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D-ERICA:

An INTEGRATED APPROACH to the assessment and management of environmental risks from ionising radiation

Description of purpose, methodology and application

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ERICA (Environmental Risk from Ionising Contaminants: Assessment and Management) concerns an integrated approach to scientific, managerial and societal issues concerned with the environmental effects of contaminants emitting ionising radiation, with emphasis on biota and ecosystems. The project started in March 2004 and ended by February 2007.

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Foreword

This report, referred to as *D-ERICA*, summarises the developments in the ERICA project (Environmental Risks from Ionising Contaminants: Assessment and Management, EC Contract FI6R-CT-2004-508847). It also describes the *ERICA Integrated Approach* to the assessment and management of environmental risks from ionising radiation, and introduces the reader to the *ERICA Tool*, which is a software programme with supporting databases, that together with its associated help will guide users through the assessment process. Most assessors should find all the information they require within D-ERICA and the ERICA Tool in order to undertake an assessment. In some instances, particularly when uncertainty is high or the environmental risks are of substantial concern, the user may wish to consult the complete project documentation, available at www.erica-project.org.

More than 60 European scientists, regulators, policy makers and environmental experts have contributed to the ERICA Integrated Approach through the ERICA project. The contributors are listed below. In addition, a large number of experts in different areas have contributed views on the Integrated Approach and its associated Tool from the user's perspective, through participation in the End Users Group. While this input has been extremely valuable, the final design of the ERICA Integrated Approach and the ERICA Tool remains entirely the responsibility of the ERICA Consortium.

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Stockholm, February 2007

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Executive Summary

Purpose and structure of the ERICA Integrated Approach

The purpose of the *ERICA Integrated Approach* is to ensure that decisions on environmental issues give appropriate weight to the environmental exposure, effects and risks from ionising radiation with emphasis on ensuring the structure and function of ecosystems. To fulfil this objective, elements related to environmental management, risk characterisation and impact assessment have been integrated (hence the *Integrated Approach*) into one common structure, illustrated in Figure I.

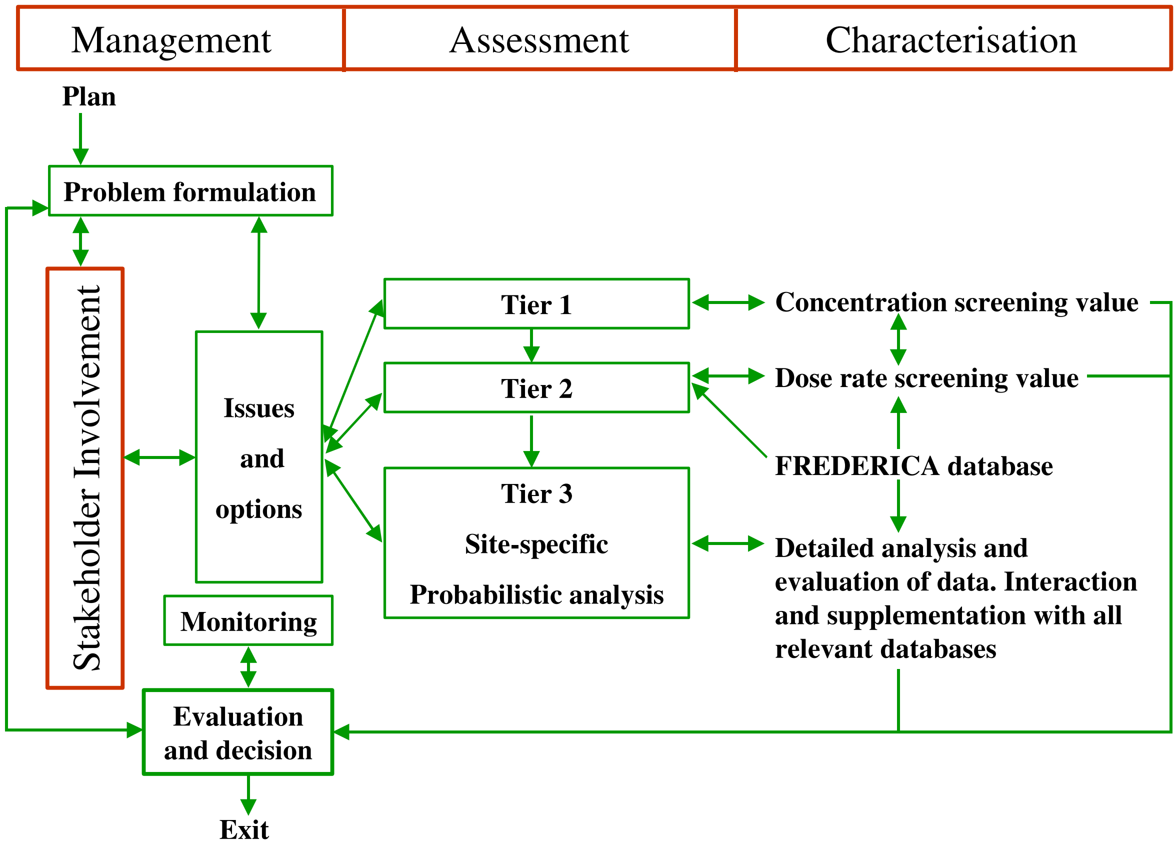

Figure I: Structure of the ERICA Integrated Approach

Assessment refers to the process of estimating exposure of biota, which involves estimating or measuring activity concentrations in environmental media and organisms, defining exposure conditions, and estimating radiation dose rates to selected biota.

Characterisation includes estimation of the probability and magnitude of adverse effects in biota, together with identification of uncertainties. Within the ERICA Integrated Approach published effects data are used as the basis of the assessment with risk characterisation performed by evaluating the output data from the assessment (estimates of exposure) against an effects analyses.

Management is used here as a general term for the process of taking decisions before, during, and after an assessment. The term covers such diverse aspects as decisions on specific technical issues associated with the execution of the assessment, general decisions relating to the interaction with stakeholders, and post-assessment decisions.

Using the ERICA Integrated Approach

The ERICA Integrated Approach advises the user on how to formulate the problem (involving stakeholders if appropriate), perform an impact assessment and evaluate data. It outlines the issues and options available to the user (and requiring decisions) before, during, and after an assessment.

The ERICA Integrated Approach is supported by the *ERICA Tool*, which is a software programme that guides the user through the assessment process, keeps records and performs the necessary calculations to estimate dose rates to selected biota. A detailed help is provided to assist the user in making appropriate choices and inputs, as well as interpret the outputs. The Tool interacts with a number of databases and other functions that help the assessor to estimate environmental media activity concentrations, activity concentrations in biota, and dose rates to biota. The databases consider the majority of the radionuclides included in Publication 38 of the International Commission on Radiological Protection (ICRP). The ERICA Tool also interfaces with the FREDERICA radiation effects database, which is a compilation of the scientific literature on radiation effect experiments and field studies, organised around different wildlife groups and, for most data, broadly categorised according to four effect umbrella endpoints: morbidity, mortality, reproduction, and mutation.

The databases of the ERICA Tool are built up around a number of reference organisms. Each reference organism has its own specified geometry and is representative of either terrestrial, freshwater or marine ecosystems. The approach is compatible with that used by ICRP; some of the geometries proposed for the ICRP ‘reference animals and plants’ are used as defaults in the ERICA Tool.

The assessment element of the ERICA Integrated Approach is organised in three separate *tiers*, where satisfying certain criteria in Tiers 1 and 2 allows the user to exit the assessment process while being confident that the effects on biota are low or negligible, and that the situation requires no further action. Where the effects are not shown to be negligible, the assessment should continue to Tiers 2 and 3. Situations of concern should be assessed further in Tier 3, by making full use of all relevant information available through the Integrated Approach or elsewhere.

Formulating the problem and interacting with stakeholders

Problem formulation is the first step of any risk assessment and includes consideration of ecological, political and societal issues when deciding on procedures and methods, who to involve, and any benchmarks or assessment criteria that the outcome will be compared to. Problem formulation also represents the first stage of the assessment where an assessor might exit the process. A decision *not* to proceed might be made on technical grounds (for example, no direct exposure route) or societal grounds (such as a veto on the discharge of radionuclides regardless of risks to biota). Stakeholder participation procedures vary and there is no single procedure or group of stakeholders that is likely to suit each purpose. In practice, and if participation is deemed important to a decision, a variety of methods are likely to be adopted.

The problem formulation and participation procedures may largely be regulated by legislation. The ERICA Integrated Approach provides information and advice for complying with such legislation and lists additional elements to consider should the user wish to do so. In the process of coming to a decision the problem may need to be re-formulated several times, with the involvement of stakeholders if appropriate, in the light of new information as the assessment proceeds. The ERICA Tool helps the user to consider relevant aspects and record decisions taken with regard to these issues.

Tier 1 assessment

The Tier 1 assessment is designed to be simple and conservative, requiring a minimum of input data and enabling the user to exit the process and exempt the situation from further evaluation, provided the assessment meets a predefined screening criterion. The default screening criterion in the ERICA Integrated Approach is an *incremental dose rate of 10 µGy* h^{-1}, to be used for all ecosystems and organisms. This value was derived from a species sensitivity distribution analysis performed on chronic exposure data in the FREDERICA database and is supported by other methods for determining predicted no effect values. However, the user can change the default screening dose rate within the ERICA Tool, For Tier 1, the predefined screening dose rate is back-calculated to yield Environmental Media Concentration Limits (EMCLs) for all reference organism/radionuclide combinations. The Tool compares the input media concentrations with the most restrictive EMCL for each radionuclide and determines a risk quotient (RQ). If the RQ is less than one, then the tool suggests that the user should exit the assessment process. If the RQ is greater than one, the user is advised to continue with the assessment.

Tier 2 assessment

Tier 2 allows the user to be more interactive, to change the default parameters and to select specific reference organisms. The evaluation is performed directly against the screening dose rate, with the dose rate and RQs generated for each reference organism selected for assessment. A 'traffic light' system is used to indicate whether the situation can be considered:

(i) of negligible concern (with a high degree of confidence);

(ii) of potential concern, where more qualified judgements may need to be made and/or a refined assessment at Tier 2 or an in-depth assessment in Tier 3 performed;

(iii) of concern, where the user is recommended to continue the assessment either at Tier 2 if refined input data can be obtained or at Tier 3.

Decisions to exit an assessment given outcomes (ii) and (iii) should be justified, for example by using information from FREDERICA provided in the Tool as 'look-up effects tables' for different wildlife groups.

Tier 3 assessment

Situations, which give rise to a Tier 3 assessment, are likely to be complex and unique, and it is therefore not possible to provide detailed or specific guidance on how the Tier 3 assessment should be conducted. Furthermore, a Tier 3 assessment does not provide a simple yes/no answer, nor is the ERICA-derived incremental screening dose rate of 10 $\mu Gy\ h^{-1}$ appropriate with respect to the assessment endpoint. The requirement to consider aspects such as the biological effects data within the FREDERICA database, or to undertake ecological survey work, is not straightforward and requires an experienced, knowledgeable assessor or consultation with an appropriate expert.

Tier 3 is a probabilistic risk assessment in which uncertainties within the results may be determined using sensitivity analysis. The assessor can also access up-to-date scientific literature (which may not be available at Tier 2) on the biological effects of exposure to ionising radiation in a number of different species. Together, these allow the user to estimate the probability (or incidence) and magnitude (or severity) of the environmental effects likely to occur and, by discussion and agreement with stakeholders, to determine the acceptability of the risk to non-human species.

Post-assessment considerations

Since the aim of the ERICA Integrated Approach is to aid decision-making so that adequate weight is given to the environmental effects of ionising radiation, the Integrated Approach is non-prescriptive and does not specify decisions that *must* be taken. This flexibility is necessary because of the diversity of environmental legislation. Nevertheless, the Integrated Approach offers guidance on a number of issues and options, and a structure for reaching a decision. However, a decision taken to justify exiting the assessment may not necessarily conclude the process. In most cases, where a decision has been taken via a full Tier 3 assessment, this may have to be revisited regularly on the basis of new information, or as part of licensing conditions.

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- D-ERICA Annex A: Uncertainty matrix applied to the ERICA Tool
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1 Introduction

1.1 Objectives and background

The purpose of the *ERICA Integrated Approach* is to ensure that decisions on environmental issues give appropriate weight to the environmental exposure, effects and risks from ionising radiation with emphasis on ensuring the structure and function of ecosystems. It can be applied in planned and existing exposure situations, and although it is not primarily intended for emergency exposure situations, parts of the Integrated Approach would still be relevant.

Decision-making on activities, facilities, existing sites and contaminated areas of potential, perceived or actual environmental concern is normally governed by an environmental impact assessment (EIA). The procedure should ensure transparent decision-making, where all concerned parties (or 'stakeholders') have been consulted and allowed to comment on the impact of the situation. The ERICA Integrated Approach supports the EIA within the area of environmental radiation, which may be a major or minor concern within the overall EIA, depending on the circumstances.

The ERICA Integrated Approach uses a comprehensive method to address the ecological effects of ionising radiation on biota and ecosystems. A software programme, the ERICA Tool, supports the Integrated Approach. The Tool, together with this document, guides the user in:

- problem formulation;
- carrying out the impact assessment;
- assessing the level of uncertainty (or confidence) in procedures and results;
- taking decisions, in consultation with stakeholders if necessary, before, during and after the assessment.

The approach is generic, flexible and non-prescriptive, enabling users to formulate problems according to their specific needs. It also allows flexibility in the choice of parameters for the assessment. Likewise, it provides guidance on important issues and options available in decision-making, but does not prescribe which decisions are 'correct' or the radiation exposure and effects considered 'acceptable'.

The Integrated Approach is intended to be user-friendly. However, ecosystem functioning is complex and the Earth hosts a diversity of life forms. Thus, an overly simplistic approach would generate assessments without real scientific meaning and, of little value for decision-making. The ERICA Integrated Approach attempts to strike a balance between the simplification required for the method to be workable, and the complexity needed to generate useful information. This is accomplished via a *tiered approach*, enabling the early screening out of situations of negligible radiological concern, leaving only those of potential or real concern for more in-depth assessment. In particular, the highest tier (Tier 3) may require the assessor to be experienced or to consult external expertise.

1.1.1 The ERICA project and other recent international and national initiatives

The ERICA Integrated Approach and the ERICA Tool are both outcomes of the EC 6th Framework Programme (FP) ERICA project. Other deliverables from the project provide more information on the reasoning behind the ERICA Integrated Approach described here. The ERICA project incorporates, and expands upon, earlier EC projects FASSET (Framework for Assessment of Environmental Impact) and EPIC (Environmental Risks from Ionising Contaminants in the Arctic), briefly summarised in Appendix 3. Supplementary documentation from all three projects (available on www.erica-project.org) provides further scientific information supporting the ERICA Integrated Approach.

The development of the ERICA Integrated Approach has taken account of a number of national initiatives, such as those in the USA [US DoE, 2002], Canada [Environment Canada, 2001] and the UK [Copplestone *et al.*, 2001]. More than fifty organisations, brought together under the umbrella of the End Users Group (EUG), have provided comments and advice on the Integrated Approach in the course of its development, and have tested a prototype version of the ERICA Tool. As a result, a number of important changes and additions have been made, and the consortium responses to the EUG input have been tracked on the project website. Broad acceptance has been obtained on both technical and general issues (see, for example, the ERICA Consensus Seminar [ERICA D7f, 2006] and its resulting Consensus Document [ERICA Consensus Document, 2006]). While the interaction with end-users has been highly valuable, the final structure and content of the ERICA Integrated Approach and its associated Tool, databases and other documentation, remain entirely the responsibility of the consortium that developed it.

Development of the ERICA Integrated Approach has coincided with the work of the International Commission on Radiological Protection (ICRP) on protecting the environment against the harmful effects of ionising radiation [ICRP 2005; web version of the draft recommendations, http://www.icrp.org/docs/ICRP_Recs_02_276_06_web_cons_5_June.pdf]. The ERICA Integrated Approach and the ICRP approach are compatible. The databases have in both cases been developed with ecosystem representatives (reference organisms in ERICA; reference animals and plants or RAPs in ICRP), as further explained in Section 2.3.1. Indeed, the method developed by ERICA has been used extensively to build the ICRP databases.

1.2 The three elements of the ERICA Integrated Approach

To aid decision-making related to the environmental effects of ionising radiation, three main elements have been combined into the ERICA Integrated Approach. These are *assessment* of environmental exposure and effects using the ERICA Tool, *risk characterisation*, and *management* of environmental risks, as shown in Figure 1.1. Figure 1.1 demonstrates that the process of taking decisions is all but linear. It is recommended, and for complex assessment necessary, to reconsider all elements of the process described in Figure 1.1 through several iterations, involving stakeholders where appropriate. Also, post-assessment decisions on, for example, the acceptability of a specific project may need to be reviewed in the light of operating experience, monitoring data, or other information becoming available with time.

The Integrated Approach uses measured or predicted radionuclide activity concentrations in environmental media or biota as inputs into the ERICA Tool. Depending on intermediary results, the assessment then continues through a maximum of *three tiers* (see Box 1.1).

1.3 How to use this report and how it relates to the ERICA Tool

This report, D-ERICA, outlines the structure of the ERICA Integrated Approach. It provides the reader with information on the basic underlying assumptions and elements of the methodology, as well as with general advice on its application. The reader will become familiar with how the Integrated Approach deals with:

- problem formulation (Chapter 2);
- interaction with stakeholders (Chapter 3);
- calculation of radionuclide concentrations and dose rates (Chapter 4);
- assessments in Tiers 1, 2 and 3 (Chapters 5, 6 and 7 respectively);
- post-assessment considerations (Chapter 8).

