any limitations specific to an organism should be considered. Consideration of sensitive or threatened species may limit field study opportunities.

Consideration should be given as to how well the set of Representative Organisms adequately describe the diversity of organisms at the evaluation area, including ecological functions, trophic levels, and phylogenetic diversity. These factors also help determine the number of Representative Organisms selected for analysis within the environment under consideration. This number will vary, depending on the physical nature of each site, and the purposes of the studies being performed. Where, for example, the radionuclide concentrations at a site are very low, and a simple screening is desired to see if site doses may affect living organisms, a small number of the most radio-sensitive organisms could be selected for the initial screening. If, however, site concentrations are elevated, or may become elevated in the future due to planned operations, a more numerous set of Representative Organisms is appropriate.

A.3 Selecting data

Transfer of radionuclides to living organisms is highly influenced by environmental conditions such as climate, vegetation type, and soil and water chemistry. Since these conditions can change from one location to another, site-specific data should be used where possible. If site-specific sampling cannot be accomplished (on a protected species for example), a number of approaches to overcome the lack of data are described below. However, this does not necessarily mean that these alternate approaches have been rigorously tested, or that their use provides valid outcomes. A principle of conservatism (i.e., err on the side of protection to the biota) is appropriate when information is scarce, or lacking. If an alternative approach is used, justification for the approach and the adequate support for the resultant outcomes should be provided.

Using pre-existing data

The Wildlife Transfer Parameter Database (WTD) (http://www.wildlifetransferdatabase.org/) has been established for use in environmental radiological assessments to estimate the transfer (CRWO-media) 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. 2013) the WTD is also providing data for derivation of transfer parameter values for the ICRPs list of RAPs. As noted above the database was initially populated with the default CR values from the ERICA Tool. During 2010-13 significant amounts of additional data have been contributed to the WTD by numerous organisations and individuals, including Australian sources. Published Australian-specific CR data are generally sparse. Australian terrestrial wildlife and livestock data were reviewed in Johansen and Twining (2010) although most data are for muscle alone and would need to be converted to whole-organism using, for example, Yankovich et al. (2010).

Addressing data gaps

General values based on organism type

Key Sources which provide meta-data summaries of concentration ratios for various organism types include

- The Wildlife Transfer Parameter Database (http://www.wildlifetransferdatabase.org/).
- International Atomic Energy Agency, Technical Report Series (TRS) Handbook on transfer of radionuclides to Wildlife (in press; for a description see Howard, 2013).
- International Atomic Energy Agency, Handbook of Parameter Values for the Prediction of Radionuclide Transfer in Terrestrial and Freshwater Environments (IAEA, 2010).
- International Atomic Energy Agency, Quantification of Radionuclide Transfer in Terrestrial and Freshwater Environments for Radiological Assessments (IAEA, 2009).

Caution is needed when proposing the use of general values with regards to the following:

- General $CR_{wo\text{-}media}$ values can reflect the conditions of one, or a few, dominant data sources which may be substantially different than at the Australian site.

- Some general $CR_{wo\text{-}media}$ values do not have clear documentation regarding important factors such as whether or not the gastrointestinal tract was included or excluded, whether the organism was washed or unwashed prior to analysis, life cycle phase, or other key information.

Information on sampling of biota in order to increase available data is provided in Annex B.

Surrogate organisms

Published values for **surrogate** organisms, defined by factors such as **taxonomy**, **physiology**, **trophic level** may be considered. For example, possible surrogates include **benthic feeding fish** for a **piscivorous fish**, or a **detritivorous arthropod** value for an **arachnid**.

Note that the surrogates in the above examples provide protective (conservative) values (e.g., an benthic fish typically has higher radionuclide burdens than a piscivorous fish).

Biogeochemical analogues and ionic potential

Biogeochemical analogues are elements which are assumed to have the same general behaviour under similar environmental/biological conditions (a simple example is caesium and potassium ions in water systems). The similarity can be used to identify $CR_{wo\text{-}media}$ values for missing data. For instance, if a Cm $CR_{wo\text{-}media}$ value for a given organism is missing, available $CR_{wo\text{-}media}$ values for Pu and Am for that organism might provide a reasonable substitute.

Data from a similar ecosystem

If data are lacking for an organism-radionuclide combination in a given ecosystem then available $CR_{wo\text{-}media}$ values from a similar ecosystem could be applied. However, this approach should be used with caution as, for example, the $CR_{wo\text{-}media}$ values for freshwater and marine systems can vary greatly. The approach should only be used to provide $CR_{wo\text{-}media}$ values for aquatic brackish ecosystem by assuming values from the marine environment and *vice-versa*. Freshwater CR values are generally higher than the marine equivalents due to the lower dissolved salt levels to compete for biological uptake.

Allometry

The dependence of a biological variable, Y, on a body mass, M, has been typically characterised by allometric equations of the form: $Y = aM^b$. Radioecological transfer parameters for terrestrial and marine animals for a limited number of radionuclides have been shown to fit such allometric relationships. Application of these relationships requires suitable dietary intake values, often also derived allometrically. Obtaining the valid dietary intake values necessary may require extensive effort including site-specific, or laboratory studies. Any allometric-based modelling would require thorough documentation. More information on the derivation and justification of allometric methods can be found in Higley and Bytwerk (2007) and USDOE (2002).

Approaches to gap filling in available model software

The existence of gaps in CR data has been an issue during development of biota dose assessment software codes, and each code has provided a range of options for estimating CRs when no site-specific data are available. An example is provided here for a currently available code:

ERICA Tool gap-filling hierarchy

(1) Use an available CR value for an organism of similar taxonomy within that ecosystem for the radionuclide under assessment (preferred option).

(2) Use an available CR value for a similar reference organism (preferred option).

(3) Use CR values recommended in previous reviews or derive them from previously published reviews (preferred option).

(4) Use specific activity models for ^{3}H and ^{14}C (preferred option).