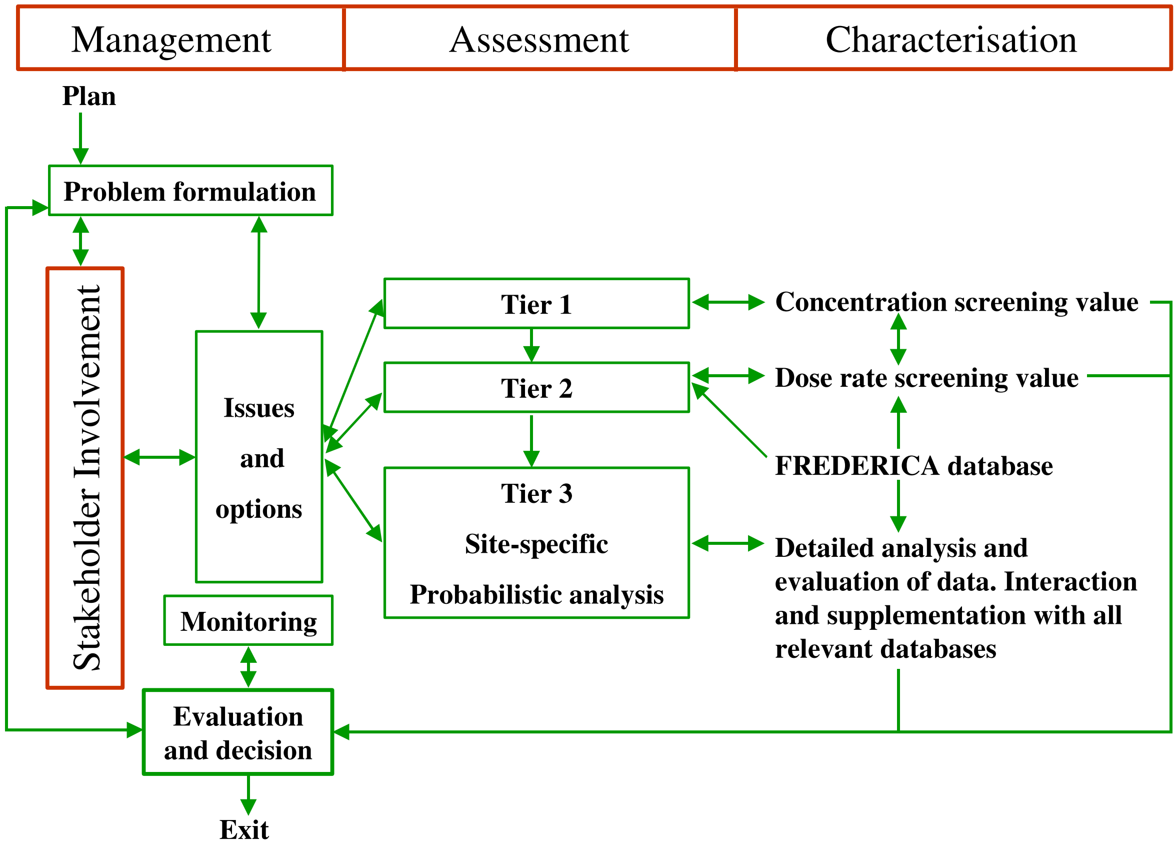


Figure 1.1: Overview of the ERICA Integrated Approach, outlining the interaction between assessment, risk characterisation and management.

Assessment refers to the process of estimating the exposure of biota. It involves estimating or measuring activity concentrations in environmental media and organisms, defining exposure conditions, and estimating radiation dose rates to selected biota.

Risk characterisation is the synthesis of information obtained during risk assessment for use in management decisions. This should include an estimation of the probability (or incidence) and magnitude (or severity) of the adverse effects likely to occur in a population or environmental compartment, together with identification of uncertainties. Published effects data effects data are used as the basis of the assessment with risk characterisation performed by evaluating the output data from the assessment with (estimates of exposure) against an effects analyses.

Management is used here as a general term for the process of taking decisions before, during and after an assessment. The term covers such diverse aspects as decisions on specific technical issues associated with the execution of the assessment, general decisions relating to the interaction with stakeholders, and post-assessment decisions. The ERICA Integrated Approach intends to aid such decisions, and does not prescribe what decisions *must* be taken.

D-ERICA serves as an introduction to the ERICA Tool, and demonstrates how the Tool and underlying science can be used to assess the environmental concern of a particular situation. The Tool can be downloaded free of charge from the ERICA website, www.erica-project.org. The user of the Tool can get help from the extensive Help incorporated into the Tool. An overview of the Tool in the form of a flowchart is given in Appendix 1, which highlights the information required at each step of the assessment. Appendix 2 lists the various points along the assessment route where a user needs to take decisions, together with some guidance on alternatives and their applicability.

For a full list of uncertainties governing assessments, the reader is advised to consult the uncertainty matrix laid out in Annex A to this report. The Glossary (Annex B) comprises not only terms, acronyms and abbreviations used in ERICA, but also those used in environmental assessments and decision-making generally.

Box 1.1 The Tiers of the ERICA Tool

Tier 1

- Highly conservative
- Requires minimal data input
- Simple and can be used by non-specialist users
- Maximum measured media concentrations suggested as input
- Compares input media concentrations to Environmental Media Concentration Limits calculated for the most limiting reference organism for each radionuclide
- If the Tool recommends that the assessment can be exited the situation can be considered to be of negligible radiological concern.

Tier 2

- Less conservative screening tier
- User can edit transfer parameters
- Media and biota activity concentrations can be input (best estimate values are recommended)
- Estimated wholebody absorbed dose rates compared directly to the screening dose rate
- 'Traffic light' system indicates if situation is:
    - of negligible concern (with a high degree of confidence) - user is recommended to exit the assessment process
- of potential concern – user recommended to review and amend assessment
    - of concern – user recommended to continue the assessment
- Results can be assessed against summarised tables of effects and exposure due to naturally occurring radionuclides

Tier 3

- Not a screening tier – so no screening dose rate
- Not prescriptive and has no 'yes/no' answer
- Provides user with guidance, template and tool to help conduct more detailed assessment
- Probabilistic and sensitivity analyses
- Access to up to date on-line database of radiological effects

2 Problem Formulation

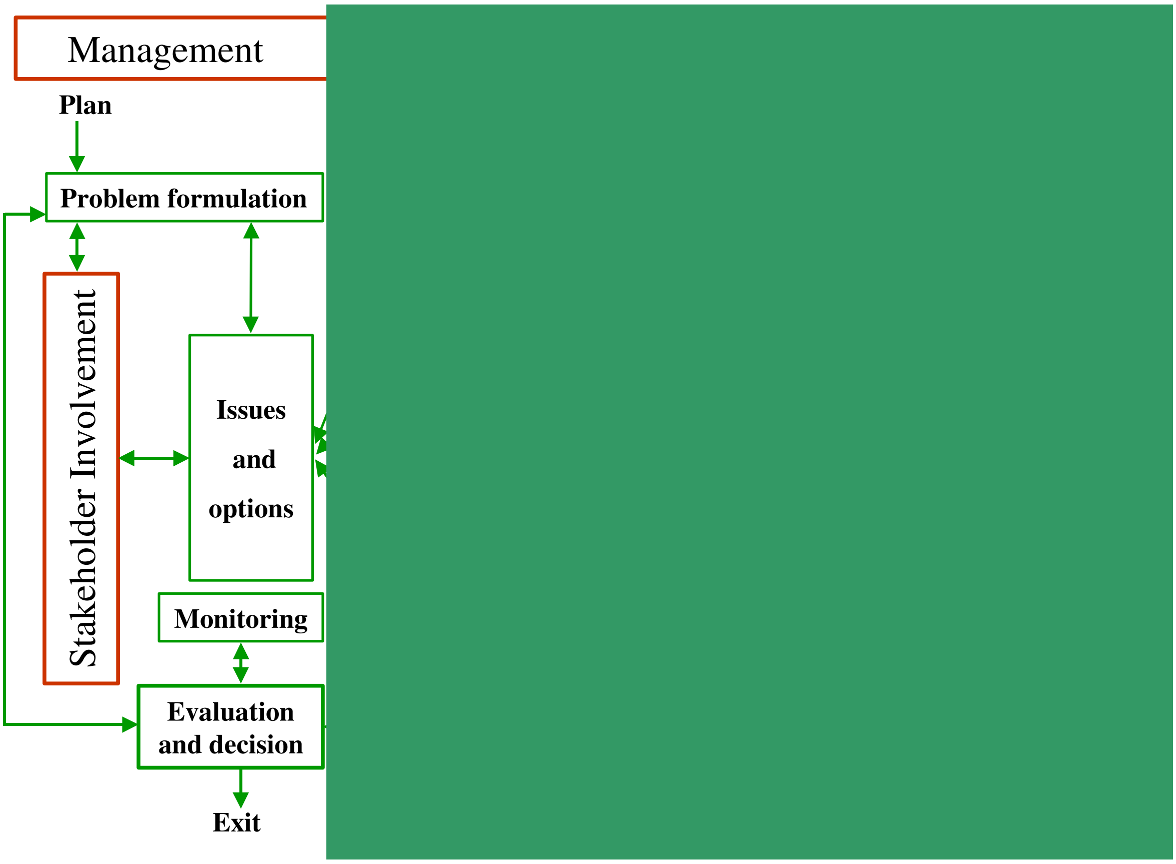


Figure 2.1: The ERICA Integrated Approach, highlighting the elements that relate to problem formulation.

2.1 Introduction

Problem formulation is the first step of any risk assessment, and within a tiered approach should be revised as new information becomes available or as decisions have to be reviewed. Problem formulation is used to identify the scope, context and purpose of the assessment. This should include consideration of ecological, political and societal issues, and should integrate the process of choosing assessment endpoints, identifying sources and describing the environment [Suter, 1993; Moore and Biddinger, 1995]. The user of the ERICA Integrated Approach may also wish to consider the three generic exposure situations for which the International Commission on Radiological Protection (ICRP) intends its forthcoming recommendations, due 2007, to be applied:

- *Planned exposure situations* - everyday situations involving planned operations, including decommissioning of nuclear facilities, disposal of radioactive waste and rehabilitation of radioactively contaminated land.
- *Existing exposure situations* - exposure situations that already exist when a decision on control has to be taken, including natural background radiation and residues from past practices.
- *Emergency exposure situations* - unexpected situations that occur during the operation of a practice, requiring urgent action.

The ERICA Integrated Approach can be used in most circumstances covered by these situations, as indicated by the examples shown in Table 2.1. However, the Integrated Approach does not fully consider the dynamic modelling necessary for non-steady state and transient scenarios associated with early emergency situations, although the method is nevertheless able to provide 'snapshots' of the situation. Furthermore, an emergency situation will eventually transform into an existing situation, where the Integrated Approach may be applied in full.

Table 2.1: Examples of exposure situations where the ERICA Integrated Approach may be used, either on its own or as part of a wider assessment which considers other issues.

Planned	Existing	Emergency
a) siting a new facility	a) exposure after an accident	a) accidents in nuclear facilities
b) re-assessing the authorisation of an existing facility	b) residues from past or existing practices	b) accidents in the transport of radioactive materials
c) decommissioning a nuclear facility and disposing of radioactive waste		c) deliberate/malevolent uses, including terrorism
d) remediation		
e) NORM/TENORM		
f) clearance		

The process of problem formulation in any of the above situations is crucial to conducting and interpreting the results of an assessment. Its purpose is to encourage the user to think carefully about the assessment to be conducted and to document any assumptions and decisions in a clear and transparent manner. For example, it is important to establish whether a full environmental risk assessment (selection of Tier 3) is appropriate or whether the legislative context calls for a Tier 3 assessment to be carried out, regardless of whether environmental risks can be deemed negligible or not.

Problem formulation also represents the first stage at which an assessor might exit the assessment process. For example, a decision **not** to proceed might be made on either technical grounds (for example, no direct exposure route) or social or economic grounds (such as if the local population says no to a practice that would discharge radionuclides for reasons other than the risk to biota).

2.2 Factors to consider in formulating the problem

A number of elements should be considered when formulating the problem to be assessed. These will also help justify the selection of the tier to begin the assessment at. Table 2.2 lists, and elaborates on, a number of fundamental factors to be considered.

It is crucial that the evidence collected during the problem formulation stage be documented in a transparent and understandable way. Commonly, a conceptual model is developed which describes what is known about the site, its geographical limits, radioactive substances of interest, potential pathways and receptors and the likelihood of exposure, along with any data gaps. Essentially, the conceptual model is a narrative summarising the site conditions, current knowledge and the problem faced. The level of detail required will be influenced by a number of factors but should comprise some, or all, of the information described in Table 2.2. Appendix 2 and the uncertainty matrix described in D-ERICA Annex A also provide information that the assessor may need to consider when formulating the problem.

The problem formulation should be reviewed as and when new information becomes available, for example as the assessment moves between tiers within the ERICA Integrated Approach.

Table 2.2: Elements of problem formulation for consideration.

Element	Explanation	Examples of questions to answer
Identification and characterisation of source	Identify anything that may cause radiation exposure, by emitting ionising radiation or releasing radioactive substances. Identify the type of radiation and/or radioactive substances. Identify the presence of other non-radioactive contaminants that might need to be considered (as part of the overall assessment).	Which radionuclide(s) and their activity concentrations should be included in the assessment? For prospective (and potentially retrospective) assessments, should you use a model to predict dispersion in the environment to determine media activity concentrations as inputs into the ERICA Tool? For retrospective assessments, what is the history of past discharges and does this need to be considered further?
Identification of the receiving media	Identify receptor(s), size and duration of exposure(s) and ecosystem(s) affected. Identify the spatial and temporal scales that need to be considered.	Is there a source-receptor pathway or can you exit the assessment? Which species and ecosystems should be included in the assessment? Does spatial or temporal averaging need to take place and if so how?
Legislative/regulatory requirements	Identify the legal framework governing the acceptability of the source in question. Identify any endpoints or assessment criteria that are listed in the legal framework.	What is the exit process (for example, is the source or exposure level acceptable or not)? Does the legal framework require an assessment to be carried out? What should be the level of stakeholder involvement? How should protection endpoints be defined, with reference to the legislation?
Stakeholder involvement	Take into account views of stakeholders. A stakeholder may be defined as anyone who has an interest in, or considers they have an interest in, the issue, which therefore goes beyond representatives of groups to include interested members of the public.	Which stakeholders should be involved? How to create awareness among stakeholders? At what stage, and what method of, engagement should be used? What results and actions from the consultation are to be implemented? Are there social or economic issues that should be considered in the assessment?
Assessment criteria	Preparation of a procedure for evaluating the results of the assessment against. This may incorporate management criteria specific to a particular assessment.	Which: (i) endpoints, (ii) dose rates or environmental concentrations, and (iii) screening values should be considered?

Element	Explanation	Examples of questions to answer
Outputs from the assessment	Depending upon the tier of the ERICA Integrated Approach, there will be different outputs available for review and evaluation.	What outputs should there be (such as risk quotients, dose rates, effects data, probability distributions)?
Uncertainties, knowledge or data gaps	Identify and record uncertainties related to the processes under evaluation within the assessment.	What are the uncertainties associated with: (i) the input data, (ii) calculations being used, (iii) effects data, (iv) underpinning radioecological data (such as concentration ratios), (v) data or knowledge gaps?
Risk characterisation	This is the synthesis of all the information obtained during the assessment for use in management decisions. This should include an estimation of the probability (or incidence) and magnitude (or severity) of the environmental effects likely to occur.	What are the levels of environmental detriment and risk? Should other contaminants be considered in the assessment? Should a sensitivity analysis be carried out?

2.3 Specific considerations in the ERICA Integrated Approach

The ERICA Tool (see Appendix 1) provides a number of initial screens for recording and justifying the problem formulation within the computer file for the assessment. The Tool prompts the user to:

- provide a detailed description of the assessment;
- list the transfer pathways and assessment endpoints;
- upload a conceptual model;
- select the ecosystem to be considered (freshwater, marine or terrestrial);
- within Tiers 2 and 3, select the reference organisms to consider (see Section 2.3.1);
- select radionuclides to include in the assessment;
- provide information on media activity concentrations;
- select the screening dose rate against which the results from Tiers 1 and 2 will be compared.

The ERICA Tool will prompt the user to provide input for the above points (see also Appendix 2). The identification of pathways and reference organisms (Section 2.3.1) may be assisted by uploading conceptual models for each of the ecosystems considered, that is terrestrial, freshwater and marine ecosystem (see example in Figure 2.2). The default radionuclides included in the Tool are listed in Table 2.3, but at Tiers 2 and 3 the Tool has the capability to undertake assessments for all but a few of the radionuclides listed in ICRP Publication 38 [ICRP, 1983]. Chapter 4 gives information on how to estimate media and biota activity concentrations. Chapter 5 describes the rationale for deriving dose rate screening values; the Tool, by default, uses 10 µGy h^{-1} as a screening incremental dose rate, but the assessor can modify this. The problem formulation may also be affected by the input from different stakeholders, as further dealt with in Chapter 3.

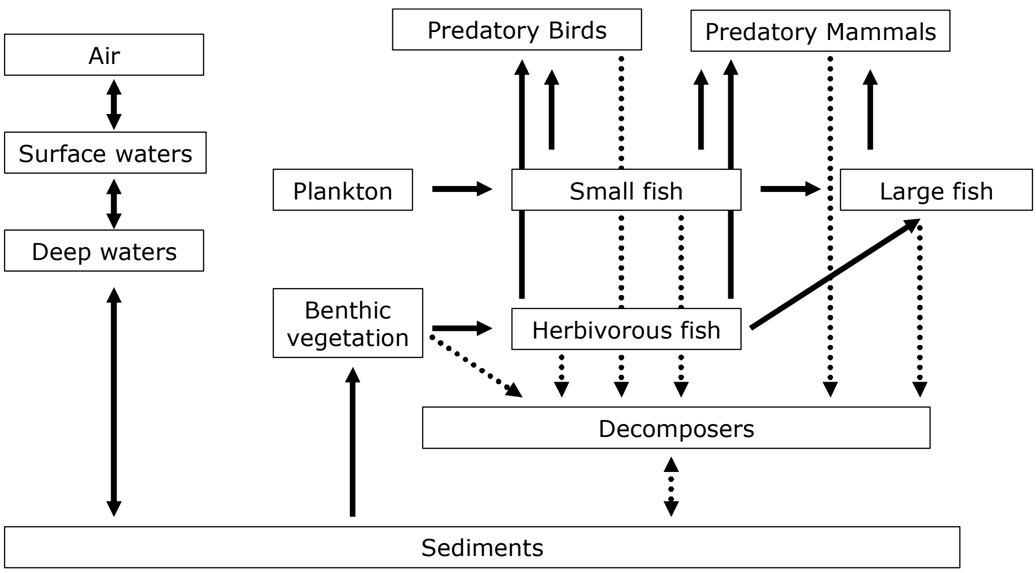


Figure 2.2: Example of a method to visualise a conceptual model (in this case, for a marine generic ecosystem).

Table 2.3: Default radionuclides for which databases are included in the ERICA Tool.

Element		Isotopes
Ag	Silver	Ag-110m
Am	Americium	Am-241
C	Carbon	C-14
Cd	Cadmium	Cd-109
Ce	Cerium	Ce-141, Ce-144
Cl	Chlorine	Cl-36
Cm	Curium	Cm-242, Cm-243, Cm-244
Co	Cobalt	Co-57, Co-58, Co-60
Cs	Caesium	Cs-134, Cs-135, Cs-136, Cs-137
Eu	Europium	Eu-152, Eu-154
H	Tritium	H-3
I	Iodine	I-125, I-129, I-131, I-132, , I-133
Mn	Mangenese	Mn-54
Nb	Niobium	Nb-94, Nb-95
Ni	Nickel	Ni-59, Ni-65
Np	Neptunium	Np-237

Element		Isotopes
P	Phosphorus	P-32, P-33
Pb	Lead	Pb-210
Po	Polonium	Po-210
Pu	Plutonium	Pu-238, Pu-239, Pu-240, Pu-241
Ra	Radium	Ra-226, Ra-228
Ru	Ruthenium	Ru-103, Ru-106
S	Sulphur	S-35
Sb	Antimony	Sb-124, Sb-125
Se	Selenium	Se-75, Se-79
Sr	Strontium	Sr-89, Sr-90
Tc	Technetium	Tc-99
Te	Tellurium	Te-129m, Te-132
Th	Thorium	Th-227, Th-228, Th-230, Th-231, Th-232, Th-234
U	Uranium	U-234, U-235, U-238
Zr	Zirconium	Zr-95

2.3.1 The concept of reference organisms

The ERICA Integrated Approach concerns the assessment of radiation effects in biota, and provides a basis for decisions governing environmental protection. Given the variation between species, it is not generally possible to develop species-specific assessment systems (*cf.* human radiation protection). The ERICA Integrated Approach is based on generalised ecosystem representations, termed reference organisms. The definition of a reference organism (originally formulated in the FASSET project) is:

"a series of entities that provide a basis for the estimation of radiation dose rate to a range of organisms which are typical, or representative, of a contaminated environment. These estimates, in turn, would provide a basis for assessing the likelihood and degree of radiation effects".

The reference organisms selected for the ERICA Integrated Approach are listed in Table 2.4 below. They have been defined and used for the derivation of geometric relationships between radiation sources and organisms, as well as for considerations of the dosimetry of both external and internal exposure. The reference organisms can be grouped into three general ecosystem categories, namely terrestrial, freshwater and marine ecosystems. Furthermore, they can be used for pooling some of the effects data generated for a range of species. The selection of reference organisms makes it possible to address all protected species within Europe.

This reference organism approach is compatible with the ICRP approach, in which reference datasets are organised around 12 reference animals and plants (or RAPs)[1]. The ERICA Tool uses, for some of the reference organisms, the proposed ICRP geometries as indicated in Table 2.4.

Table 2.4: Reference organisms for each ecosystem in the ERICA Tool. The corresponding ICRP RAPs, for which the ERICA Tool uses the proposed ICRP geometries as default, are indicated in italics within brackets.

Freshwater	Marine	Terrestrial
Amphibian *(frog)*	(Wading) bird *(duck)*	Amphibian *(frog)*
Benthic fish	Benthic fish *(flat fish)*	Bird *(duck)*
Bird *(duck)*	Bivalve mollusc	Bird egg *(duck egg)*
Bivalve mollusc	Crustacean *(crab)*	Detritivorous invertebrate
Crustacean	Macroalgae *(brown seaweed)*	Flying insects *(bee)*
Gastropod	Mammal	Gastropod
Insect larvae	Pelagic fish	Grasses and herbs *(wild grass)*
Mammal	Phytoplankton	Lichen and bryophytes
Pelagic fish *(salmonid/trout)*	Polychaete worm	Mammal *(rat, deer)*
Phytoplankton	Reptile	Reptile
Vascular plant	Sea anemones/true corals	Shrub
Zooplankton	Vascular plant	Soil invertebrate (worm) *(earthworm)*
	Zooplankton	Tree *(pine tree)*

The reference organisms are used to calculate the EMCLs used in Tier 1, and they can be selected individually for Tier 2 assessments. They also form the basis for assessments at Tier 3.

[1] The proposed RAPs currently under study by the ICRP are: Deer, Rat, Duck, Frog, Trout, Flat fish, Bee, Crab, Earthworm, Pine tree, Grass, Brown seaweed.

3 Guidance on interactions with stakeholders

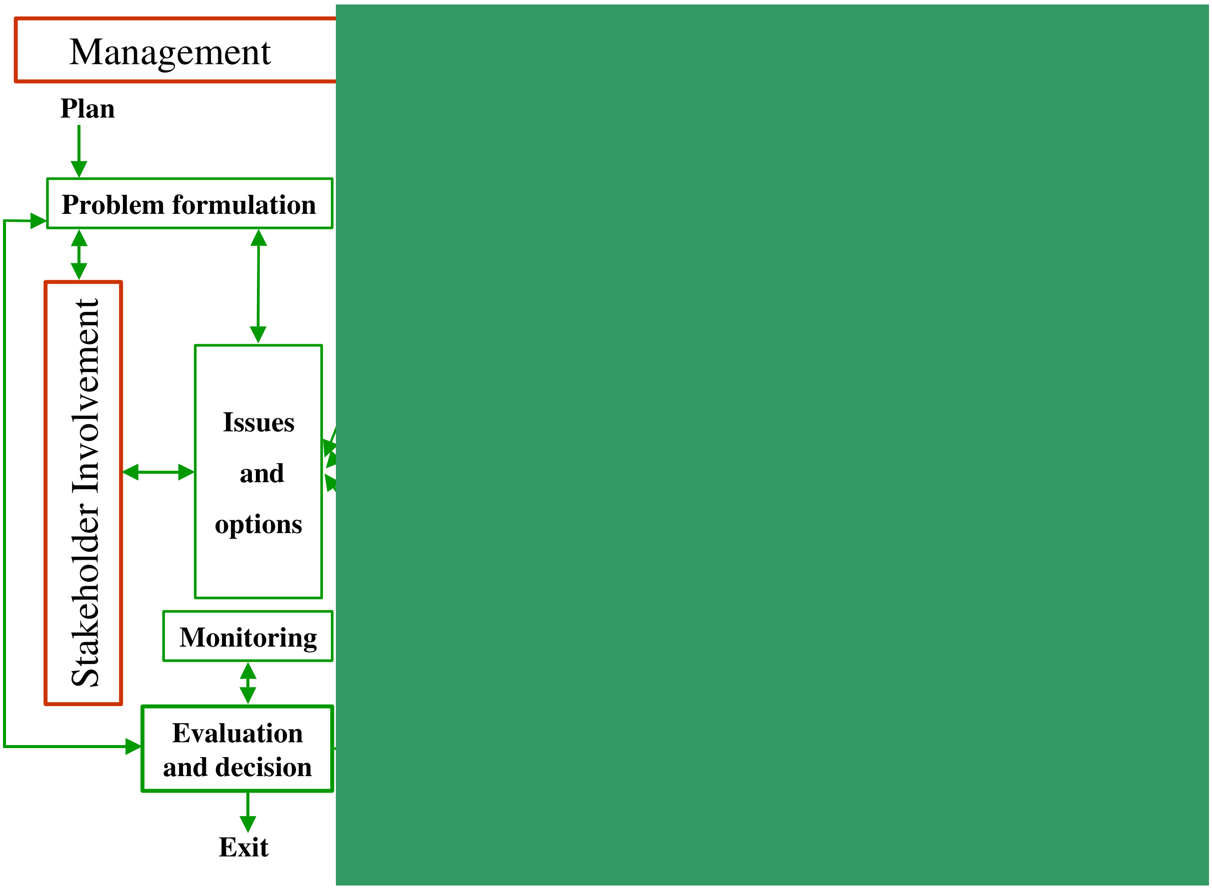


Figure 3.1: The ERICA Integrated Approach, highlighting the elements that relate to stakeholder involvement.

3.1 Introduction

The ERICA Integrated Approach does not determine whether or not the assessor should engage with stakeholders because:

- the need to involve stakeholders is specifically covered by national legislation in many countries;
- the Integrated Approach might be part of a wider environmental impact assessment that has its own broader stakeholder engagement process.

However, the involvement of stakeholders is considered to be good practice and should be encouraged.

The ERICA Tool allows the assessor to openly record stakeholder issues so that if anyone reviewed the outputs from the assessment, all relevant information would be available. The Tool also allows the assessor to review and revise the stakeholder engagement as they progress through a tiered assessment.

The word stakeholder originates from considerations of a company's obligation to its shareholders, but has since been expanded to cover any person or organisation that could either be affected by, or interested in, the outcome of a decision. Hence, stakeholder participation procedures vary according to the objective of the assessment (information gathering or decision-making), participants (experts or laypersons, elected, selected or volunteers), and processes. Such processes can include the simple provision of information (one-way communication), expert review or full public consultation procedures. There is no one procedure or group of stakeholders that may suit each purpose. In practice, and if stakeholder participation is deemed important to a decision, a variety of methods may be used in the course of evaluating an environmental issue.

3.2 Factors to consider and record when involving stakeholders

The ERICA Tool initially allows the user to select whether stakeholders will be involved or not.

If the assessor selects *no*, the Tool will ask them to provide a brief justification for their decision not to include stakeholders. This could be as simple as stating that there is a wider ongoing consultation.

If the assessor selects *yes*, the Tool will ask them for a brief summary of the stakeholder involvement (such as who is involved, how they are involved, what the aims and outcomes of the involvement are).

Table 3.1 contains a generic list of stakeholders that can be used to help to group stakeholders into different classes. The ERICA Tool will record different types of information including timing options, where consideration should be given to whether engagement:

- is required only at the problem formulation stage;
- is required throughout the process;
- should serve as a source of knowledge and/or data for a particular purpose;
- should involve review of the assessment;
- should be requested for any other reason.

Table 3.1: List of generic stakeholder classes.

- Decision makers
- General public
- Independent experts (research and academia)
- Industry No. 1, then No. 2 and so on
- International representatives (for transboundary questions)
- Local authorities and/or government representatives
- Media
- Next generation*
- NGOs (particularly environmental and nature organisations)
- Non-human species*
- Other NGOs
- Other No. 1, then No. 2 and so on
- People/organisations 'who care'
- Regulators
- Risk bearers
- Users of the environment (for recreation, food production, and so on)
- Worker representatives

*The groups would be represented by appropriate organisations/individuals.

Once the stakeholders have been identified, it can be helpful to assign them to categories based on whether they have a high or low influence on the assessment process and/or decision and whether they have a high or low interest in its outcome. This categorisation may help to identify the best methods for engagement and the likely level of interest. For example, stakeholders with low influence and low interest may be harder to reach and may not need to be involved, but those with a high interest and high influence would normally be targeted. Potential methods of engagement are summarised in Table 3.2.

Table 3.2: Potential methods for stakeholder engagement for different purposes.

Information provision	Straightforward and can be considered as a one-way process (although the stakeholders might also provide specific information). Dissemination of information related to the project may involve the use of leaflets, websites, public relations and media, open house, exhibitions, seminars and announcements (usually in newspapers).
Consultation	Can be used for the purpose of discussion and gaining agreement on, for example, appropriate input values for the assessment and for gaining an understanding of the stakeholders' points of view and arguments.
Consensus building	Process aimed at reaching agreement on particular points through informed debate and discussion. This is different to consultation where areas of disagreement are likely to remain, because consultation is about identifying different views so that decision makers can consider all possible aspects. In contrast, consensus building attempts to bring all parties to some form of agreement. Whilst the aim of the process might be to come to some form of consensus, this may not always be possible. In these cases, the reasons for disagreement should be recorded, as they might shed light on key issues for consideration by decision-makers.

Once stakeholder engagement is completed, the ERICA Tool asks the user to record the results. The information recorded relates to the influence of stakeholders' comments on the assessment process. The Tool poses the following questions:

- *Have stakeholders been engaged as defined in the problem formulation?*
- *Did the assessor do as intended?*
- *Where is the supporting documentation?* This allows the assessor to record the physical or electronic location of any files that might be useful or should be associated with the assessment using the ERICA Tool or as part of a wider consultation process.
- *Did the stakeholder involvement impact on how the assessment was carried out?* This allows the assessor to record how the assessment problem formulation might have been, or was, modified in consultation with stakeholders.
- *How did the stakeholder involvement impact on the final decision?* This allows the assessor to record any stakeholder involvement in the decision regarding the final outcome. Decisions need to be documented in an open and transparent way, which is particularly important in cases where consensus is limited or absent.

4 Media and biota activity concentrations and dose rates

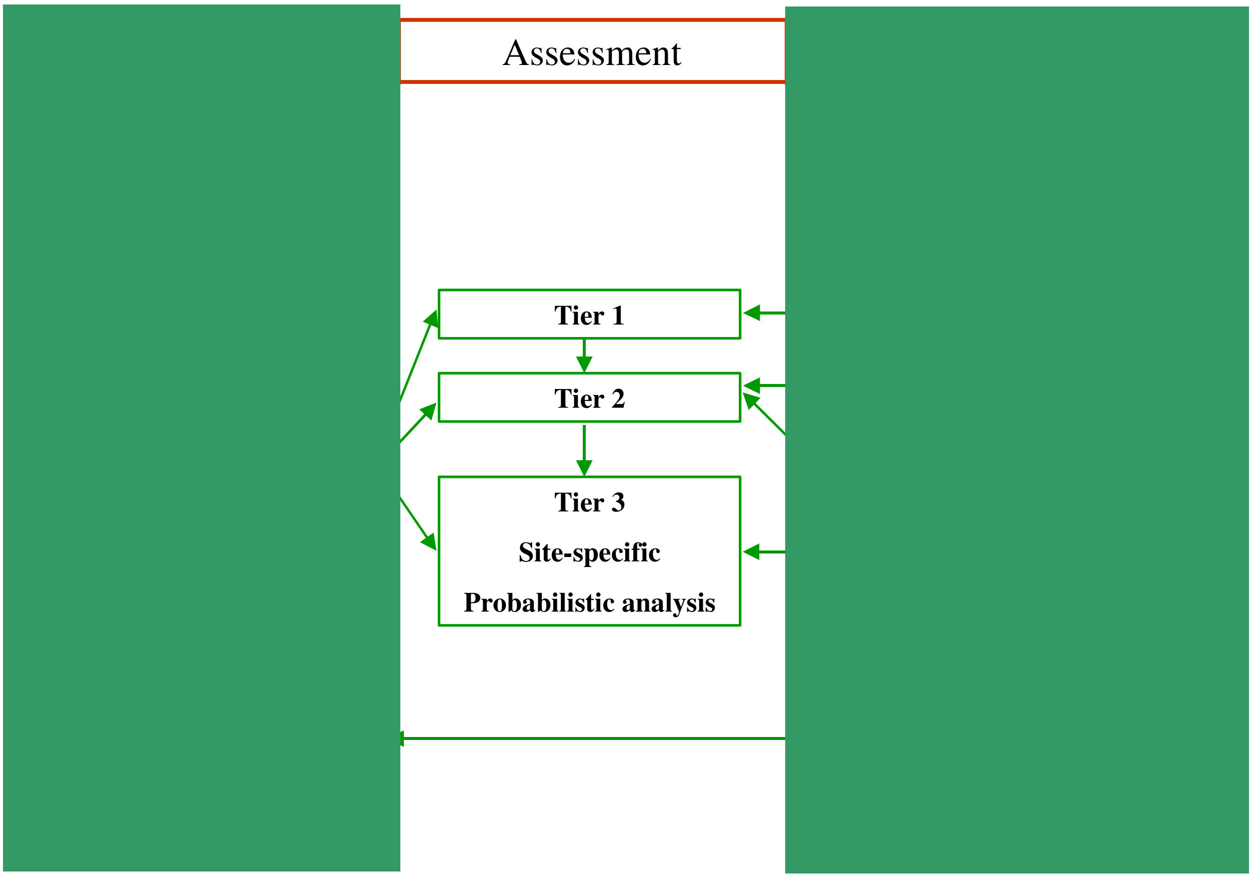


Figure 4.1: The ERICA Integrated Approach, highlighting the elements that relate to estimation of media and biota activity concentrations and absorbed dose rates.

4.1 Introduction

Exposure to radiation is estimated as the absorbed dose rate (the quantity of energy imparted by ionising radiation to a unit mass of an organism per unit time, with $\mu Gy\ h^{-1}$ used within the ERICA Tool). To determine this, the activity concentrations in both media and biota are required, together with the ability to convert these into estimates of external and internal exposure. Radionuclide activity concentration in media and/or biota may be known, or they may need to be estimated.

This chapter provides an overview of the methods used within the ERICA Tool to estimate radionuclide activity concentrations in media and biota and, from these, whole body absorbed dose rates. Advice on conducting complex assessments, such as those involving multiple sources or transitional ecosystems, is also provided.

4.2 Radionuclide concentrations in environmental media

The radionuclide activity concentrations in media (water, sediment, soil or air) are the basic inputs required in all three tiers of the ERICA Tool. However, sufficient data may not always be available from environmental monitoring. If this is the case, media activity concentrations need to be estimated using dispersion models (for assessments of proposed facilities, this will always be the case). The assessor may have their own models which can be used to derive these inputs. If not, screening transport models adopted from IAEA [2001], subsequently referred to as the SRS-19 models, have been built into the

ERICA Tool and can be used to estimate media concentrations for various scenarios. The SRS-19 models were developed for the purpose of screening radioactive discharges for either new or existing practices in the context of human radiological protection. The models incorporated within the ERICA Tool are generic and account for dilution and dispersion in the environment, using a minimum of site-specific input data. The following SRS-19 models for the three ecosystems are available in the ERICA Tool:

- Small lake (freshwater)
- Large lake (freshwater)
- River (freshwater)
- Estuarine (freshwater and marine)
- Coastal (marine)
- Air (terrestrial)

The SRS-19 models are designed to minimise the possibility that the calculated media concentrations will underestimate doses (to humans) by more than a factor of 10. They can estimate average concentrations in water or air from continuous releases from a single source assuming that an equilibrium, or quasi-equilibrium, has been established between released radionuclides and the environmental medium. The models and their uncertainties are summarised within the ERICA Tool help and a full description is available from the International Atomic Energy Agency (IAEA) website (www-pub.iaea.org/MTCD/publications /PDF/Pub1103 _scr.pdf).

4.3 Activity concentrations in biota

Radionuclide activity concentrations in biota are required for Tier 2 and 3 assessments. As for radionuclide concentrations in environmental media, sufficient data may not be available. If this is the case, the ERICA Tool provides the user with the ability to estimate them. Users of Tiers 2 and 3 need to have some understanding of the approaches used, as they will need to decide on the acceptability of default parameters or provide alternative values. Assessors using only Tier 1 of the ERICA Tool do not need to decide on these issues.

Whole body activity concentrations of radionuclides in biota within the ERICA Tool are predicted from media activity concentrations using equilibrium concentration ratios (CRs). For aquatic environments, the distribution coefficient (K_d) is used to relate equilibrium activity concentrations in sediments with those in water. Concentration ratios and K_d for the ERICA ecosystems are defined in Box 4.1.

The ERICA Tool has three default radioecology databases (one for each ecosystem) containing a complete set of CR and K_d values for all reference organisms and default radionuclides (see Table 2.3) within ERICA. By preference, values of CR were empirically derived from reviews of original publications. Various manipulations of reported data were necessary, as they were often not in the format required (for example, organ-specific rather than whole body activity concentrations). The manipulations and assumptions used in the derivations are fully documented, together with details of statistical analyses used, within the Tool's help. The default databases contain arithmetic mean values together with standard deviations, minimum and maximum values, probability distribution functions (pdfs), number of data entries, comments (such as notes on the data used), and date of last update for each value. The calculation of biota activity concentrations of radioisotopes of H, C, P and S using air concentrations rather than soil is common practice for human assessments.