(5) Use an available CR value for the given reference organism for an element of similar biogeochemistry.

(6) Use an available CR value for biogeochemically similar elements for organisms of similar taxonomy.

(7) Use an available CR value for biogeochemically similar elements available for a similar reference organism.

(8) Use allometric relationships, or other modelling approaches, to derive appropriate CRs.

(9) Assume the highest available CR (least preferred option).

(10) Use a CR or K_d for appropriate reference organism from another ecosystem (least preferred option; aquatic ecosystems only).

The above alternatives have been assessed and discussed in a paper entitled: *Approaches to providing missing transfer parameter values in the ERICA Tool – how well do they work?* (Brown et al., 2012)

Annex B Guidance on field sampling to support environmental dose assessments

This Annex provides guidance on some approaches for field sampling of wildlife and environmental media. The guidance is not intended to be prescriptive, or to provide for all contingencies. The overarching guiding principle is that the field sampling should be conducted in a manner that fairly represents conditions at the site being assessed.

B.1 Guidance on defining the evaluation area

The general approach to define the evaluation area is to:

- Delineate the area(s) of contamination; and
- Overlay the habitats of the representative organisms.

The area that encompasses both the contaminated area and the biota habitat is then considered for evaluation. If the area of contamination and the area of habitat do not overlap, then exposure is unlikely. This approach helps to avoid the problem of choosing an area that is too large (i.e. the contaminated area is only one very small portion of the entire site) in which case the averaging of soil samples would underrepresent the contaminated area. It also helps to avoid selecting an area that is too small and which may miss areas used by a foraging species. When evaluating existing sites, the area of contamination can sometimes be obtained from existing sampling results. In the case of a prospective assessment for a planned situation, potentially contaminated areas should be considered (e.g. future locations of waste piles, watercourses that may be impacted).

In general, the principle of susceptibility should be followed in which the boundaries of the evaluation area should fairly consider how flora and fauna may be exposed to contamination as they follow routine habitats at a site. These habits may include multiple pathways of exposure and may include potential for mobile fauna to use more than one discrete contaminated area.

B.2 Guidance on spatial and temporal averaging of samples and data

Environmental exposures can vary over time depending on the physical half-life of the radionuclides in question, and on the ecological half-life which depends on such factors as dispersion, dilution, water turnover, and chemical transformations. Screening levels and environmental reference values The dose limits for wildlife are typically expressed as dose rates in units of microGray per hour ($\mu Gy\ h^{-1}$) or milliGray per day ($mGy\ d^{-1}$). However, reference values are not intended to be applied on each day of exposure, rather dose considerations are for longer periods of time, often over the lifespan of the environmental receptors. The reference values are intended to provide protection of populations, not individuals, thus time averaging was inherent in their development.

In practise, the soil and water data used should represent longer-term exposure conditions on the order of one year for most organisms, although this may vary depending on the organism lifespan and reproduction rate. A correction factor for organism residence time on the contaminated area (sometimes called an occupancy factor) may be applied to account for intermittent exposure (e.g. diurnal foraging, seasonal usage, or in the case of fish the amount of time spent in contact with contaminated sediments).

Environmental exposures can also vary spatially depending on the variation of contamination levels across the site. Applying a rational spatial averaging technique to the media (i.e. soil or water) concentration data used in a biota dose evaluation is generally appropriate. However the particular averaging approach must be suitable and justified for the site.

The following are suggested approaches:

- For judging demonstration of protection some degree of conservatism (protectiveness) is warranted. It would be appropriate to select soil/water concentrations toward the upper end of the range of measured values at the site. This is consistent with standard screening approaches (e.g. ERICA integrated approach in which the maximum concentrations are first used. If compliance can be demonstrated with above-average, or even maximum values, then confidence is provided to the regulatory authority and other stakeholders that the evaluation demonstrates a protective approach.

- In instances where use of the above-average or maximum values does not give a clearly protective result, a mean or averaging approach can be pursued. In these instances, sufficient sampling data are needed to determine the mean, but also that the variation from the mean is acceptable. Where contamination data are comprehensive, it should be possible to confidently determine the statistical distribution of the data, the mean or median, and the variation. The total variation should include both real-world variation (e.g. from heterogeneous contamination) and statistical uncertainty (e.g. from sampling bias). Compliance can be demonstrated using the mean + variation. The level of variation applied can be stated in terms of confidence (e.g., 75% confidence, 95% confidence). If the variation is large, the analysis may result in over-predicting dose rates (i.e. a false positive). In this case, additional data on contaminant levels can be collected which may reduce uncertainty.

In the above approaches, practitioners should avoid assuming that data are normally distributed (i.e. should avoid automatically using the normal distribution statistics such as arithmetic mean and standard deviation). Environmental contamination data are more likely to be distributed lognormally than normally (both spatially and temporally). Assuming a normal distribution will likely overestimate the mean in most cases. Further guidance on application of data distributions in environmental radiological assessments is given in Wood et al. (2013).

B.3 Guidance on environmental media sampling

In general, the soil and water data used for assessment should represent the real-world exposure conditions. For plants, the root depth is important for determining the amount of radionuclides transferred from the soil to plant tissues. Soil sampled from too shallow, or too deep of depths may not represent the exposure pathway well. Most of the standardised concentration ratio data are based on a generic soil sampling depth of 0-10 cm. In cases where the standard does not match well with exposure conditions at a site, site-specific sampling should be performed. A similar approach should be adopted for water. For fish, a water sample taken at the surface may not represent the exposure to a benthic species. Site specific sampling is most representative when it is targeted to the relevant pathways of exposure to the representative organisms.

Sample locations should be chosen to best align with potential exposure to site organisms. In practice, the evaluation of environmental dose should present discussion on the likely exposure pathway of each representative species being evaluated and demonstrate that site sampling data cover these pathways.