For many of the reference organism-radionuclide combinations, there were no reported data from which to derive empirical CR values. Various options were used to populate the default CR databases in the absence of reported values for Tier 1 assessments (which require a complete set of default CR values to derive EMCL values; see Section 5.2.2). Values derived by these methods are identified within the default databases. The options used are summarised in Box 4.2 and described in more detail within the Tool help. By preference, the first four options were used wherever possible. With the exception of the last two options, which were used as a last resort, the remaining options were applied depending on availability of information. These approaches could be used by the assessor to help select CR values for newly defined reference organisms or for radionuclides added within Tier 2 and 3 assessments (as the Tool will not contain CR values for these).

Box 4.1 Definition of CR and K_d

Terrestrial ecosystems

$$CR = \frac{\text{Activity concentration in biota whole body (Bq kg}^{-1}\text{ fresh weight)}}{\text{Activity concentration in soil (Bq kg}^{-1}\text{ dry weight)}} \quad (4.1)$$

Exceptions are for chronic atmospheric releases of ^{3}H, ^{14}C, $^{32,33}P$ and ^{35}S where:

$$CR\ (m^3\ kg^{-1}) = \frac{\text{Activity concentration in biota whole body (Bq kg}^{-1}\text{ fresh weight)}}{\text{Activity concentration in air (Bq m}^{-3}\text{)}} \quad (4.2)$$

Aquatic ecosystems

$$CR\ (l\ kg^{-1}) = \frac{\text{Activity concentration in biota whole body (Bq kg}^{-1}\text{ fresh weight)}}{\text{Activity concentration of filtered water (Bq l}^{-1}\text{)}} \quad (4.3)$$

$$K_d\ (l\ kg^{-1}) = \frac{\text{Activity concentration in sediment (Bq kg}^{-1}\text{ dry weight)}}{\text{Activity concentration in water (Bq l}^{-1}\text{)}} \quad (4.4)$$

Within Tiers 2 and 3, it is possible to edit CR and K_d values and input measured activity concentrations for biota (all default values derived using the methods in Box 4.2 are clearly identified). A recent comparison of site-specific data to generic data (specifically, soil-plant concentration ratios), however, concluded that generic data may often constitute the best choice, owing to the very large inherent variability in transfer parameters, which a few site-specific measurements may not encapsulate [Sheppard, 2005]. The ERICA Integrated Approach is not prescriptive on the use of site-specific data, and the assessor is advised to consider carefully whether the quality of any available site-specific data justifies its application. Site-specific data will always provide a useful comparison with predictions generated using the Tool's generic parameters. A reasonable level of agreement would be for predicted and observed data to fall within an order of magnitude of each other (consistent with the approach taken in the development of the SRS-19 screening models). However, if there is consistent under- or over-prediction at a given site, alternative transfer parameters should be considered or sufficient measurements of biota conducted. It is also likely that the default CR and K_d databases included within the ERICA Tool will not be applicable to certain ecosystems (such as saltmarshes).

In situations where radioactivity concentrations are decreasing (such as decommissioning or remediation scenarios), the assumption of equilibrium between radioactivity in the medium and in the biota (the concentration ratio) may result in significant underestimation of the dose to organisms. Organisms retain some radionuclides in their bodies over timescales that can range from days to years. Alternative methods have been developed to derive biota activity concentrations under non-equilibrium conditions [for example, Thomann, 1981] although parameterisation of the models used in such assessments is often difficult, requiring resource-demanding experimental work [Vives i Battle *et al*., 2005; Wilson *et al*., 2006]. If such information or models are lacking, the use of allometric approaches (based on the observation that many metabolic parameters, including ingestion rates, radionuclide biological half-lives and so on, are proportional to a simple power function of organism mass) should be considered [see US DoE, 2002; Avila *et al.,* 2004; Brown *et al*., 2004].

Box 4.2 Approaches used to derive default CR values in the absence of empirical data

Use an available CR value for an organism of similar taxonomy within that ecosystem for the radionuclide under assessment (a preferred option) – for example, a value for marine pelagic fish was assumed to be applicable to marine benthic fish.

Use an available CR value for a similar reference organism (a preferred approach) – for example, available CR values for one vertebrate reference organism were applied to other vertebrate reference organisms.

Use CR values recommended in previous reviews or derive them from previously published reviews (a preferred approach) **-** in some instances, it was necessary to use broad reviews of stable element concentrations in media and biota to derive CR values or adopt previously recommended values without being able to go back to the source reference to confirm these.

Use specific activity models for ^{3}H and ^{14}C (a preferred approach) - specific activity models were used to derive ^{3}H and ^{14}C CR values for all reference organisms in terrestrial ecosystems (no values were based on observed data).

Use an available CR value for the given reference organism for an element of similar biogeochemistry **-** for instance, available CR values for transuranic and lanthanide elements were used if CRs were not available for another member of these series.

Use an available CR value for biogeochemically similar elements for organisms of similar taxonomy - for instance, actinide element CRs for marine reptiles were assumed to be the same value as for marine birds.

Use an available CR value for biogeochemically similar elements available for a similar reference organism - for instance, Nb CRs for marine vertebrates were derived from available Zr values.

Use allometric relationships, or other modelling approaches, to derive appropriate CRs - for instance, CRs for wild bird eggs were derived from available CRs for wild birds and published relationships between radionuclide concentrations in eggs and meat of domestic poultry.

Assume the highest available CR **(a least preferred option) - this option was used on a few occasions only to provide Po and Tc CR values for terrestrial invertebrate reference organisms and a small number of Ru and C CRs for freshwater reference organisms.**

For aquatic ecosystems use (if justified) an appropriate CR value for the reference organism in a different ecosystem *(*a least preferred option*)* - in the ERICA freshwater database, CR values for the same reference organism in the marine ecosystem (from the ERICA marine database) were assumed for a limited number of freshwater CR values.

4.4 Dosimetry

4.4.1 Basic concepts

The estimation of absorbed dose rate (µGy h^{-1}) is an essential step within the ERICA Integrated Approach, enabling media/biota activity concentrations to be interpreted in terms of potential effect. Radionuclides in the environment lead to plants and animals being exposed both externally and internally to ionising radiation. Internal exposure arises following the uptake of radionuclides by the organism via pathways such as ingestion or root uptake; it is determined by the activity concentration in an organism, the size of the organism, and the type and energy of emitted radiation. External radiation exposure depends on various factors including contamination levels in the environment, the geometric relationship between the radiation source and the organism, habitat, organism size, shielding properties of the medium and the physical properties of the radionuclides present.

The geometric relationship between radiation source and the exposed organism is an important factor in relation to the received absorbed dose rate. The intensity of the radiation field around a source decreases with distance and is influenced by the media between the radiation source and the target. The number of possible source/target configurations is infinite, therefore a set of limited and representative situations need to be considered.

The relationship between the activity concentration of an organism or media and internal or external absorbed dose rates is described by the dose conversion coefficient (DCC; µGy h^{-1} per Bq kg^{-1} fresh weight) (see Box 4.3). The method used to derive DCC values within the ERICA Tool is that described by Pröhl *et al*. (2003). A key quantity for estimating internal absorbed doses is the absorbed fraction (ϕ), defined as the fraction of energy emitted by a radiation source that is absorbed by an organism. Within the ERICA Integrated Approach, the absorbed fractions for photon and electron sources assumed to be uniformly distributed in spheres/ellipsoids immersed in infinite aquatic medium have been calculated using Monte Carlo simulation. The calculations for ERICA default geometries (see Table 2.4) cover an energy range from 10 keV to 5 MeV, a mass range from 1 mg to 1000 kg, and shapes from sphere to ellipsoids with varying degrees of non-sphericity [Ulanovsky and Pröhl, 2006]. From the computed absorbed fractions, a set of 're-scaling factors' have been derived and interpolated to allow user-defined organisms to be defined within certain limitations of size (see the Tool help for more details).

BOX 4.3 Dose conversion coefficients

In the simplest case, an organism is assumed to be in an infinite homogeneous medium of the same density and elemental composition as itself, and have radioactivity distributed homogenously throughout its body or in the medium. Under these conditions, both internal (DCC_{int}) and external (DCC_{ext}) ***dose conversion coefficients*** (defined as absorbed dose rate (µGy h^{-1}) per unit activity concentration in organism (Bq kg^{-1} fw) or medium (Bq kg^{-1} or l^{-1} media fw)) for mono-energetic radiation can be expressed as a function of the absorbed fraction:

$$DCC_{\mathrm{int}} = 5.77 \times 10^{-4} \times E \times \phi_E \qquad (4.5)$$

$$DCC_{ext} = 5.77 \times 10^{-4} \times E \times (1 - \phi_E) \qquad (4.6)$$

where:
E (MeV) is the energy of a mono-energetic source
ϕ_E is the absorbed fraction for a given energy
5.77×10^{-4} is a conversion factor

Equation 4.6 is an approximation that assumes the organism and the surrounding medium are of the same density and elemental composition.

For aquatic organisms, which are immersed in water, there is no substantial difference between the density of water and the organism and therefore the assumptions made within Equations 4.5 and 4.6 are justified. However, for terrestrial organisms the estimation of external exposure is more complex. Soil, air and organic matter differ considerably in composition and density. Consequently, radiation transport cannot be adequately taken into account by applying analytical solutions. Instead, the derivation of DCCs is based on radiation transfer simulated for mono-energetic photons using Monte Carlo techniques. Generalised, representative cases as defined by radiation energy, contaminated media and organism size were selected for detailed consideration. Exposure conditions, for which detailed calculations were not available, were then deduced by interpolation between these cases. The source–target relationships taken into account are presented in Box 4.4.

Box 4.4 Terrestrial source-target relationships

Source-target combinations for calculations of DCCs for external radiation:

- External exposure of on- and above- soil organisms to a uniformly contaminated volume with a thickness of 10 cm (µGy h^{-1} per Bq kg^{-1} soil fresh weight).
- External exposure of organisms that live in the middle of a uniformly contaminated soil layer with a thickness of 50 cm (µGy h^{-1} per Bq kg^{-1} biota fresh weight).

From the calculations for mono-energetic radiation sources, nuclide-specific dose conversion coefficients (DCCs) are derived for external and internal exposure, taking into account the type of radiation as well as energy and intensity of the emission for most radionuclides included in ICRP Publication 38 [ICRP, 1983]. Radioactive daughter nuclides are included in the calculation of the DCCs, if their half-lives are shorter than 10 days.

The simplifications made when estimating whole body DCC values in the ERICA Approach are comparable with those made in other approaches to estimating exposure of non-human biota [Beresford et al 2005]. The ERICA project has assessed the uncertainty associated with the heterogeneous distribution of some radionuclides and this is discussed in full in the Tool help. In summary, it can be concluded that: (i) for photons, the uncertainty due to a possible non-homogeneous radionuclide distribution is lower than 20-25 per cent in the considered cases; (ii) for electrons, uncertainty is negligible below a threshold energy dependent on the size of the organisms.

4.4.2 Dose rate calculation

The dose conversion coefficients can be used to estimate the unweighted absorbed dose rate from media and organism activity concentrations (see Box 4.5). However, radiation effects depend not only on unweighted absorbed dose, but also on the type of radiation. For example, for a given unweighted absorbed dose rate, α-radiation may result in a more significant effect than β- or γ-radiation. Therefore, radiation weighting factors are introduced to account for the relative biological effectiveness of the different types of radiation (see Box 4.5). Default radiation weighting factors of 10 for alpha radiation and 3 for low beta radiation are assumed within Tier 1, in line with suggested values in the FASSET project [Pröhl *et al*., 2003]. This is also consistent with the upper bound on the range of variation reported by Chambers *et al.* [2006] for α-radiation weighting factors in relation to deterministic endpoints (mainly mortality). At Tiers 2 and 3, whilst these values are provided as the defaults, they can be altered by the user.

4.5 Complex assessments – considerations for all tiers

The ERICA Tool allows assessments to be conducted for terrestrial, marine or freshwater environments. It does not address situations where an organism may inhabit more than one ecosystem (such as amphibians, sea birds or aquatic mammals), or where a radioactive release may impact upon more than one ecosystem (for example, flooding events may contaminate terrestrial ecosystems with aquatic discharge) or transitional environments (such as saltmarshes, sand dunes and other estuarine ecosystems). Similarly, the Tool does not allow for multiple input sources into an area (such as for an assessment site downstream of several facilities discharging into a river catchment).

As the ERICA Tool does not explicitly deal with these issues, it is recommended that the assessor undertake a series of linked assessments within the Tool. A key issue for this type of assessment is the need to consider whether the default ERICA data is appropriate to some of these specialised ecosystems. For example, chemical forms and contamination pathways of radionuclides within saltmarshes are likely to differ from those of other terrestrial ecosystems, affecting CR values. Below, two example scenarios illustrate how such assessments may be conducted using the Tool.

Box 4.5 Estimation of unweighted absorbed dose rates

$$\dot{D}^{b}_{\text{int}} = \sum_{i} C^{b}_{i} * DCC^{b}_{\text{int},i} \qquad (4.7)$$

Where:

$\dot{D}^{b}_{\text{int}}$ is the absorbed internal dose rate for reference organism *b*

C^{b}_{i} is the average concentration of radionuclide *i* in reference organism *b* (Bq kg^{-1} fresh weight)

$DCC^{b}_{\text{int},i}$ is the radionuclide-specific dose conversion factor (DCC) for internal exposure defined as the ratio between the average activity concentration of radionuclide *i* in the organism *b* and the dose rate to the organism (μGy h^{-1} per Bq kg^{-1} fresh weight)

$$\dot{D}^{b}_{\text{ext}} = \sum_{z} v_{z} \sum_{i} C^{\text{ref}}_{zi} * DCC^{b}_{\text{ext},zi} \qquad (4.8)$$

Where:

v_z is the occupancy factor, the fraction of time that organism *b* spends at a specified location *z* in its habitat

C_{zi}^{ref} is the average concentration of radionuclide *i* in the reference media of a given location *z* (Bq kg^{-1} fw or dw (soil or sediment) or Bq l^{-1} (water))

$DCC^{j}_{ext,zi}$ is the dose conversion factor for external exposure defined as the ratio between the average activity concentration of radionuclide *i* in the reference media corresponding to the location *z* and the dose rate to organism *b* (μGy h^{-1} per Bq unit media)

Weighted total dose rates (in μGy h^{-1}) can be calculated as:

$$DCC_{\text{int}} = wf_{\text{low}\beta} \cdot DCC_{\text{int,low}\beta} + wf_{\beta+\gamma} \cdot DCC_{\text{int},\beta+\gamma} + wf_{\alpha} \cdot DCC_{\text{int},\alpha} \qquad (4.9)$$

$$DCC_{\text{ext}} = wf_{\text{low}\beta} \cdot DCC_{\text{ext,low}\beta} + wf_{\beta+\gamma} \cdot DCC_{\text{ext},\beta+\gamma} \qquad (4.10)$$

Where:

wf are the weighting factors for various components of radiation (low β, β + γ and α)

4.5.1 Example of an assessment of a transitional environment (a saltmarsh)

For a saltmarsh, the ERICA Tool should first be run to assess dose rates to each reference organism (and assessor-specified organisms at Tiers 2 and 3) in the terrestrial environment. The Tool should then be run to assess dose rates to each organism in the marine environment. In both cases, for a retrospective assessment, where sufficient measured data are available these should be used as input into the Tool.

If, at Tier 1, the risk quotients for both assessments are predicted to be well below unity – the qualification of 'well below' having been agreed by assessor and stakeholders – then there is no further need for assessment. If there is any doubt, the assessor may want to consider the proportion of time organisms of concern spend in terrestrial and aquatic locations within the saltmarsh ecosystem, and alter the occupancy factors at Tiers 2 and 3 of the assessment accordingly. For example, if a particular organism spends 50 per cent of its time in the terrestrial environment and 50 per cent in the marine environment, all occupancy factors could be reduced by 50 per cent to reflect this.

4.5.2 Example of an assessment of multiple sources discharging into a river catchment and impacting one site downstream

For multiple sources affecting one site, the key information required is the input activity concentrations for radionuclides discharged into the river that arrive at the site of interest.

In a retrospective assessment, measurement data, if available, should be used if the assessor is satisfied that the measurements adequately represent contamination levels at the site under study. This would address the need to take into account any transport or dispersion from the points of discharge. However, it may be difficult to determine the relative contributions of different sources to the doses predicted. If an impact on non-human species is predicted as a result of a multi-source assessment, the assessor will need to determine the contributions of individual discharges to the estimated dose rate.

In a prospective assessment (or where little measured data exist), the SRS-19 models provided (at Tiers 1 and 2) can be used to determine activity concentrations reaching the site of interest; other models could be used to provide these data if available, and would be needed in Tier 3. The assessor can thus estimate dose rates to biota from each source. Estimated dose rates can be compared against the screening levels, but the assessor must remember to add up the dose rates for each organism from each source. This needs to be done outside of the assessment tool, although an alternative would be to conduct an additional assessment inputting the total amount of radioactivity received by the site of interest from all the discharges.

Prospective assessments may also need to consider exposure from historical contamination of a site. This could be considered in a similar manner to the method described above, where doses from historical contamination (from measured data) and prospective releases could be assessed separately and then summed.

5 Tier 1 – a simplified screening tier

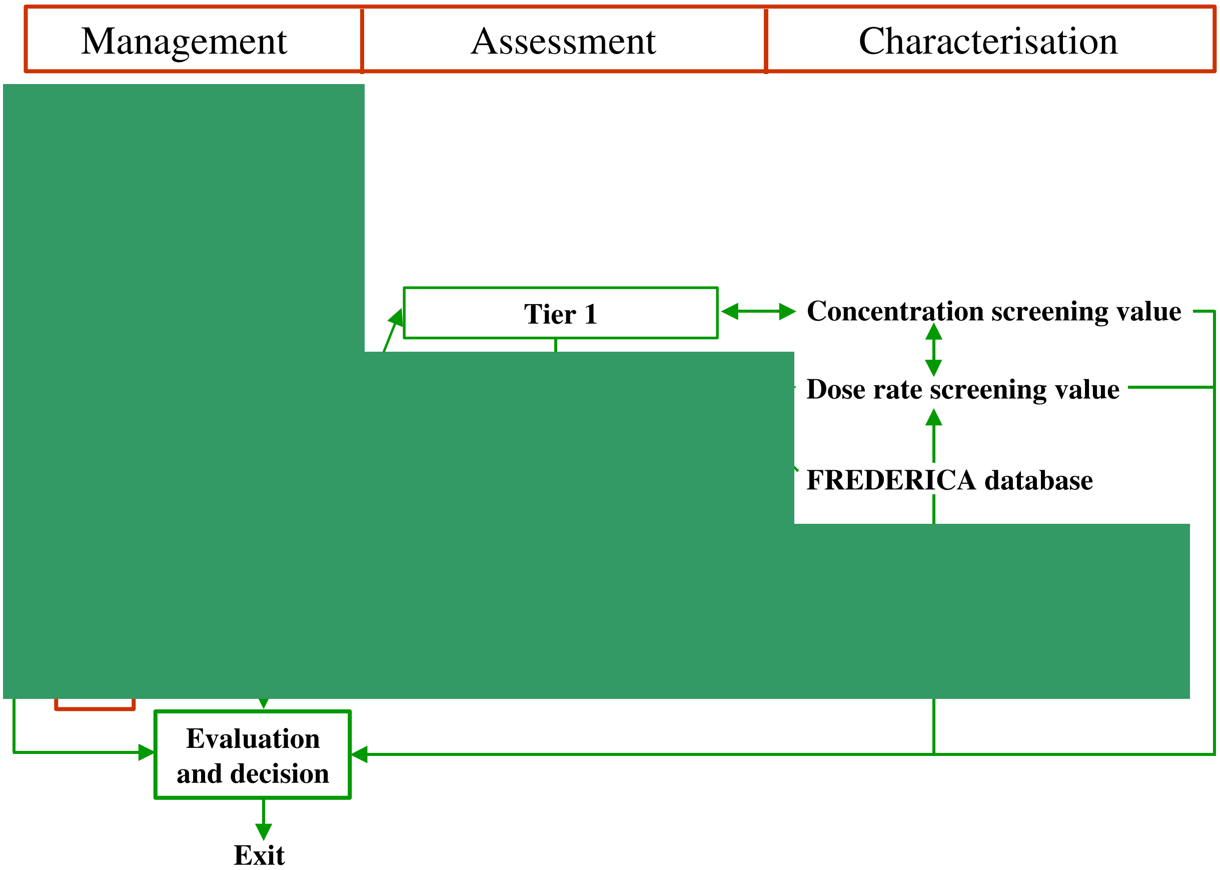


Figure 5.1: The ERICA Integrated Approach, highlighting the elements that relate to Tier 1.