When establishing concentrations ratios for a site, the soil or water is sampled along with the biota to determine site-specific biota-to-soil ratios. In this case, the soil and water samples should be taken at locations that represent the exposures to the specific biota that were also sampled. For plants, this is easily accomplished by for example, gathering a branch from a shrub then taking multiple (e.g. four or more) soil samples around the same shrub at the appropriate root depth. For animals, the soil or water samples should be taken from the foraging area of the sampled biota which can be established through camera surveys, expert advice, or similar means (see below for more discussion on sampling design).

B.4 Guidance on biota sampling

A scheme for general planning for biota sampling is presented in Figure 8. The selection of representative organisms for sampling has been discussed elsewhere in this Safety Guide. Two general considerations are worth noting. First receptors with small home ranges relative to the defined contamination area are preferred because they will be more exposed than would be wide-ranging and migratory receptors. Second contaminants are often localised in particular media (e.g. caesium in soil, tritium in water). Receptors with behaviours that increase their contact with those media should be preferred. For example, bottom-feeding fish may accumulate more caesium than surface feeding fish.

Figure 8. Conceptual diagram for design and collection of field samples in support of environmental dose assessments.

Special considerations for biota sampling

Consideration of animal care and ethics is essential to planning of biota sampling. In Australia, the states and territories regulate scientific study of flora and fauna. Each state and territory has specific requirements that may include permits for handling or gathering wildlife samples. These permits typically require the study participants to demonstrate consideration of ethical standards in justifying sampling, and to demonstrate adequate methods, knowledge, and training level in animal capture, handling, and release or euthanasia.

In Australia, an animal that falls under permit approval is defined as : any live non-human vertebrate (that is , fish, amphibians, reptiles, birds and mammals encompassing domestic animals, purpose-bred animals, livestock, wildlife) and cephalopods. For further information, see The Australian Code for the Care and Use of Animal for Scientific Purposes 8th Edition 2013 published by the National Health and Medical Research Council, Australian Government.

Many wild animals can serve as vectors for parasites and pathogens that are communicable to humans. These include ticks, mites, viruses, and bacteria. Anyone involved in collection and handling of wildlife may be exposed. Similarly, the various habitats being sampled may provide their own risks (toxins, trips, slips, falls, immersion, dehydration, exposure etc). Adequate safety measures must be in place including appropriate training by personnel, appropriate methods and personal protective equipment as well as any necessary vaccinations. A laboratory or premises for processing animal samples may also need to meet certain standards in terms of its design.

Sampling design

A comprehensive discussion on the design of sampling schemes is beyond the scope of this document. We present here some key points to be considered in designing biota sampling plans.

As discussed above, when establishing site-specific concentrations ratios (CRs) for a site, the soil or water should be sampled along with the biota. The soil and water samples should represent the spatial and temporal scale of exposures to the specific biota that were sampled. This will generally require multiple samples, particularly for soils, as environmental contamination typically varies from location to location even over short (i.e. metre) scales. In practice taking one, or a few, soil samples per organism sample will be insufficient. The sampling scheme may be **random** within the exposure area, or follow a **stratified random** or **systematic** scheme. Random sampling is generally employed when little information exists concerning the contamination at the site. Stratified random sampling involves the division of the sample area into strata based on knowledge of the site, and then random samples are taken within the strata. Systematic sampling involves the collection of samples at regular spatial or temporal intervals. In many situations, access to some sites and/or collection of some biota may be impractical. There is no one system that is best for all situations and the approach should be chosen such that the gathered sample data are representative of the exposure of the biota.

In addition to sampling of contaminated areas, an appropriate control site should also be sampled. The general concept of a control site is a site that is similar to the principle location in question, but lacks the contamination of concern. It therefore provides a basis for determining the impact of the contamination above natural or ambient background (which contains natural or man-made contamination). The data from the control site are used to calculate an ambient or background dose rate. Such a dose rate ensures that the site-related dose rates represent an actual increase in exposure. This is generally useful to separate site-related impacts from natural or ambient impacts and is particularly relevant during a remediation action where typically the site is not remediated to levels lower than natural background. It is particularly useful to provide adequate sampling of any area that is likely to be exposed to any activity before that exposure commences. Such sampling would provide the best control/reference levels for later comparisons.

Sampling methods

A wide variety of methods are available for collecting biota samples. Some common examples are provided below, many of which involve trapping of wild animals. All trapping methods require careful consideration of, and adherence to, the animal care and ethics permit obtained for the study. Some considerations include: how often and at what times to check traps; prevention of trapped animals becoming prey through use of sheltering containers within the trap; prevention of aggression among trapped animals; closure of traps during high temperatures; whether or not to provide water and food in the trap (food may affect subsequent gut content analysis); handling methods of trapped animals to minimise stress; optimal release of non-target animals; release of hazardous/venomous animals; and ultimate closure and removal of traps.

When considering sample collection methods, the potential use of non-lethal methods should be considered first. These methods include use of:

- Already reported values
- Hair, blood, faeces, scales, fin clips, ear punctures, or other non-lethal samples
- Found bones, exoskeletons, or naturally deceased carcasses from the site
- parasites

Also, in cases where population dymanics are considered, it is important to measure the collection efficiency per unit time or effort to facilitate comparisons.

Aquatic Biota

- Benthic Invertebrates

  Kick sampling is a sample method used in running waters. A net is placed against the streambed, and the substrate upstream of the mouth of the net is agitated for a defined time period to suspend the organisms, which are then washed into the net by the current. While this method is easy, the exact area sampled is undefined; therefore, it is unsuitable when quantifying sample mass per sediment area. When quantitative samples from running water are needed, Surber samplers should be used. Surber samplers consist of a frame with an attached net. The frame is placed on the streambed, the substrate within the frame is disturbed and rocks and other debris are rubbed to dislodge invertebrates. Water current carries invertebrates into the sampling net.

  Core samplers may be employed in both shallow and deep water. They consist of a metal or plastic tube which is inserted into the substrate. When the tube is removed, samples of both the substrate and organisms are obtained. The samples are then washed in a sieve and the organisms are removed from the remaining sample debris. Core samplers are inappropriate for loose or unconsolidated sediment, sand, or gravel.