5.1 Introduction

Tier 1 is designed to be relatively simple, so that non-experts can use it; it requires minimal input and is highly conservative. It is anticipated that many assessments will be screened out (that is, judged to be of negligible concern with a high degree of confidence) using this tier.

This chapter describes the main components underpinning Tier 1 and explains its results. Uncertainties associated with this tier are described within the uncertainty matrix in Annex A of this report.

5.2 The risk quotient

The risk quotient (RQ) method provides a simple means of assessing risk. Within the ERICA Integrated Approach, the risk quotient integrates exposure and effects data to determine ecological risk by calculating the quotient of estimated exposure and benchmark dose rate. The benchmark dose rate is the dose rate which is assumed to be environmentally 'safe'. The RQ is defined as:

$$RQ = \frac{predicted\ \ environmental\ dose\ rate}{benchmark\ \ dose\ rate\ assumed\ to\ be\ environmentally\ 'safe'} \qquad (5.1)$$

The ERICA Integrated Approach requires benchmark values for Tiers 1 and 2. Generally, a benchmark value designates any value that is used for the purpose of comparison. It becomes a *screening value* when it is used to screen out sites of negligible concern. For all organisms and ecosystems, ERICA has a screening incremental dose rate of **10 µGy h^{-1}** for chronic exposure to human activities that use radioactive substances and/or increase the levels of ionising radiation in the environment.

Within Tier 1, the RQ is simplified such that the screening dose rate is used to derive benchmark media activity concentrations which are compared to user input activity concentrations. The approach taken to estimating RQs in Tier 2 is described within the next chapter.

5.2.1 Deriving the ERICA Integrated Approach incremental screening dose rate

The aim of the ERICA Integrated Approach is for generic ecosystems (freshwater, marine and terrestrial) to be protected from effects on their structure and function from chronic exposure to radionuclides. The proposed 10 µGy h^{-1} screening dose rate has been derived from data on the effects of ionising radiation in non-human biota collated in the FRED effects database (see also Chapter 7). This database includes data from the original FASSET Radiation Effects Database (FRED), covering the period 1945-2001, plus data from new references up to the end of the ERICA project (early 2007). FREDERICA also contains the output from experiments conducted within the ERICA project and field data from the former Soviet Union [Sazykina et al 2003].

The 10 µGy h^{-1} incremental screening dose rate is the result of an analysis of chronic exposure data from amongst the 26,000 data entries in the original FRED database. The analysis conducted follows EC recommendations for estimating predicted no effect concentrations (PNEC) for chemicals [EC, 2003]. A three-step method was used:

- A data subset was extracted from each experiment, covering endpoints related to mortality, morbidity and reproduction.
- A systematic mathematical treatment was applied to reconstruct dose rate-effect relationships and to estimate critical toxicity endpoints. For chronic exposure, the critical toxicity endpoint is the estimated EDR_{10} (in µGy h^{-1}); that is, the effect dose rate giving rise to a 10 per cent change in observed effect.
- These estimated critical toxicity data were used to derive a predicted no effect dose rate (PNEDR) using the species sensitivity distribution method (SSD) [EC, 2003].

The SSD method was used to estimate the dose rates below which 95 per cent of species in the aquatic/terrestrial ecosystem should be protected: the HDR_5 or hazardous dose rate giving a 10 per cent effect to five per cent of species. After analysing the data for different ecosystems separately, there was no statistical justification to attempt to derive ecosystem-specific screening dose rates and all data were analysed together as a generic ecosystem. The resultant HDR_5 value was 82 µGy h^{-1} (with 95th percentile confidence intervals of 24 and 336 µGy h^{-1}). To derive the final dose rate screening (or PNEDR), a safety factor of five was applied to account for the remaining extrapolation uncertainties (such as the irradiation pathway that could lead to a dominant internal dose by α or β emitters) and the resultant number rounded down to the nearest one significant digit. This resulted in **the ERICA Integrated Approach screening dose rate for incremental exposure of 10 µGy h^{-1}**. The method used to derive this screening value is fully documented within ERICA D5, where the value is also shown to be similar to that derived using alternative methods to SSD.

At the ecosystem level, the ERICA Integrated Approach screening dose rate value lies in the dose range giving rise to minor effects [Woodhead & Zinger 2003; ERICA D5; Garnier-Laplace et al 2006]. These minor effects are not expected to be important at higher organisational levels, such as the structure and functioning of ecosystems. Furthermore, natural background dose rates may be in excess of 10 µGy h^{-1} for some organisms in some areas. The proposed screening dose rate is lower than the US Department of Energy (DoE) dose rate limit of 10 mGy d^{-1} (around 400 µGy h^{-1}) for native aquatic animals, and benchmarks of 400 and 40 µGy h^{-1} for terrestrial plants and terrestrial animals respectively (based on the intent of DoE orders as no statutory dose limits were in place as of 2006), as used in the US DoE's graded approach [US DoE, 2002].

5.2.2 The Environmental Media Concentration Limit

To simplify Tier 1, environmental activity concentrations are compared to the Environmental Media Concentration Limit (EMCL). The EMCL is derived for each radionuclide-reference organism combination by back-calculating from the proposed screening dose rate (see Box 5.1). Under the conservative assumptions used within Tier 1, only the minimum value obtained from the suite of reference organisms is used to provide the EMCL value for a given radionuclide. As a consequence, the user cannot select reference organisms within Tier 1. For the terrestrial environment, EMCL values always refer to soil activity concentrations, except for isotopes of H, C, S and P that refer to air concentrations. For aquatic systems, EMCL values are derived for both water and sediment activity concentrations. The derivation of the EMCL used within the ERICA Tool is fully described within the Tool help.

Box 5.1 Environmental Media Concentration Limit

For each radionuclide and each organism, the EMCL (in Bq l^{-1} or kg^{-1} (dry weight) or m^{-3} of medium) is defined as:

$$ECML = \frac{Screening\ dose\ rate}{F} \qquad (5.2)$$

Where:

F is the dose rate that a given organism will receive for a unit concentration of a given radionuclide in an environmental medium (µGy h^{-1} per Bq l^{-1} or kg^{-1} (dry weight) or m^{-3} of medium).

The value of F depends upon the reference organism type, which is defined by specific DCC values, position(s) within habitat and the radionuclide-specific DCC, CR and K_d values. Derivation of the F value is summarised below (and explained in full within the Tool help). An example equation to estimate F is shown in Figure 5.3 – equations for every reference organism can be found in the Tool help.

In deriving EMCLs, the default location within the habitat is based on the configuration that will result in maximum exposure of a given organism (see Figure 5.2 for the default habitats considered). For example, for the terrestrial soil invertebrate, the assumption is made that the organism spends 100 per cent of its time underground (when in reality it will also spend time on the soil surface).

To ensure defensible and conservative ECML values in this initial screening tier, the F values are calculated for each radionuclide-reference organism combination using all available information, including statistical information relating to CR and K_d by probabilistic methods. Data availability varies and can be summarised as follows:

- Well-defined datasets with arithmetic mean, standard deviations and (assumed) log-normal probability distribution functions. This is the case for some reference organism-radionuclide CR values.

- Poorly defined datasets with expected values only. This is the case for most K_d and many CR values. In this case, an exponential distribution is assumed.
- Precisely calculated values for which the uncertainty is assumed to be zero, namely the DCC values.

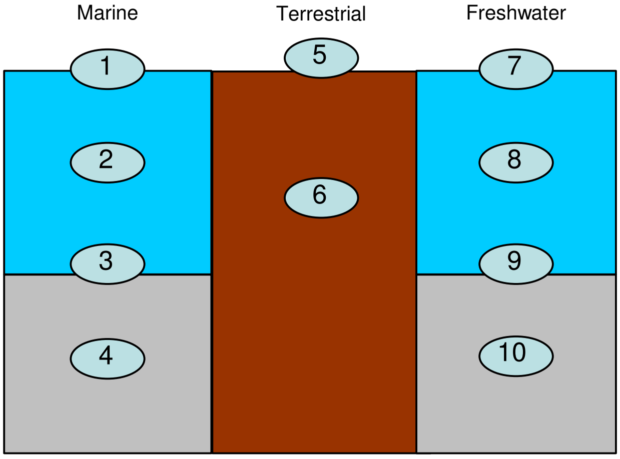


Figure 5.2: The ten habitats in the ERICA Integrated Approach.

The output of the probabilistic (Monte Carlo) simulation is a probability distribution for the F value which enables the calculation of any percentile of the ECML. The ERICA Tool uses conservative EMCL values, set at five per cent. An illustrative example of the probabilistic derivation of an F value is provided in Figure 5.3.

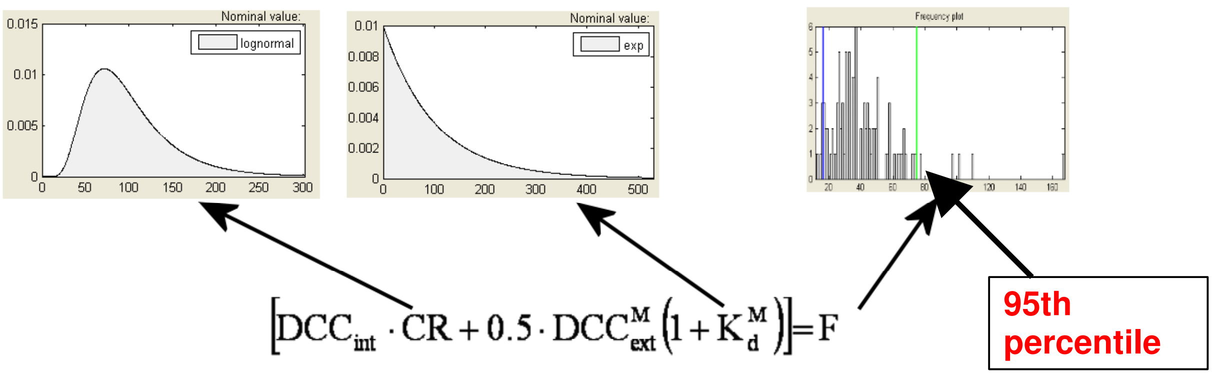


Figure 5.3. Example of the use of probabilistic calculations in the derivation of EMCLs. The equation shown here is for benthic organisms living at the water-sediment interface (habitats 3 and 9 in Figure 5.2).

In addition to having EMCL values calculated for the ERICA screening dose rate, the ERICA Tool allows the user to select two alternatives:

- Values of 40 µGy h^{-1} for terrestrial animals and 400 µGy h^{-1} for terrestrial plants and all aquatic species. It has previously been suggested that below these values of chronic exposure, no measurable population effects would occur [IAEA, 1992; UNSCEAR, 1996]. As already noted, these values also correspond to those used in the US DoE's graded approach [US DoE, 2002].

- User-defined value that enables the user to put in any number they consider justifiable. If this option is selected, the resultant RQ values are derived by scaling those for the ERICA screening dose rate of 10 µGy h^{-1} by the difference between the user input dose rate and the ERICA screening dose rate; for example, if the user defines a screening dose rate of 20 µGy h^{-1}, the tool simply divides the RQs by a factor of two.

5.3 Screening at Tier 1

At Tier 1, the assessor is prompted to enter the measured or modelled radionuclide activity concentrations for their site. The activity concentrations entered should be either the **maximum** values available or other justifiable values (for example, at the edge of the mixing zone rather than the end of a discharge pipe). The ERICA Tool compares the measured or modelled radionuclide activity concentrations with the EMCLs for the most limiting reference organism by calculating RQs for each radionuclide (see Box 5.2). The ECMLs are then summed to provide an overall RQ for the ecosystem being assessed.

Box 5.2 Calculation of RQ in Tier 1

$$RQ = \frac{M}{EMCL} \quad (5.4)$$

Where:RQ = Risk quotient for a given radionuclide;

M = Estimated or measured activity concentration for a given radionuclide in Bq l^{-1} for water, Bq kg^{-1} dry wt for soil/sediment or Bq m^{-3} for isotopes of C, H, P and S within the terrestrial environment;

EMCL = Environmental media concentration limit for a given radionuclide **for the most limiting reference organism** (same units as medium).

As the ERICA Tool only contains the EMCL value for the limiting reference organism, the sum of RQs may be derived from different reference organisms (see Table 5.1). This will result in the overall RQ being in excess of the total RQ for any one species.

Table 5.1. Approach used for summing RQs at Tier 1, where the limiting RQ is identified in red for each radionuclide. The overall RQ, which is used to decide the assessment outcome, is the sum of the three limiting RQ values. As the ERICA Tool only contains EMCL values for the limiting reference organism for each radionuclide, only the limiting RQs are reported (in this example, only the red values are reported by the Tool).

	RQs			**∑RQ**
	Cs-137	**Po-210**	**Ra-226**	
Zooplankton	0.10	0.2	0.35	
Bivalve mollusc	0.12	0.36	0.02	
Polychaete worm	0.41	0.01	0.02	
Vascular plant	0.14	0.03	0.05	
				1.12

5.3.1 Interpreting the Tier 1 RQ value

The outputs of a Tier 1 assessment are the RQ values for the limiting reference organism and the sum of the individual radionuclide RQs. These enable the user to decide whether to conclude the assessment or conduct a more detailed one, as follows:

- ***If the sum of the RQs is less than one*** there is a very low probability that the absorbed dose rate to any organism exceeds the screening dose rate, and the situation may be considered to be of negligible radiological concern. The ERICA Tool will recommend the user to conclude the assessment.
- ***If the sum of the RQs is greater than one*** the assessment dose rate to one or more organisms may exceed the screening dose rate, and there is insufficient evidence to conclude that the situation is of negligible radiological concern. The ERICA Tool will recommend the user to continue the assessment using Tier 2.

The default EMCLs used at Tier 1 can be considered conservative estimates, because a screening dose rate and the 95th percentile of the F value have been used in its derivation as described above. Furthermore, the lowest radionuclide-specific EMCL value from across the whole suite of ERICA reference organisms, which will result in the highest RQ value, is selected for each radionuclide. This means that when summing RQs for all radionuclides present in a given situation, the limiting or most ‘affected’ reference organism may not be the same for each radionuclide (see Figure 5.3). All of these considerations, together with the recommendation that the maximum measured or predicted media concentrations are generally used within Tier 1, allow for a very high degree of confidence in concluding that environmental effects are of negligible concern when being able to exit the assessment at Tier 1 (if the sum of RQs is less than one). Although the approach might be deemed overly conservative, it has nevertheless been selected because it:

- is reasonably consistent with other assessment approaches currently available (such as US DoE [2002]);
- reflects the uncertainty associated with the severe lack of data for some radionuclide-reference organism combinations;
- is simple and resource effective and does not require an expert user.

6 Tier 2 assessments

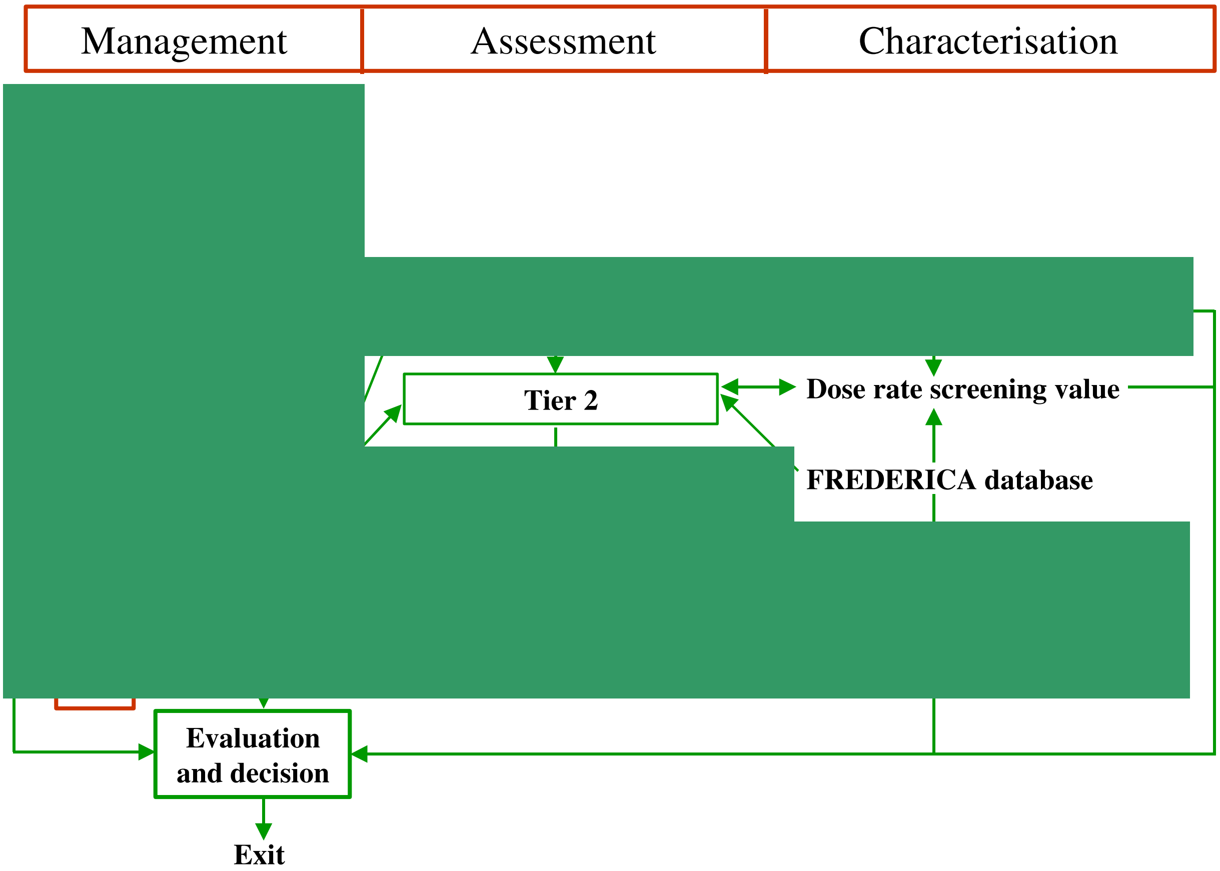


Figure 6.1: The ERICA Integrated Approach, highlighting the elements that relate to Tier 2.

6.1 Introduction

Tier 2 of the ERICA Tool is also a screening tier, but enables a more informed assessment and hence does not need to be as conservative in its approach as Tier 1. The objective of Tier 2 is to identify situations where there is a very low probability, for example a few percent, that the dose to any selected organism exceeds the adopted screening dose rate.

Within this tier the user can:

- obtain RQ values for the organisms of interest within their assessment (compared to the combined ecosystem worst case RQ output in Tier 1);
- define their own organism to represent species of interest;
- add additional radionuclides;
- provide their own CR and K_d values;
- put their results into context with effects data and typical background exposure rates.

Some of these additional functions may mean that some users start their assessment at Tier 2 (for example, if a radionuclide not considered within the ERICA default list needs to be assessed). The user-defined organism, addition of radionuclides and editing of CR and K_d values functions are all discussed in the Tool help. Further background is also provided in Chapter 4. This chapter concentrates on describing the Tier 2 RQ value and interpretation of results. Uncertainties associated with this tier are described within the uncertainty matrix in Annex A of this report.

Users who have progressed to Tier 2 on the basis of a Tier 1 assessment should review and refine their problem formulation as the first step of the Tier 2 assessment (see Chapter 2).

6.2 The Tier 2 Risk Quotient

In Tier 2, the ERICA screening dose rate of 10 µGy h^{-1} (see Section 5.2.1) is compared directly to the total estimated whole body absorbed dose rate for each individual organism:

$$RQ = \frac{\textit{Whole body absorbed dose rate}}{\textit{Screening dose rate}} \tag{6.1}$$

The approach differs from that in Tier 1 in that, in effect, the RQ for a given organism equals the sum of the radionuclide-specific RQs for that organism, whereas in Tier 1 the overall RQ is the sum of the RQs for the most limiting reference organism for each radionuclide. The Tier 2 approach is less conservative than the approach used at Tier 1 (compare Tables 5.1 and 6.1) but justified because, at Tier 2, the assessor is more directly involved with selecting the reference organisms to include in their assessment.

Table 6.1: Representation of the Tier 2 RQ values.

	RQs			∑RQ
	Cs-137	**Po-210**	**Ra-226**	
Zooplankton	0.10	0.20	0.35	0.65
Bivalve mollusc	0.12	0.36	0.02	0.50
Polychaete worm	0.41	0.01	0.02	0.44
Vascular plant	0.14	0.03	0.05	0.22

In addition to media activity concentrations, at Tier 2 the user can input whole body activity concentrations for biota if they are available. Users may find the data manipulations used by ERICA to derive the CR database useful if only organism-specific activity concentrations are available – see the Tool help. In Tier 2, it is recommended that the user inputs best estimate activity concentrations for media and organisms (if available).

As with Tier 1, the user can chose alternative screening dose rates, being able to either: (i) select 40 µGy h^{-1} for terrestrial animals or 400 µGy h^{-1} for terrestrial plants and all aquatic species; or (ii) input a user defined value.

6.2.1 Uncertainty factors

As the aim of Tier 2 is to identify situations where there is a very low probability that the dose to any selected organism exceeds the adopted screening dose rate, the screening test is implemented as follows:

1. An **expected value** of the RQ is calculated using expected (or best estimate) values for the input data and the parameters;
2. The 95th or 99th percentile of the RQ is estimated by multiplying the expected value of the RQ by an uncertainty factor (UF) of 3 or 5 respectively (reported as the **conservative RQ** in the ERICA Tool). The uncertainty factor is defined as the ratio between the 95th or 99th percentile and the expected value of the probability distribution of the dose rate (and RQ). To estimate UFs, it is

assumed that the dose rate and RQ follow exponential distributions with means equal to the estimated expected values. In this case, the UFs corresponding to the 95th and 99th percentiles are equal to three and five respectively (the assessor can select which to use). This approach is explained and justified within the Tool's help.

The UFs also maintain conservatism between Tiers 1 and 2. With the same input values and default settings, the results for Tiers 1 and 2 should approximate to one another because the user will not have thought in more detail about the problem they are facing and may not have amended the problem formulation accordingly. The use of the UF value of three (95th percentile) results in conservative RQ estimates compatible with the results of Tier 1 (the EMCL being derived from the 95th percentile F value).

In addition to the UF values of three and five, the user can input their own number although this will need to be derived and justified (see Tool help).

6.3 Interpreting the Tier 2 Risk Quotient

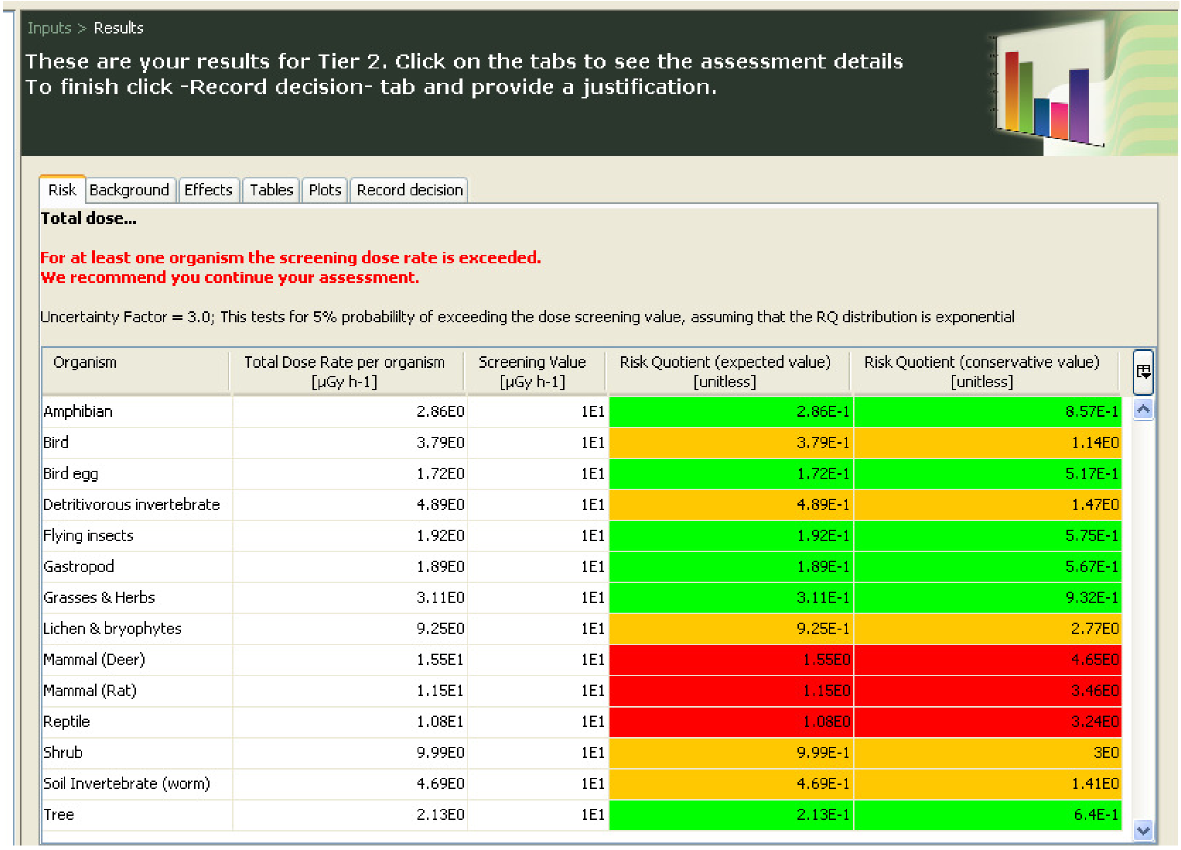
As described above, two RQs are reported in Tier 2 for every organism selected in the assessment: the best estimate RQ and the conservative RQ (see Table 6.1). Used in combination with other information provided within the Tier 2 assessment screens (as discussed below), these enable the assessor to make a decision on whether to conclude or continue the assessment:

- ***If the conservative RQs are below one*** for all organisms, then the assessment has not exceeded the screening level at Tier 2. If a UF of three or five (or higher) is used, there is low probability that the estimated dose rate to any organism exceeds the screening dose rate, but the resulting risk to non-human biota can be considered to be trivial (on the basis of the analyses of effects data conducted to derive the ERICA screening dose rate, as discussed in Section 5.2.1). The ERICA Tool will recommend the user to exit the assessment.

- ***If the conservative RQ is above one*** for any organism, then the probability of the assessment exceeding the screening value at Tier 2 is above that selected (as defined by the UF). However, if the expected value RQ is below one there is a possibility that (i) further work to reduce uncertainties in the estimate may result in the conservative RQ falling below unity or (ii) putting the results into context with the available effects data or background dose rates may lead to the assessor (and stakeholders) agreeing that the likely risk is minimal. The ERICA Tool will recommend that the assessment and results are reviewed.

- ***If the expected value RQ (and by implication the conservative RQ) is above one*** for any organism, then the assessment has exceeded the screening value at Tier 2 and the ERICA Tool will recommended that further assessment be conducted.

In those cases where is it recommended that the assessment be continued or that the assessment and results are reviewed, this does not necessarily mean an automatic progression to Tier 3. For instance, it may be possible to refine the input data or Tool parameters (for example, obtain CR vales applicable to the site) if justifiable and to then rerun the assessment at Tier 2. In instances where the conservative RQ is above one whilst the best estimate RQ is below one, interpretation of the results may lead to a decision that the assessment can be justifiable exited. These issues are expanded upon below.



Organism	Total Dose Rate per organism [µGy h-1]	Screening Value [µGy h-1]	Risk Quotient (expected value) [unitless]	Risk Quotient (conservative value) [unitless]
Amphibian	2.86E0	1E1	2.86E-1	8.57E-1
Bird	3.79E0	1E1	3.79E-1	1.14E0
Bird egg	1.72E0	1E1	1.72E-1	5.17E-1
Detritivorous invertebrate	4.89E0	1E1	4.89E-1	1.47E0
Flying insects	1.92E0	1E1	1.92E-1	5.75E-1
Gastropod	1.89E0	1E1	1.89E-1	5.67E-1
Grasses & Herbs	3.11E0	1E1	3.11E-1	9.32E-1
Lichen & bryophytes	9.25E0	1E1	9.25E-1	2.77E0
Mammal (Deer)	1.55E1	1E1	1.55E0	4.65E0
Mammal (Rat)	1.15E1	1E1	1.15E0	3.46E0
Reptile	1.08E1	1E1	1.08E0	3.24E0
Shrub	9.99E0	1E1	9.99E-1	3E0
Soil Invertebrate (worm)	4.69E0	1E1	4.69E-1	1.41E0
Tree	2.13E0	1E1	2.13E-1	6.4E-1

Figure 6.2: Presentation of RQ values in Tier 2.

6.3.1 Effects data

Predicted dose rates can be compared with dose rates known to cause biological effects in non-human species. For convenience, in Tier 2 the available data within the FREDERICA database (see Section 7.3) have been summarised in look-up tables based on 16 wildlife groups into which each reference organism has been categorised (Table 6.2). Users need to select a suitable wildlife group for their own defined organisms. An example of a look-up table is given in Figure 6.3. For each entry, the effect is categorised as: no effect, minor effect, moderate effect, major effect or severe effect).

The look-up tables enable the assessor to put their estimated dose rates into context with biological effects on the organism.

If there are no effects data for a specific wildlife group close to the estimated dose rate, options to progress the assessment (if either Tier 2 RQ is greater than one) could include: (i) accessing the FREDERICA database which may contain more recent data (see Section 7.3); (ii) conducting effects experiments for the organism. Either of these options could lead to a justifiable reassessment at Tier 2 rather than the need to progress to Tier 3. If the effects data for a given wildlife group are sufficient and demonstrate insignificant effects at the estimated dose rate then the assessment could be justifiably exited.

Table 6.2: Wildlife groups and their associated reference organisms used in the effects look-up tables at Tier 2.

Wildlife Group	Associated reference organism(s)
Amphibian	Amphibian
Aquatic invertebrate	Insect larvae, Polychaete worm
Aquatic plant	Macroalgae, Phytoplankton, Vascular plant
Bird	Bird, Bird egg, Wading bird
Crustacean	Crustacean
Fish	Benthic fish, Pelagic fish
Insect	Flying insect
Mammal	Mammal
Mollusc	Bivalve mollusc, Gastropod
Moss and Lichen	Lichen and Bryophytes
Plant	Grasses and Herbs, Shrub, Tree
Reptile	Reptile
Soil fauna	Soil invertebrate (worm), Detritivorous invertebrate
Zooplankton	Zooplankton

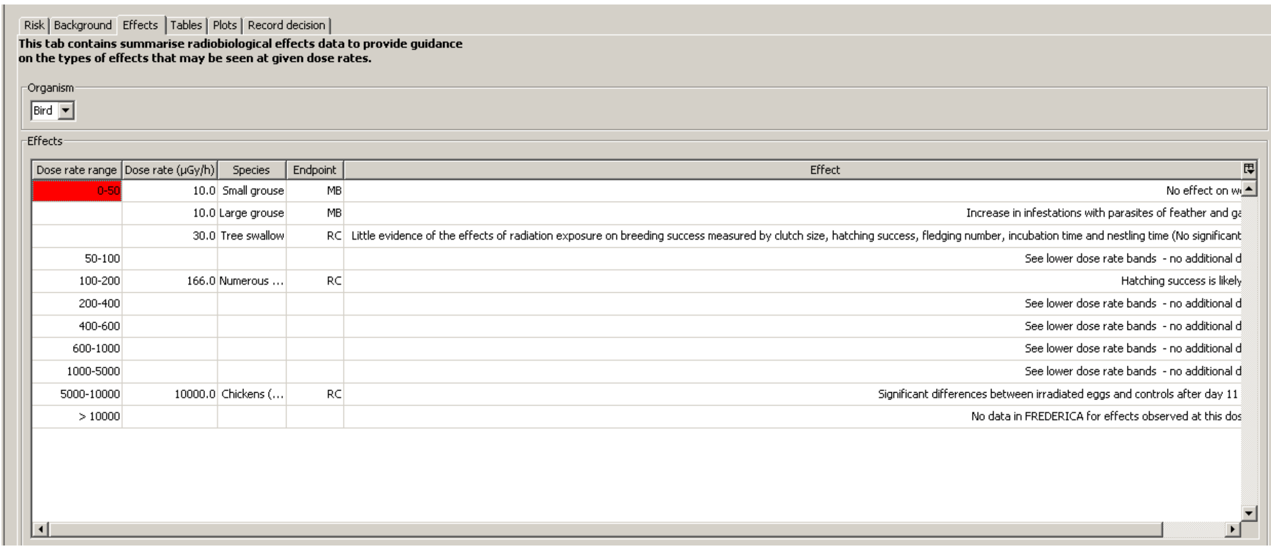


Figure 6.3: Tier 2 biological effects look-up table for birds.

6.3.2 Natural background exposure

Tier 2 also provides ranges in background exposure rates due to naturally occurring radionuclides. As specified within Chapter 1, the ERICA Integrated Approach should be used to assess incremental doses from human activities only. If dose rates estimated within Tier 2 result in RQ values in excess of one, but are within or close to natural background exposure rates, the user could conclude that there is negligible cause for concern. If activity concentrations of naturally occurring radionuclides are available for the assessment site, the assessor could estimate site-specific absorbed dose rates for comparison to dose rates from exposure to radionuclides from anthropogenic sources. It is possible that within normal ranges of activity concentrations of naturally occurring radionuclides, the Tool will estimate dose rates for some organisms in excess of 10 µGy h^{-1} (which is compatible with the background exposure rates in the Tool summary table).

For sites being assessed for TeNORM contamination, the dose rates estimated will include a contribution from background levels of the radionuclides of interest. In this instance, the total dose rates should be compared to the summarised background dose rate provided within Tier 2, to determine if the incremental dose is likely to be of concern.

7 Tier 3 Assessments

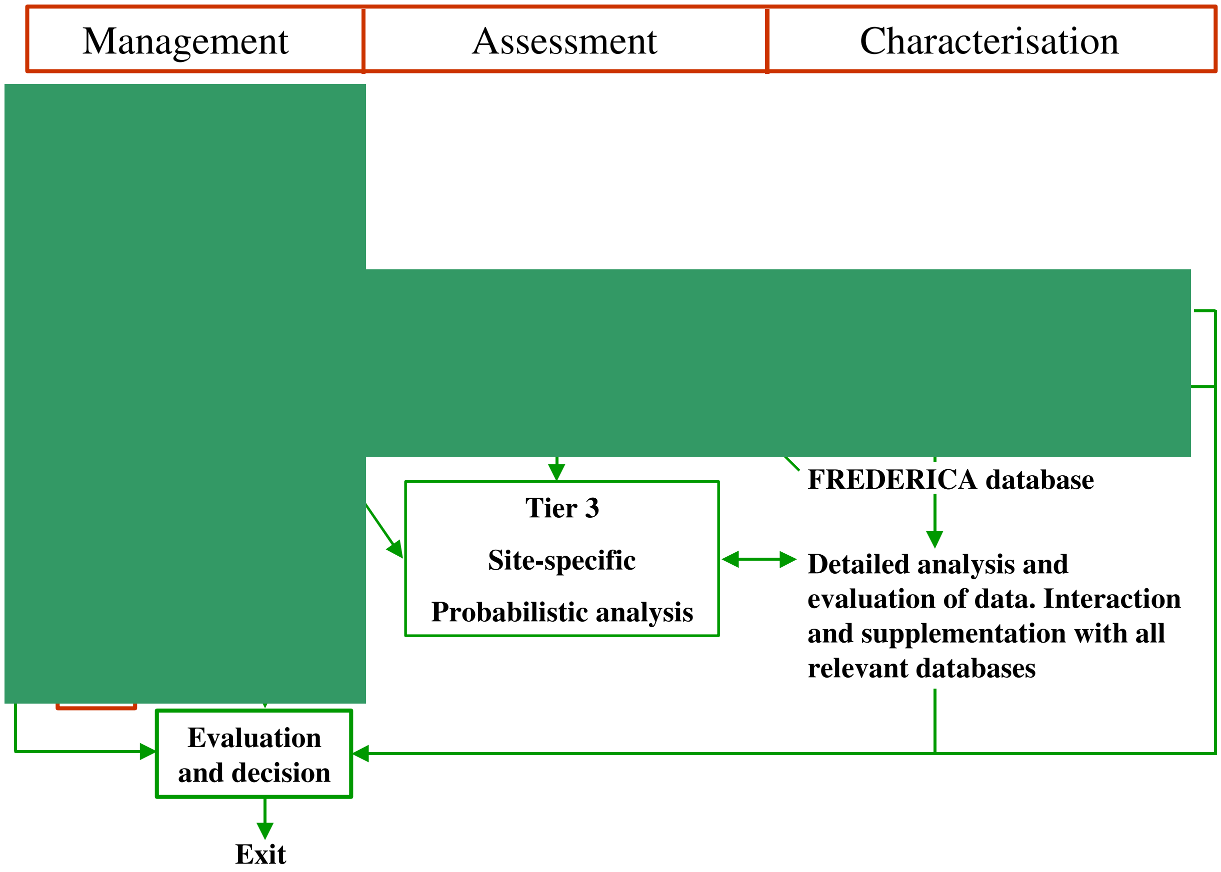


Figure 7.1: The ERICA Integrated Approach, highlighting the elements that relate to Tier 3.