  Grab samplers such as the Ekman, Petersen, Ponar, and Smith-Mcintyre samplers may be used to collect organisms from deep-water habitats. These devices engulf a portion of substrate (and its associated organisms), which is then hauled to the surface for processing.

  Organisms are separated from the sample material by washing the substrate in a box screen. Grab samplers are generally easy to use and are suitable for a variety of water depths. Depth of sediment penetration may vary with sediment type and rocks or other obstructions may prevent complete closure, resulting in partial sample loss. Because grab samplers tend to produce large samples, the processing effort may be considerable.

  Large crustaceans can often be captured using traps or nets (see Fish below).

- Fish

  Sampling techniques for fish include electrofishing, nets, or traps. Selection of the appropriate method will depend on the species of interest and the type of aquatic system being sampled.

In electrofishing, an electric current is employed to stun fish, which are then captured with a net. Electrofishing is effective for both juveniles and adults of most species and for sampling structurally complex habitats. It also efficiently samples large areas in a relatively limited time while capturing a large percentage of individuals within an area. Numerous studies indicate that under proper conditions, electrofishing can be the most effective sampling technique. Disadvantages include potential mortality; low efficacy for benthic or deep water species, for very low- or high-conductivity water, and for turbid water; and potential hazards to users.

A wide variety of nets and traps are used to sample fish populations. Two basic types exist: nets that snag or entangle fish, and traps or net arrangements that provide a holding area into which fish are enticed. The most common entanglement nets are gill nets and trammel nets that use an open mesh through which fish attempt to swim. Gill nets are generally more effective in turbid water and areas without snags and are effective for sampling deep areas not accessible by other techniques. Gill nets are also highly effective for a variety of larger fish sizes (depending on mesh size used) and for fast swimming or schooling species. Consideration should be given to the use of floating or sinking nets to sample pelagic or benthic species. Disadvantages of nets include potential injury or mortality of snagged fish, the ability of any one gill net mesh size to sample only a limited size of fish, the capture of non-target species at high rates (with the resulting increase in sampling time and total mortality), low success for fish species with low mobility (e.g., sunfish), and highly variable results. Care should also be given to the size of the net in relation to the habitat. For example, netting a pond will be more efficient than netting a large lake or river.

Stationary fish traps include fyke nets, hoop nets, trap nets, and pot gear (e.g., slat baskets and minnow traps). All of these devices work by allowing the movement of the fish to take them through a small opening into a larger holding area. Stationary traps are available in small (minnow traps) to large (fyke nets) sizes, allowing multiple species and life stages to be sampled. Because fish remain alive while in the trap, they do not need to be checked as frequently as entanglement nets. Stationary traps are effective for cover-seeking species or benthic species. Disadvantages of these traps are that they are not equally effective for all species and that catch rates are susceptible to changes in temperature and turbidity.

- Amphibians and Reptiles

Amphibians and reptiles often have special protection status. Methods selected to sample reptiles and amphibians will vary depending on the type of habitat, time of year, weather conditions, and age of target species. Representative techniques for sampling reptiles and amphibians in aquatic and terrestrial habitats include opportunistic collection by hand, nets and traps, electrofishing, and seines.

Opportunistic collection consists of searching suitable habitats for species of interest. Once found, individuals are collected by hand, net, or other devices that may facilitate immobilizing individuals. Numerous types of nets and traps are available for sampling herpetofauna. To prevent inadvertent mortality from trapping, traps should be checked often at specified times to reduce stress to animals and to provide for release of non-target animals inacceptable conditions (e.g., dawn, dusk, etc.) Aquatic traps should be set partially above the water line to permit the captured organisms to breathe.

Terrestrial Biota

- Plants

  Collecting plant material for analysis is a simple procedure. After plants of the appropriate species are identified in accordance with a suitable sampling design, they may be sampled either as whole organisms (roots plus aboveground parts) or as discrete parts (roots, foliage, seeds, fruit, etc.). Samples may be collected by stripping or breaking parts from the plant, by cutting plant parts with shears, or by digging up plants with a spade. Height may constrain tree sampling. Bark samples or trunk cores may be considered under those circumstances.

  Note that leaves and other aerial plant parts can be contaminated directly by deposition rather than by root uptake if contamination has at atmospheric vector. Surface washing may be a means of determining if this vector is occurring.

- Mammals

  Numerous methods are available for collecting mammals. Suitable methods vary by species and habitat, with multiple methods often being suitable for the same species. Small mammals, primarily within the orders Rodentia, and Insectivora, are the taxa most commonly collected. This is because they are often assessment endpoints themselves, important food items for predatory endpoints, and more likely to be present in sufficient numbers than larger mammals. Methods discussed will, therefore, focus on these taxa.

  Small mammals are generally collected by one of three methods: snap traps, box traps, or pitfall traps.

  Box traps are the most effective method for capturing small mammals unharmed. The use of box traps allows the selection of species of interest and the release of non-target species. Box traps are typically metal or wooden boxes with openings at one or both ends and a baited trip pan. Animals are captured when they contact the trip pan, causing spring-loaded doors to close. The type and size of the trap, ambient conditions at the trapping site, and body size of animals to be trapped all influence trapping success.

  Pitfall traps consist of a container buried into the ground so that its rim is flush with the surface. Animals are captured when they fall into the container. Success rates for pitfall traps may be dramatically increased by employing drift fences. Drift fences are barriers of metal, plastic, fiberglass, or wood that direct small mammals into the pitfall trap. Pitfall traps should be at least 40 cm deep to prevent small mammals from jumping out.

Snap traps are the familiar "mouse trap," consisting of a spring-powered metal bale that is released when the animal contacts the baited trigger pan. These traps are lethal and in most cases would not be used due to their indiscriminate lethality.