Those situations that give rise to a Tier 3 assessment are likely to be complex and unique, and it is therefore not possible to provide highly specific guidance on how the Tier 3 assessment should be conducted. Furthermore, a Tier 3 assessment does not provide a simple yes/no answer, nor is the ERICA derived screening incremental dose rate of 10 µGy h^{-1} appropriate with respect to the assessment endpoint. The requirement to consider aspects such as the biological effects data contained within the FREDERICA database, or to undertake ecological survey work, is not straightforward and requires an experienced, knowledgeable assessor or consultation with an expert. The following sections explain how the ERICA Tool and the FREDERICA database can be used within a Tier 3 assessment.

7.1 Introduction

Within the ERICA Integrated Approach, environmental risk is characterised in a tier-specific manner and the previous two chapters have described how Tiers 1 and 2 can be used to estimate risk using a *deterministic* approach. Both Tiers 1 and 2 are valuable for screening out situations where the environmental risk from ionising radiation is such that the situation can be exempt from further action.

Where it is not possible to state with confidence that the risk is below concern at Tiers 1 and/or 2, it is recommended that the assessment proceed to Tier 3. The assessor may choose to refine and repeat earlier tiers, depending on the case under evaluation, before moving to Tier 3. A Tier 3 assessment differs from the previous tiers in a number of respects, as outlined below:

- Tier 3 allows the assessor to carry out a detailed assessment of a given situation if there have been other drivers that have prevented the assessor from using Tier 1 or 2; for example, the requirements of stakeholders or legislation may have stated that a full detailed assessment be conducted.
- Tier 3 allows the assessor to refine the problem formulation (if Tier 1 or 2 have been used previously), although the SRS-19 models are no longer available because these are designed to be conservative; therefore, the assessor should use their own dispersion model.
- Tier 3 allows the assessor to input probability distribution functions for the different input data and parameters and thus allows the assessment to be run probabilistically. This provides the assessor with an estimate of the probability of exposure at a given dose rate.
- Tier 3 provides information on the uncertainties associated with the exposure assessment, by performing a sensitivity analysis. This is most useful when trying to understand the uncertainties associated with the derivation of total dose rate estimates, and can allow the assessor to target the need for additional work in a cost effective manner.
- Tier 3 generates information on the internal, external and total dose rate received by each organism and this can be compared directly with current data on the effects of ionising radiation on the species of interest. Whilst Tier 2 provides effects look-up tables, these have been created in January 2007 within the ERICA project whereas the FREDERICA database will be updated, through a quality controlled procedure, and may therefore contain information on species of relevance to the assessment.
- Tier 3 does not use a screening dose rate. Instead, Tier 3 provides access to the compilation of scientific literature on the effects of ionising radiation that is collated within the FREDERICA database. Instead of using a screening dose rate, the assessor is able to look at the available data and, with experience and/or expert support, make judgements on the likely consequences of the predicted dose rates for the species of interest. In addition, the assessor may wish to derive his or her own benchmark from the effects data. This will determine the likely magnitude of the adverse effects likely to occur in a population or environmental compartment.
- Tier 3 then provides a mechanism for determining the likely magnitude of, and probability of, exposure that the assessor can use, possibly in conjunction with stakeholders, to determine whether:
    - the risk is below concern;
    - there is insufficient confidence that the risk is below concern;
    - the risk is of concern.

Tier 3 is a probabilistic risk assessment in which uncertainties associated with the results may be determined using sensitivity analysis. It allows the assessor to access a compilation of up-to-date scientific literature (which may not be available at Tier 2) on the biological effects of exposure to ionising radiation in a number of different species. The assessor can then estimate the probability (or incidence) and magnitude (or severity) of the environmental effects likely to occur and, by discussion and agreement with stakeholders, to determine the acceptability of the risk to non-human species. The following sections describe how the ERICA Integrated Approach has incorporated these points.

7.2 Problem formulation for Tier 3

If the assessor is starting at Tier 3, then the advice provided previously (Chapter 2) should be reviewed and used in formulating the problem being assessed. The points made below regarding the revision of the problem formulation for Tier 3 should also be addressed.

If a Tier 1 and/or Tier 2 assessment has already been conducted, it is important to revisit and revise the problem formulation and the conceptual models, particularly with regard to the use of probability distribution functions on the input values (Section 7.2.1)

The refinements made in the Tier 3 risk assessment are anticipated to be driven primarily through the use of revised exposure estimates (by the use of site-specific exposure models and distributions of input data and parameter values instead of single values). Refinement of the effects analysis will probably be needed to increase its relevance with regard to problem formulation, especially by introducing ecological realism; this is covered in Section 7.3.

A full site-specific assessment may require the gathering of additional data. Rather than relying on a single approach, a battery of tests, modelling and/or field observations can be used to estimate risk. This may include ecological surveying, environmental monitoring and other work, depending on the revised problem formulation and the endpoints of interest. Obviously, there is a difference between prospective and retrospective assessments in the availability of data, and hence the lines of evidence. In the retrospective assessment, monitoring and field data are often available and can be supplemented with additional sampling as the assessment moves through tiers. Furthermore it may, for example, be possible to perform toxicity testing on contaminated media, or measure biomarkers and other effects directly in exposed populations. With prospective assessments, field data are usually unavailable or very limited and there is a reliance on modelling approaches and standard toxicity data to predict environmental exposure and effects. In cases where a practice is granted based on a prospective assessment, there may be a requirement to reassess data after a certain time to compare model outcomes with actual measured data.

The assessor, possibly with stakeholders, might predefine the assessment endpoint in terms of an acceptable dose rate (not the same as a screening dose rate) against which dose rate estimates from the ERICA Tool can be compared. Further information on how an acceptable dose rate might be defined is given in Section 7.3.

Appendix 2 describes other aspects that the assessor may wish to consider.

7.2.1 Dealing with uncertainty

Uncertainty in the results of an exposure assessment can arise from a number of sources, including:

- conceptual uncertainties in the models applied;
- uncertainty in the values of the model parameters;
- uncertainties in the empirical data due to natural variability;
- measurement errors;
- biases in the sampling.

The sources of uncertainty can be broadly categorised as follows:

- *Scenario uncertainty* refers to uncertainty related to the current, historic (for retrospective assessments) and future (for prospective assessments) situations and how this might influence the outcome of the assessment. This type of uncertainty is usually dealt with by considering several alternative scenarios. Performing several assessments for a given case can do this. However, the Tool does not support aggregation of a number of assessments.
- *Model uncertainty* arises from imperfect knowledge about ecological processes, which leads to imperfect mathematical models, which are often over-simplified. Uncertainty of default parameter values also falls into this category. This type of uncertainty is usually assessed by performing inter-comparisons between alternative models and between model predictions and empirical

observations. The ERICA Tool is being used in the IAEA Environmental Modelling for Radiation Safety (EMRAS) inter-comparison programme.

The assessor can consider the uncertainties associated with exposure parameters, such as distribution coefficients, concentration ratios and radiation weighting factors, and input data such as activity concentrations in soil, water, sediments and the organisms. However, uncertainties related to the effects analysis must be dealt with outside the Tool. Whilst there are a number of different methods for characterising uncertainty documented in the literature (such as IAEA [1989]; Morgan and Henrion [1990]), the ERICA Tool can quantitatively assess some of the modelling uncertainties by using probabilistic and sensitivity analyses.

7.2.2 Input data for Tier 3 – probability distribution functions (pdf)

Within Tier 3, the ERICA Tool supports the entry of single values or a probability distribution function (pdf) for each user-defined input parameter except soil/sediment dry weight and occupancy factors. However, there are no pdfs for the DCCs.

The ERICA Tool supports the most common pdf types, that is, uniform, loguniform, exponential, normal, lognormal, triangular and logtriangular. The properties of these distribution types are well documented in the literature (see, for example, IAEA [1989] and Evans *et al.* [2000]). Table 7.1 provides information on the parameters required by the supported distribution types. All parameters refer to untransformed data. For example, for the lognormal distribution the mean and the standard deviation of the sample data, without taking logarithms, should be used.

Table 7.1: Distribution types supported by the ERICA Tool and required parameters.

Distribution type	Distribution parameters
Uniform	Minimum, maximum
Loguniform	Minimum, maximum
Exponential	Arithmetic mean
Triangular	Mode, minimum, maximum
Logtriangular	Mode, minimum, maximum
Normal	Arithmetic mean, standard deviation
Lognormal	Arithmetic mean, standard deviation

There are a number of ways of assigning a probability distribution depending upon the availability and quality of data for example:

- Distribution fitting [Taylor, 1993]
- Maximum entropy method [Herr, 1987]
- Bayesian inference [Gelman et al., 2003]
- Expert elicitation [Hofer, 1986].

The probability distribution type should be selected on a case-by-case basis using one or more of these methods. However, experience has shown that the uncertainty of radioecological data, such as concentration ratios (CRs) and distribution coefficients (K_ds), are often well fitted by lognormal distributions. Several explanations for this have been given [for example, see Aitchison and Brown, 1957; Crow and Shimizu, 1988]. One possible explanation is that the values of the radioecological parameters are the result of multiplication of many factors and this should lead to lognormal distributions. For this reason, a pdf has been defined for each entry in the default CR and K_d databases within the ERICA Tool using the following simple rules:

- where a standard deviation could be determined from the raw data used to derive a particular parameter (for example for a CR), a lognormal distribution was applied;
- for all other cases, an exponential distribution was applied.

Assessors can therefore use the default probability distributions for each parameter in the ERICA Tool or they can define their own pdf for each parameter (or a combination of both), depending upon the availability and quality of the data. Assessors are advised to obtain expert help if needed to assign pdfs to the input values.

7.2.3 Propagating the uncertainties through the models

To estimate the uncertainty of the endpoints of the exposure assessment, uncertainties in the inputs and parameters must be propagated though the model. When analytical methods cannot be applied, the uncertainties can be propagated using the Monte Carlo analysis, which is the approach used in the Tool. The bases of the Monte Carlo method are straightforward (see Vose [1996]): point estimates in a model equation are replaced with probability distributions, samples are randomly taken from each distribution, and the results are combined, usually in the form of a probability density function or cumulative distribution. This process is illustrated in Figure 7.2 for the case of a simple model with one input, one parameter and one endpoint.

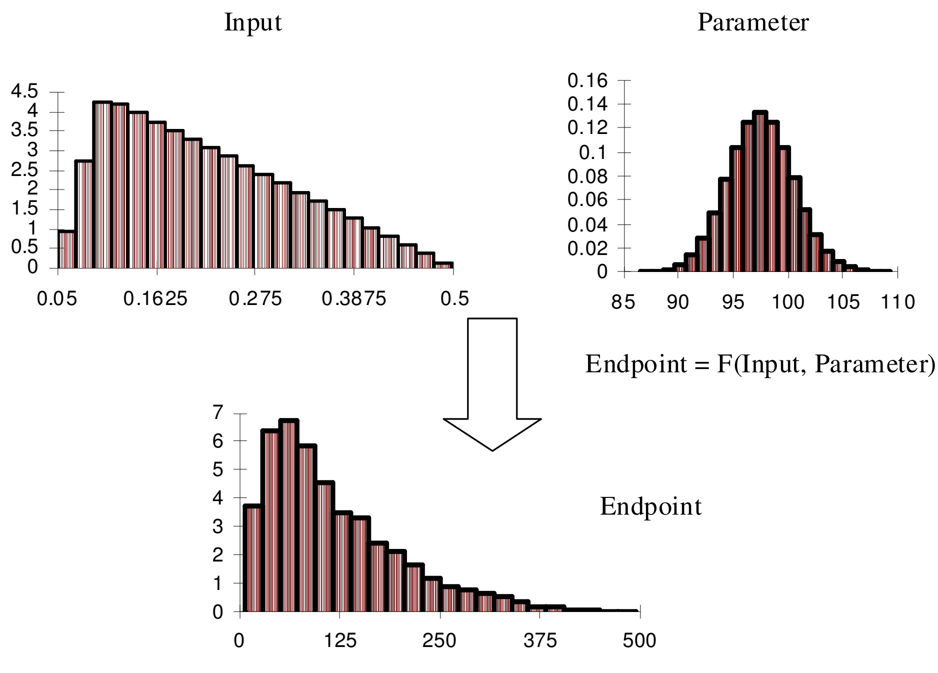


Figure 7.2: In the ERICA Tool, Monte Carlo probabilistic simulations are used for propagating uncertainties in the inputs and parameters through the model. As a result, a probability distribution of the endpoints is obtained, which can be used to quantify uncertainties in the estimations. In this example, the endpoint is calculated with a function F (the model) of one input and one parameter.

7.2.4 Sensitivity Analysis

Sensitivity analysis is used to identify the relative contribution of uncertainty associated with each input and parameter value to the endpoint of interest. There are several sensitivity analysis methods available [Saltelli *et al.,* 2004], but the choice of method depends on factors such as computing power and time needed, the number of uncertain parameters and the type of dependency between the inputs/parameters and the simulation endpoints of interest. For linear dependencies such as those found within the ERICA Tool, simple methods based on correlations are sufficient.

Within the ERICA Tool, sensitivity analysis is based on the correlation between the inputs/parameters and the endpoint. Two correlation coefficients are computed: the Pearson Correlation Coefficient (CC) and the Spearman Rank Correlation Coefficient (SRCC). Further guidance on the application of these analytical methods is provided in the help of the Tool.

The results of the sensitivity analysis are presented as a tornado plot, shown in Figure 7.3. These are simple bar graphs where the sensitivity statistics – the CC or the SRCC – are visualised vertically in order of descending absolute value. The longer the bar, the larger the effect of the parameter on the endpoint. Parameters that have positive values of sensitivity measures have a positive effect on the endpoint, while ones with negative values have a negative effect.

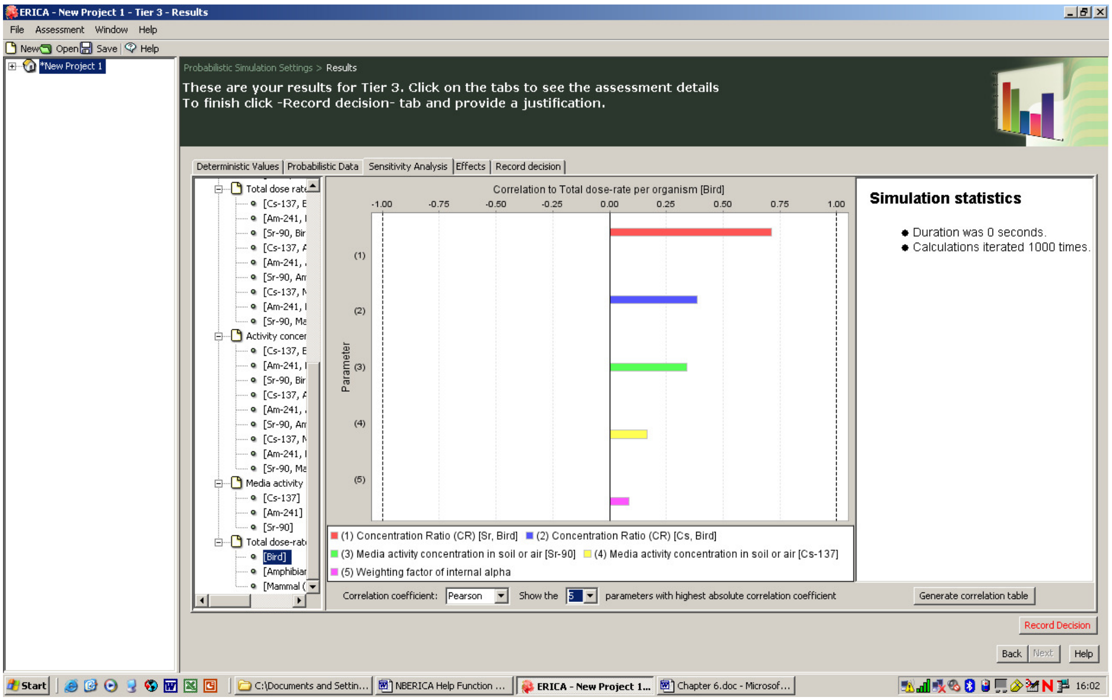


Figure 7.3: Illustrative example of a tornado plot for total dose rate to the bird reference organism. The longer the bar, the bigger the effect of the parameter on the endpoint. In this example, the parameters visible all have a positive effect on the endpoint.

7.2.5 Presentation of the results of the probabilistic assessment

Several methods are available in the ERICA Tool to construct the frequency histograms. The Tool provides several statistics for each endpoint, such as the mean, the median and the standard deviation. The Tool also allows the assessor to find the endpoint value corresponding to any given percentile and the percentile corresponding to any given endpoint value. The later functionality can be used, for example, to estimate the probability that the calculated dose rates fall above or below a benchmark value, or between two benchmark values and so on.

7.3 Biological effects and their relationships to dose rates

7.3.1 FREDERICA

Like Tier 2, Tier 3 generates information on dose rates and these can be used to interpret the available information on dose-effect and dose-response relationships. As briefly described in Chapters 4 and 5, the primary source of information to analyse biological effects in relation to dose rate within the ERICA Integrated Approach is the FREDERICA database (www.frederica-online.org), which may be searched either directly through the ERICA Tool (Tier 3) or as a stand alone package available online [ERICA D1, 2005]. FREDERICA contains information from the FASSET Radiation Effects Database (FRED), which covered the period 1945-2001, plus data from new references up to the end of the ERICA project (early 2007). FREDERICA also contains the output from experiments conducted during the ERICA project. Field data from the EC-funded EPIC project have also been included in the database. All these data have been used in three main ways:

1. to derive a chronic no effect benchmark used as a screening incremental dose rate, as described in Chapter 5;
2. to establish look-up tables for Tier 2 to obtain a qualitative description of the effects potentially induced within a given range of exposure, including information on background (Chapter 6);
3. for specific searches in FREDERICA by focusing on, for example, the protection of keystone species and/or endangered species, and/or on specific endpoints.