Trapping efficiency improves with use of baits, which depend on the species sought. Generally, peanut butter and oats or other seeds are effective in box and snap traps for most granivorous or omnivorous small mammals. Pitfall traps do not need to be baited because small mammals simply fall into the buried container, but may benefit from bait smeared on the side of the container.

Trapping success is generally enhanced if traps are set but locked open within the sampling area for several days prior to trapping. This allows the animals to acclimatize to the presence of the traps. Traps should be placed at habitat features favoured by or indicative of small mammals, e.g., logs, trees, runways, burrow entrances, dropping piles, etc. In addition, sampling must be appropriately distributed with respect to the distributions and locations where media are sampled.

- <u>Birds</u>

  Methods for collecting birds include baited traps, cannon nets, mist nets, drive and drift traps, decoy and enticement lures, and nest traps. Methods employed depend upon the species to be sampled.

Baited traps are most useful for gregarious, seed-eating birds. In their simplest form, a wire- mesh box is supported at one side by a stick over bait (generally seeds or grain). Once birds enter the box to feed on the seeds, the operator pulls a string attached to the support stick, the box falls, and the birds are entrapped. Other types of baited traps include funnel or ladder traps. These traps are designed with entrances through which birds can easily enter but not easily exit.

Cannon nets may be used for birds that are too wary to enter traps. Cannon nets consist of a large, light net that is carried over baited birds by mortars or rockets. In use, nets are laid out and baited for 1 to2 weeks to allow the birds to become acclimated to the net and bait. Once birds make regular use of the bait, the trap may be deployed. Mist netting is a method useful for some species that are not attracted to bait. This method may be used for birds as large as ducks, hawks, or pheasant but is most applicable to passerines and other birds under -200 g. Mist nets are constructed from fine black silk or nylon fibres; the nets are usually 0.9 to 2.1 m wide by 9.0 to 11.6 m long, attached to a cord frame with horizontal crossbraces. The net is attached to poles at either end such that the crossbraces are tight but the net is loose. The loose net hangs down below the shelf strings, forming pockets. When the net is properly deployed, birds (or bats) strike the net and become entangled in the net pocket. Mist nets may be employed passively or actively. In a passive deployment, nets are set across flight corridors and birds are caught as they fly by. For an active deployment, a group of nets is set and birds are driven toward the nets. Another effective approach is to use recorded calls of conspecifics or distress calls to attract birds to the net.

Nest traps are useful to capture birds at the nest for reproductive studies. For ground-nesting birds, drop nets erected over the nest are sometimes effective. For cavity nesting birds, trip doors may be devised that can be closed once the adult enters the nest.

Although firearms have traditionally been used to collect birds, this method is highly dependent on the skill of field personnel, and may extensively damage samples during collection. The projectiles or shot may interfere with contaminant analyses. Moreover, because of safety considerations, the use of firearms is not a recommended sampling method. In addition, the use of firearms precludes repeated sampling of the same individual.

- Earthworms

  The primary methods for collecting earthworms are hand sorting of soil, wet sieving, flotation, and the application of expellants. Hand sorting is regarded as the most accurate sampling method, but is very laborious and may underestimate the abundance of small individuals. Wet sieving consists of using a water jet and a sieve to separate earthworms from the soil. In contrast to methods that require excavation and processing of soil, expellants have been applied in situ to collect earthworms. In practice, an expellant solution is applied to the soil surface within a sampling frame laid on the soil and allowed to percolate. Earthworms are then collected as they emerge from the soil. However, traditional expellants have introduced issues of carcinogenicity, phytotoxicity, and toxicity to earthworms. In addition, these expellants also may introduce additional contamination and interfere with contaminant analysis. Some newer commercial expellants have become available that use mustard emulsion mixed with water. If worm samples are being collected for residue analysis, analyses should be performed on samples of the mustard expellant.

- Terrestrial Arthropods

  Many methods are available to sample terrestrial arthropods. Because of the great diversity of life-history traits and habitats exploited by arthropods, no single method is efficient for capturing all taxa. Methods include hand gathering, pitfall trap, sticky trap, shake-cloth, sweep-net, light trap, and various box traps. Every sampling method has some associated biases and provides reliable population estimates for only a limited number of taxa.

Sample definition, processing and transport

The manner in which samples are defined, handled and transported can have large influence on their usefulness.

If the amount of sample is too small for accurate radionuclide analysis, then samples from multiple individuals may be composited to produce a sample of sufficient size. Alternatively, samples may be composited over the contaminated site in an effort to reduce analytical costs. However, compositing samples can reduce statistical information from within the composite (e.g. loss of minimum and maximum values). If the samples are to represent internal body burdens for endpoint species (e.g., concentrations in target organs), compositing of samples will result in underestimates of body burdens. Because compositing samples loses information and may result in biased estimates, all compositing must be performed with caution.

Most dose and transfer models use activity concentration data that are on a fresh mass (wet weight) basis. Therefore a fresh mass measurement of the final dissected sample is very important, and should be compared with the dried and ashed masses of the same sample.

Biota samples may have external contamination in the form of soil or dust adhering to their surfaces. Depending on the purpose of the analyses and the intended use of the analytical results, these external residues may or may not be washed off, or removed with the skin, prior to analysis. If the contaminant of interest has a significant aerial deposition pathway or if soil ingestion is not being considered in the exposure model, then samples should not be removed. It should be recognized that these unwashed samples will be biased and will represent both bioaccumulation factors and external adhesion of contaminants. Note that for radiological dose estimates, surface contamination may be a significant contributor to whole body dose.

Likewise, the inclusion or exclusion of the gastrointestinal tract (GI tract) can have major (order of magnitude) influence on the resulting measurements. Many radionuclides are poorly absorbed across the gut wall and therefore the stomach and intestines can carry relatively high concentrations (relative to the muscles, bone, etc.) Whether to include or exclude depends on the objectives of the study. It is often most prudent to remove the GI tract, and have it (or its suborgans) analysed separately.

Care should be used in dissecting samples to avoid cross-contamination. Standard cleaning of tools between samples should be performed. Some studies report using beeswax (dipping the organism in beeswax) or similar to prevent dust on the fur from cross-contaminating interior samples during dissection. Alternately, washing in insecticide (to kill parasites that pose a hazard to humans) followed by detergent followed by multiple rinses. Samples should bagged (double or triple bagged) then be frozen as soon as possible to avoid growth of bacteria. Transport should be in a timely manner to prevent degradation.

Depuration refers to the voiding of the Gl tract of sampled animals. Undepurated earthworms will generally have higher radionuclide concentrations than depurated earthworms from the same location. This is due to the large amount of soil retained in the Gl tract of undepurated earthworms. Radionuclides in the soil in the Gl tract will bias the body-burden estimates. If the model used to estimate exposure of animals that consume earthworms does not include a term for soil ingestion, this bias is not critical. However, if a soil ingestion term occurs in the model, the use of undepurated worms will result in some double counting of the amount of soil consumed and will overestimate exposure.

Annex C Radiation protection of the environment in different exposure situations

C.1 Radiation protection of the environment in planned exposure situations

Planned exposure situations are defined as those where deliberate action or change of sources has been made which will result in the modification to the pre-existing exposure situation. In general, a planned exposure situation is the most amenable to control as it can be actively regulated and the exposure situation modified if required. The control of potential impacts of planned exposure situations is generally the subject of assessment and approval processes prior to the situation proceeding. In the consideration of planned exposure situations, both exposures which are anticipated to occur (normal exposures) and exposures which are not anticipated to occur (potential exposures) need to be considered.

In its most simple form, a planned exposure situation is the introduction of a new source of radiation exposure to an environment. The environment is already exposed to some level of pre-existing radiation exposure either due to natural sources or from historic human activities in the area. Interactions between the pre-existing levels and the change in exposure as a result of planned exposure are often complications when considering environmental impacts. It is possible for the planned exposure situation to provide a net benefit for the surrounding environment. In the consideration of the impact on the environment from a planned exposure you often need to separate the practice-related radiological component from the pre-existing or natural background component. Any pre-existing man-made component may need to be considered as an existing exposure situation.

Some industries where radiation protection of the environment issues might arise

Although almost everything in nature contains some radioactivity, it is not practical to apply radiation protection of the environment for all situations. To prevent unnecessary regulatory burden, the protection of the environment needs to be prioritised on the practices which have some credible impacts on the environment. Some quick screening criteria can be used to assess if there is likely to be a radiological impact on the environment and these can be used to assist regulatory authorities in determining those practices with the highest priority.

The first consideration would be whether there is material of enhanced radioactivity present or being produced. If the material is below the level considered as radioactive in the jurisdiction then it is unlikely to give rise to sufficient levels of radiation to have an impact on the environment. There are recommended specific activities and total quantities of radionuclides used for exemption and these will most likely remain relevant for consideration of environmental impact. Examples of practices which may not need further assessment are industrial processes using material below exemption levels and bulk transport of commodities. Similarly, education facilities using small radiation sources for teaching purposes may not need to be considered.

The second consideration is the time the radioactivity remains in the environment. Short lived radionuclides do not have sufficient time to concentrate in the environment and the assessment of impact is very short range/duration. Impacts will generally be restricted to the immediate area of operation/release and as such have well defined and easy to assess impacts. Examples of practices which may not need further assessment are hospitals and imaging centres discharging ^{99m}Tc due to its short half-life in the environment.

The third consideration is the amount of material being handled and how it can potentially be concentrated in the environment. If there is only a small quantity of material present and it is not released into the active biosphere, then the potential for impact is low. Similarly, even a large quantity of material containing low levels of radioactivity is unlikely to effect the environment unless there is some means of concentrating the radioactivity to a level where harm is possible. Care should be taken however, as long time periods may need to be considered and all potential concentration processes should be taken into account. Examples of practices which may not need further assessment are mines which do not produce large quantities of wastes such as in-situ recovery mines. However, the potential for inadvertent off-site transport of any radioactivity potentially produced should be considered.

Practices which would potentially require an assessment would be recognised as either using or producing radioactive material and have sufficient quantity or activity to pose a potential for environmental impacts. There are limited facilities existing or planned in Australia which meet this criteria and the following is a list of potential industries which may need further assessment:

- Reactor and radioisotope production facilities;
- Uranium or mineral sands operations which produce large quantities of waste (tailings, monazite, waste rock);
- Mines or facilities where substantial quantities of naturally occurring radioactive materials (NORMs) are included in the process streams (e.g. coal, oil or gas processing);
- Waste storage or disposal facilities; and
- Pre-existing exposure situations which are being reopened or potentially remediated.

Normal and potential exposure scenarios

Once a practice is being assessed for potential impact on the environment, it is important to consider both normal and potential exposure situations.

Normal exposure situations are those which result from the routine and expected operation of the practice. This includes not only the handling of the material and any potential discharges to the environment but also the planned long term storage or disposal of waste materials and site rehabilitation. In considering normal exposures it can be assumed that the material is behaving as per design and that active measures may be incorporated to protect the environment. This is often considered the base case for any assessment and reflects the most probable potential impacts on the environment.

Potential exposure scenarios are those which may happen due to either ineffective design, failure of systems or external events. By definition they are not certainties but reflect a probability envelope around the planned impacts to account for departure from the normal scenarios. Realism in the consideration of these scenarios is important for effective controls and scenarios should be restricted to those with a credible probability but including consideration of catastrophic events. In considering potential exposures you need to also consider how initiation events may change the environment from the non-radiological perspective as well. For example, a major flood event may increase the potential for release of material from a mine site with a tailings dam containing uranium series radionuclides but also will give rise to far higher levels of dilution than would be expected under normal situations. A flood may also significantly change the species being potentially exposed and flood effects may totally dominate over far smaller radiological related impacts.

Assessment of potential impacts from planned exposure scenarios

Given the type of radiological sources in Australia, the potential for significant radiological impacts on the environment is very small. Studies indicate that radiological impacts are generally several orders of magnitude less than other non-radiological impacts of practices (Johnston et al., 2003). It is therefore important that assessments are as simple as possible and complex as necessary and are considered in the context of other potential factors.

Where possible, initial screening assessments should be utilised to determine if there is any significant potential for radiological impact on the environment (see Section 3.5). This screening can be conservative in nature and be used to reduce the need for more formal assessments of radiation protection on the environment.

Control actions in planned exposure situations

Planned exposures allow for the inclusion of control actions as part of both routine operations and potential exposure scenarios. These control actions should be incorporated in the assessment to ensure realism in the potential environmental impacts. Control actions can range from the use of waste treatment facilities, through to design storage facilities and implementation of active measures to reduce the impacts of external events (e.g. flow control bunds). However, avoidance or minimisation of contamination is preferable to control.

One of the critical concerns with the use of control actions is they should only be considered whilst the practice remains active. For long term post closure of the practice, active controls may no longer be appropriate and more reliance on passive controls will be required.

Transition from a Planned Exposure Situation

All practices eventually cease and this may involve a transition from a planned exposure situation to an existing exposure situation. Incorporated into this transition is the removal of active controls and the decision that the practice is no longer occurring. Associated with this is the need for a range of criteria to ensure long term protection of the environment.

C.2 Radiation protection of the environment in existing exposure situations

Existing exposure situations are those situations that already exist when a decision on control has to be taken, including natural background radiation and radioactive residues from past practices, events and accidents. In an environmental context, existing exposure situations typically involve areas that have been contaminated by human actions conducted in the distant past, or as a result of accidents. Some relevant Australian examples of such situations include:

- former British nuclear weapons test sites at Maralinga, which were principally contaminated through dispersal of plutonium isotopes (DEST, 2003); and
- legacy mining and ore processing sites contaminated with naturally occurring radioactive material (NORM).

For existing exposure situations involving environmental contamination, people may have been removed from the contaminated area as a precautionary measure, or the area may be one that is not normally occupied by people. The question may then arise as to the health or status of other organisms in the contaminated area. This question may be particularly relevant to heritage listed environments and nature conservation zones (e.g. national parks, Ramsar wetlands, marine reserves, etc.), or if the contaminated area forms part of the natural habitat of a rare, protected or culturally significant species.

For existing exposure situations involving environmental contamination, an initial assessment should be conducted to characterise the existing radiological conditions of the contaminated area, including baseline background data. This should include identifying the sources and pathways of exposure for key receptor organisms, estimating the dose rates to those organisms and comparing with relevant environmental reference values (see Section 4). A decision should then be made as to what management or intervening action may be required, and why, taking full account of the costs and benefits of the action. The outcome of the initial assessment should help guide the decision-making process in the following way:

- If assessed dose rates to key receptor organisms (or keystone species) are above the relevant environmental reference value, then the level of ambition for optimisation should be to reduce exposures to levels that do not exceed the relevant environmental reference value, assuming that the costs and benefits of doing so are justified.
- If assessed dose rates to key receptor organisms are at or below the relevant environmental reference value, then the principle of optimisation of protection should continue to be applied, assuming that the costs and benefits are such that further efforts to reduce exposure are justified.
- In either case, the justifiable effort should be to reduce the exposure to levels as low as reasonably achievable rather than to simply achieve a value lower than the screening or reference levels.

Two basic options are available in relation to intervening actions in existing exposure situations (i.e. 'take no action' or 'take action'). The decision on whether or not to take action to reduce the radiological risk to wildlife from existing exposure situations should be guided by quantitative methods such as cost-benefit analysis and qualitative methods such as stakeholder consultation to help ensure that any remediation goal for wildlife is both agreed and achievable. Some additional advice on the possible circumstances under which each option may be appropriate is provided below.

Take no action. This option may be appropriate to those existing exposure situations where assessed dose rates (compared to baseline) are at or below the relevant environmental reference value or where there is evidence to suggest that there has not been (nor is there expected to be) any deleterious radiation effects on wildlife populations. In other words, biological diversity within the contaminated area has been effectively conserved through natural processes.

Take action. This option may be appropriate to those existing exposure situations where assessed dose rates are above the relevant environmental reference value or where there is evidence to suggest that there has been (or is expected to be) deleterious radiation effects on wildlife populations. It should be considered whether action to reduce radiation exposure will have a net positive effect on the population.

C.3 Radiation protection of the environment in emergency situations

Introduction

Emergency exposure situations (accidental or malicious) can be considered in three stages;

- Planning phase – normal operation prior to an emergency being declared,
- Emergency phase – during an uncontrolled release to the environment,
- Recovery phase – after an emergency situation stabilises.

During each phase the protection of humans should be considered in parallel with protection of the environment, however the Emergency Phase will always have inclusion of humans taking precedence over the protection of wildlife.

Planning for an emergency

Protection of the environment should be considered in planning for emergency exposure situations. Significant effects on certain populations (such as endangered species) may lead to the consideration of alternative siting options or the implementation of procedures to specifically protect these populations in the case of an emergency.

Assessment of wildlife in emergency planning is particularly important in areas which are not populated by people. Environmental impact assessments should consider likely consequences of exposure as a result of different possible emergency exposure situations (ICRP, 2008). In these situations, it should be noted that models and databases usually need to be relevant to the dynamic conditions of an emergency – steady-state models are not always relevant for these types of releases.

Emergency planning should include consideration of catastrophic events.

During an emergency

During the emergency it is likely that the protection of the environment will be optimised by normal emergency practises, such as minimisation of contaminant dispersal at the source. Decisions on protection of wildlife should be made while regarding human protection (for example, culling of contaminated domestic or agricultural animals for protection of the human food chain is not considered as a part the environmental protection framework).

It is clear that human protection will take precedence during this time as resources are usually spent on humans, however thorough planning will mean that clearly defined procedures are in place which can be applied during the emergency phase. These include decisions on protection of the environment weighed up against protection of the food chain.

Doses to wildlife from emergency discharges to the environment can be estimated through the use of dynamic models (e.g. see UNSCEAR, 2013). The use of these models is being investigated in the IAEA's four-year MODARIA programme (IAEA, 2012).

Late (or recovery) phase of an emergency

After the situation has stabilised, the emergency phase transitions to the recovery phase. The situation then becomes an existing exposure situation (Section C.2). The need for intervention should be weighed up against the immediate and long-term impacts on flora and fauna populations. Particular attention should be given to the effects on threatened or endangered species.

After the emergency situation has stabilised it is possible to use traditional (steady-state) assessment models to determine the long-term impacts of exposure.

GLOSSARY

acute

Occurring within a relatively short time period in the context of the effects being observed.

background

Concentrations and variability of natural radioactivity and associated radioactive dose in any environment. If measured prior to any contamination (q.v.) can be used as a baseline for measuring change.

benthic (feeding fish)

Referring to the habitat on or adjacent to the sediments in marine or freshwater ecosystems (fish using those regions to eat).

chronic

Occurring or recurring over a substantial time period in the context of the effects being observed.

contamination

Releases to the wider environment of chemicals, including radionuclides, from human activities.

DCRLs (Derived Consideration Reference Levels)

An ICRP (q.v.) term which is conceptually equivalent to environmental reference values (q.v.) in this safety guide.

dose – absorbed

The energy deposited within any material by the passage through it of ionising radiation (Grays: 1 Gy = 1 joule/kg).

dose – effective

The energy deposited within the human body by the passage through it of ionising radiation which also takes into account the relative biological effectiveness of different radiation types (alpha, beta, gamma) and the sensitivity of different tissue types to radiation damage. (Sieverts: 1 Sv = 1 joule/kg x radiation weighting factor x tissue weighting factor).

dose conversion coefficients (DCCs)

Factors used to relate radionuclide activity concentrations in soil or water to external doses of exposed organisms, and concentrations in the organism to internal doses. See also *modelling*; *background.*

dose rate

The average level of dose that any material or biota is exposed to over time (biota dose rate is typically measured in mGy/hr).

dosimetry

The measurement or modelling of dose (q.v.) or dose rate (q.v.).

emergency exposure situation

An unexpected situation of exposure that arises as a result of an accident, a malicious act, or any other unexpected event, and requires prompt action in order to avoid or to reduce adverse consequences.

environment

The areas outside of sites under direct human control.

environmental exposure

The exposure of wildlife to ionising radiation (q.v). This includes exposure of animals, plants and other organisms in the natural environment.

equilibrium

The assumed condition whereby the activity concentration and/or dose in a reference organism is stable in respect to the environmental media concentrations to which it is exposed.

equivalent dose

The absorbed dose delivered by a type of radiation averaged over a tissue or organ multiplied by the radiation weighting factor for the radiation type.

existing exposure situation

A situation of exposure that already exists when a decision on the need for control needs to be taken, including prolonged exposure situations after emergencies.

exposure scenario

The postulated means by which the wider environment, and biota within it, may be exposed to contamination (q.v.).

gray

See Dose-absorbed.

IAEA

International Atomic Energy Agency.

ICRP

International Commission on Radiological Protection.

impacted

Affected by contamination (q.v.)

ionising radiation

For the purposes of radiation protection, radiation capable of producing ion pairs in biological material(s).

MODARIA

The IAEA (q.v.) program entitled *Modelling and Data for Radiological Impact Assessments.*

modelling

The estimation of environmental media concentrations and/or dose (q.v.) or dose rate (q.v.) using equations to emulate natural processes. As far as possible, extant data are used to parameterise the equations but assumptions need to be made where adequate data do not exist.

physiology

The branch of biology that deals with the normal functions of living organisms and their organs.

piscivorous fish

Fish that predate on other fish. Top aquatic predators.

planned exposure situation

A situation involving the deliberate introduction and operation of sources. Planned exposure situations may give rise both to exposures that are anticipated to occur (normal exposures) and to exposures that are not anticipated to occur (potential exposures).

population (of organisms)

a. A group of individual organisms belonging to a same species and sharing a well-defined pattern of environmental conditions.

b. An abstract group of individuals of the same biological species that share the same geographic patch and can interact with one another with limited interactions from outside.

radiosensitvity

The relative effect of similar radiation on different biota. Some organisms are more sensitive (e.g. mammals, trees) than others (e.g. insects, plankton).

RAPs (Reference Animals and Plants)

A suite of organisms recommended as models by the ICRP (q.v.) as Reference Animals and Plants for the purposes of estimation environmental dose.

reference values

Values for absorbed dose rate (q.v.) to living organisms at which a more considered level of evaluation of the situation might be considered (see also DCRLs).

representative organism

A living organism that is typically present in a contaminated environment.

reference organism

An entity that provides a basis for the estimation of radiation dose rate to any living organism that is typical, or representative, of an impacted environment.

screening level

The absorbed dose rate to an organism above which further considerations or investigations are warranted.

sievert

See Dose-effective.

species

Groups of actually or potentially interbreeding natural populations, which are reproductively isolated from other such groups.

surrogate

An organism providing data for another that exists in a similar ecological niche, has a similar physiology, and/or is in some other way suitably representative of the organism under consideration.

taxonomy

The branch of science concerned with classification, especially of organisms.

trophic level

The position of an organism within a food web. For example, plants are primary producers and hence trophic level 1, grazers that eat plants are trophic level 2, organisms that eat grazers are a higher level and top predators are higher still. The number of trophic levels within any habitat is constrained by the biological diversity present and by the number of ecological niches available.

UNSCEAR

United Nations Scientific Committee on the Effects of Atomic Radiation.

wildlife

Any wild animal or plant living within its natural environment.

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