The database contains some 30,000 data entries from more than a thousand literature references. These data correspond to pairs of points (exposure level, biological effect) along with information on the conditions in which these data were experimentally obtained (such as the tested species and its life stage, the exposure regime defined by the duration and irradiation pathway, the effect endpoint). The information is broadly divisible into effects of acute and chronic exposures. The data are organised into different 'pseudo-taxonomic groups' called wildlife groups: amphibians, reptiles, aquatic invertebrates, aquatic plants, bacteria, birds, crustaceans, fish, fungi, insects, mammals, mosses/lichens, soil fauna, terrestrial plants and zooplankton. These are then allocated to one of three ecosystems: freshwater, marine and terrestrial. While this classification may appear taxonomically arbitrary, it reflects the way experiments or field observations have been performed, and thus represents a practical way of presenting and analysing the effects data.

In terms of biological effects, the vast majority of data come from effects observed at an individual level followed by sub-individual (such as genetic and molecular) levels. Biological effects were grouped into four categories of effects (called umbrella effects) for use on a population-wide level:

1. morbidity including growth rate, effects on the immune system, effects on behaviour linked to central nervous system damage;
2. mortality including the stochastic effects of mutation and the consequences for cancer formation, and the deterministic effects which alter mortality rates and life expectancy;
3. reproductive capacity including fertility, fecundity, embryo development;
4. mutations of somatic and reproductive cells.

Most effects data compiled in FREDERICA concern terrestrial ecosystems (73 per cent of all data) and for each ecosystem, there are roughly twice as many data on acute exposure, typically from an external γ irradiation source, than for chronic exposure. Chronic effect data information is limited and largely dominated by external γ irradiation exposure conditions. Currently, data devoted to effects induced by external γ irradiation are adequate to be mathematically processed in terms of dose-effect relationships.

FREDERICA data also includes about 400 records from the EPIC database from Russian/Former Soviet Union experimental and field studies relating to chronic dose rate effects for wildlife in ecosystems, including the Arctic. Radiobiological effects within the EPIC data range from stimulation at low dose rate to death from acute radiation effects at high doses. The effects data were grouped under the same umbrella endpoints as those used in FREDERICA, plus three additional endpoints: ecological (such as changes in biodiversity, ecological successions), stimulation and adaptation effects.

7.3.2 Refining the effect analysis

At Tiers 2 and 3, one of the outputs from the assessment tool is a predicted dose rate to the organism of interest. Predicted dose rates can then be compared with dose rates known to cause biological effects in non-human species. To do this, Tier 3 makes direct use of the FREDERICA database to identify available information for the dose rates and the non-human species considered, by running an online database search from within a screen window in the ERICA Tool.

At Tier 3, the assessment may concern a particular object of protection such as keystone species[2] or protected species. Protection may be directed at the individual level, against which adverse effects on various functions such as growth, reproduction and survival would be considered negative. In such cases, a specifically directed search can be undertaken within the FREDERICA database. The most appropriate 'surrogate species' or wildlife group would need to be selected if the actual species were not represented in the database.

There are a number of ways to search the data contained within the FREDERICA database and to generate results (by selecting which information the assessor would like to view). Searches can be conducted by:

- author
- keywords
- source of radiation (internal, external)
- specific type of radiation (alpha, beta and gamma)
- specific radionuclides as the source of radiation
- specific endpoints
- particular species (or all) from within a particular wildlife group
- wildlife group
- dose or dose rate steps
- umbrella endpoints.

The user can consult the FREDERICA database directly and use its search capability to locate information specific to the assessment being conducted. As well as online, the FREDERICA database can be accessed at Tier 3 by opening a web browser window, through which the assessor can request information on particular reference organisms and biological endpoints for the dose rates calculated within the Tool. The ERICA Tool provides information on the dose rates directly to the FREDERICA database after the user selects the reference organism(s) and endpoint(s) of interest. Access to the biological effects information contained within the FREDERICA database, either directly or through the Tool, requires an Internet connection.

The output of searches conducted in the FREDERICA database is initially displayed in the web browser. If more than one result is available, these can be browsed on the screen. There is the option to export the

[2] Keystone species is used here to describe species that influence the ecological composition, structure or functioning of their community far more than their abundance would suggest.

search output as a comma separated file (CSV) file that can be read directly into programmes such as Microsoft® Excel. There is a full help available online within the FREDERICA database, which describes how to conduct searches, view and export the outputs and add new biological effects literature to the database.

ERICA Deliverable D5 outlines methods that can be used to derive refined predicted no effect dose rates (PNEDR) for specific endpoints, such as;

- using SSD methodology and selecting more conservative levels of protection (moving from 95 per cent to 99 per cent of species being protected);
- using SSD methodology and introducing more ecological realism to describe a particular ecosystem or habitat by: (a) applying trophic/taxonomic weightings that better describe the structure of a specific ecosystem; (b) revising the FREDERICA database to set new benchmarks whilst restricting the statistical analysis to a particular endpoint (for instance, reproduction) and/or a particular trophic/taxonomic group (such as vertebrates or fish);
- refining the effects analysis by focusing on the protection of keystone species and/or endangered species;
- extrapolating particular issues, such as from individual to population, or external to internal irradiation effects;
- refining the effects analysis to address situations when knowledge of effects is scarce, and when additional experimental/modelling studies may be required.

The Tier 3 assessment may need to determine whether individuals, populations, communities or ecosystems are being protected. The ERICA EUG Consensus document [2006] states:

> "*While there is a lack of direct data identified as ecologically relevant within FREDERICA, conservative screening benchmarks have been derived based on available data for mortality, morbidity and reproduction endpoints, which are population relevant. Where protection of the population is the objective then extrapolation from effects on individuals to a population is necessary, but may not be straightforward.*"

The problem, when assessing effects at the population level, is the complexity of the system coupled with the lack of available data and knowledge gaps at both population (for example, population size to population growth rate relationship [Silby *et al.*, 2005]) and individual level. Linking effects across levels of biological organisation is, however, a well-known problem within ecological risk assessments [Hinton *et al.*, 2004]. A number of parameters are known to be of importance when extrapolating from individual to population level and these are summarised in Table 7.2 [Garnier-Laplace *et al.*, 2004].

Table 7.2: Parameters of importance at population level to be considered during extrapolation.

Parameter	Knowledge gap	Solution
Different life stages	Which life stage is the most important to maintain the population? The most sensitive life stage may not be the most important.	Add margin of safety if there is a lack of data. The best solution, however, is to integrate the effects on various life stages via population growth rate analysis. This may not be possible due to lack of data.
Different life cycles for different species - different reproductive strategies respond differently to the same degree of radiation.	Which population dynamic features may result in increased sensitivity at the population level?	Taking life-cycle characteristics should be considered to increase the reliability of the risk assessment (see Woodhead [2003]).
Density dependent factors	Do density dependent factors such as temperature and competition of resources render the population less sensitive than its individuals? The opposite has been observed in some studies.	Hard to draw general conclusions on how those factors may influence extrapolation.
Effects of DNA damage	In the case of increased mutation rates due to radiation, which other accelerating factors would lead to reduced fitness and population decline?	Need to consider further, particularly for long-lived organisms.

8 Post-assessment considerations

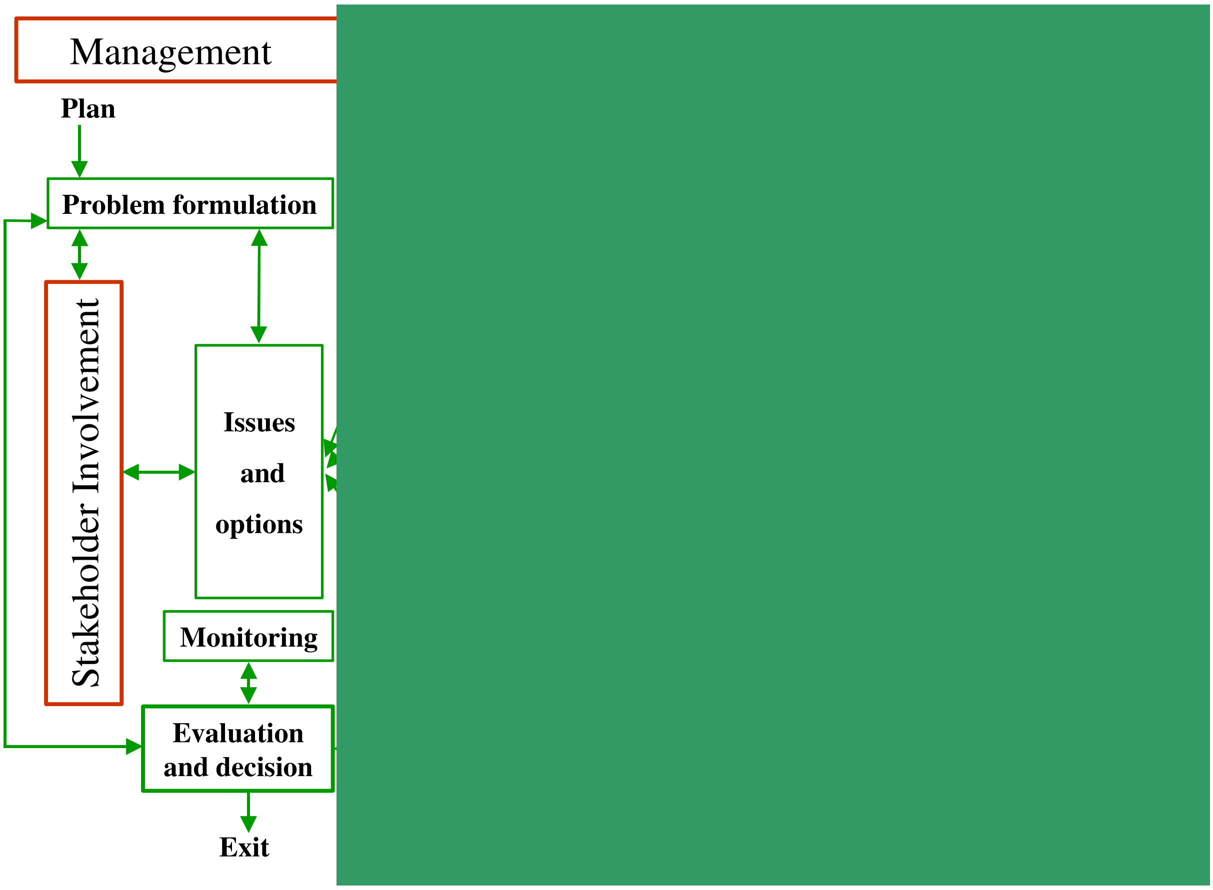


Figure 8.1: The ERICA Integrated Approach, highlighting the elements that relate to post-assessment considerations.

8.1 Introduction

Once an assessment is completed, three outcomes are possible:

- there is negligible concern (where an assessment has not exceeded the conservative screening criteria used for Tiers 1 and 2), or more qualifications can be provided that would make it possible to exempt the situation from further assessment or action;
- there is insufficient confidence that there is negligible concern (for example, a Tier 3 assessment indicates a significant probability that there are, or may occur, radiation effects of concern);
- there is concern.

It is evident that the second and third of the above outcomes, which most likely have required a full Tier 3 assessment, would be more difficult to handle in post-assessment decision-making. Since the ERICA Integrated Approach is intended to ensure that adequate weight is given to the environmental effects of ionising radiation, the ERICA Integrated Approach is non-prescriptive and does not specify decisions that *must* be taken post-assessment. Flexibility is necessary in view of differences between countries' legislation. Furthermore, there are at present no international criteria or standards that specifically address the protection of the environment from the effects of ionising radiation (although such criteria and/or standards may exist at a national scale). Approaches are under development by a number of international organisations, and it would be advisable for any user of the ERICA Integrated Approach to keep informed of this work and to consider the possible practical implications of emerging recommendations for the way in which ERICA is applied.

This chapter mainly covers factors that might need to be considered post-assessment (decisions to be taken as part of the assessment are listed, together with options, in Appendix 2). An in-depth account of factors governing decision-making can be found in D8 [ERICA D8, 2007]. Decisions taken post-assessment may not necessarily conclude the process. Most likely, in cases where a decision has been taken via a full Tier 3 assessment, the decision may have to be revisited regularly on the basis of new information or as part of licensing conditions, resulting in a new problem formulation and, potentially, less uncertainty. As this may change the rationale for the assessment as well as the outcome substantially, stakeholders may need to be consulted.

8.2 Evaluation of assessment results against criteria set up during problem formulation

Chapter 2 lists factors to be considered as part of problem formulation, and that has direct relevance to the way the assessment is carried out. During the assessment, these factors may have to be reconsidered and revised. Further guidance on this is given in Appendix 2. Following the assessment, and in particular if the assessment has to be carried all the way to Tier 3, which does not necessarily give a simple yes/no answer to the question under study, the user of the ERICA Integrated Approach might wish to examine the assessment results against some of the objectives of the international legal framework and/or binding agreements, as well as recommendations. Table 8.1 summarises the main factors affecting decision-making and how they are related to such drivers.

8.3 Socio-economic factors

Sustainable development forms the background to many environmental management decisions. This, by definition, requires environmental, social and economic development objectives to be balanced. The use of the precautionary principle and requirements to apply 'best available techniques' also require the balancing of risk, cost and benefits. In practice, *decisions regarding the acceptability of a plan or project will necessarily involve the consideration of a range of consequences, including potential impacts on human health, and environmental, economic, ethical and societal factors*. If a Tier 3 assessment, using the ERICA Integrated Approach, results in concern over the environmental effects, there is obviously a need for considering the outcome of the assessments against a background of socio-economic factors. The ERICA Integrated Approach is only a component of the broader decision-making process, which is illustrated in Figure 8.2 (see further [ERICA D7g, 2007]).

8.3.1 Undertaking socio-economic analysis

Socio-economic analysis is a process that allows for the explicit, systematic and consistent consideration of social and economic factors, which have an impact on decision-making. The main aspects of such an analysis are as follows:

- establish a baseline (the health, social, environmental and economic conditions in the absence of the risk or environmental management measures under consideration);
- identify and assess the risks and benefits associated with the risk or environmental management measure and alternatives (for example, from application of ERICA);
- manage uncertainties and communication issues;
- consider the distribution of risks and benefits and the implications of this distribution;
- consider the time periods and assessment implications of this and other assumptions.

The type of objectives that underpin the decision-making process may be illustrated by the social criteria recently identified by the Environment Agency to inform its decision-making [Environment Agency, 2005], and earlier by Environment Canada for chemical risk management (see Box 8.1 and 8.2).

Table 8.1: Factors affecting decision-making derived from legal instruments and binding agreements. Based on [ERICA D8, 2007]

Driver	Factors affecting decision-making
General environmental protection	- The need to prevent, reduce and control potential sources of environmental contamination - The need to ensure nuclear safety to prevent environmental impact - The need to control shipments of radioactive substances
Protection of specific ecosystems and species	- The need to identify and designate species and areas of significance (such as for conservation or biodiversity) and to protect them accordingly - The need to establish a baseline status and surveillance measures - The need to establish suitable protective measures to species or areas defined
Protection of specific environmental media	- The need to control emissions into transboundary media, including air, watercourses and lakes
Prospective and retrospective assessment of the impact	- The need to undertake EIAs for any plan or project likely to result in significant environmental impacts (in advance of decisions being made) - The need to ensure that assessments take account of direct and indirect impacts of all stages
Monitoring or measurement of the impact	- The need to monitor compliance with emission limits and environmental objectives
Provision of information	- The need to exchange information with EU states potentially subject to transboundary impacts and to report on progress against specific environmental objectives included in various conventions - The need to make information available to the public in an accessible form, particularly for participation in decision-making
Decision-making	- The need to take due account of the EIA and comments made in the decision-making process - The need to include all interested parties (including the public) in the decision-making process - The need to involve representatives from other Member States that may be affected by impacts
Unusual events	- The need to reduce and mitigate the impacts of any unusual event - The need to inform other EU states of monitoring results in the event of an accident - The need to agree arrangements for liability and compensation in the event of environmental damage

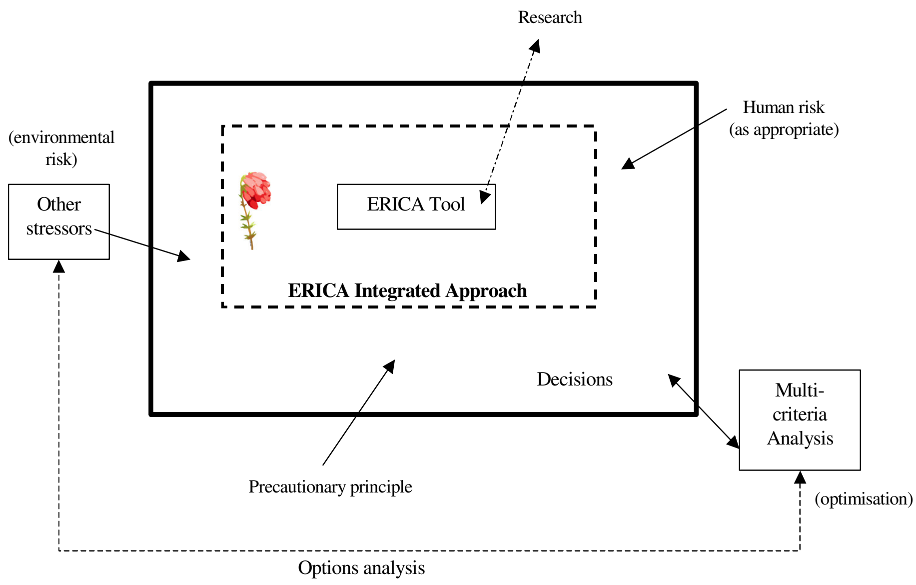


Figure 8.2: Illustration of factors affecting decisions, and the position of the ERICA Integrated Approach and Tool. From [ERICA D7g, 2006].

The selection of an appropriate approach for socio-economic analysis will depend upon the specifics of the situation. The decision-making context will determine the extent to which quantitative or qualitative analysis is appropriate. For example, the magnitude and complexity of the situation under consideration will influence the resources available for the analysis, the costs and benefits that need to be considered and the nature of information available. The European Commission [EC, 1998] suggests that the form of analysis appropriate for developing risk reduction strategies will depend upon the factors summarised in Box 8.3.

Given the diverse range of considerations to be included in the decision-making process, and the need for transparency and stakeholder involvement, a range of tools have been developed for a systematic approach to including socio-economic factors in decision-making. The approaches most commonly encountered are: cost-effectiveness analysis (CEA); cost-benefit analysis (CBA) and multi-criteria analysis (MCA). The key features of these methods are summarised in Box 8.4.

A stepped approach to socio-economic analysis has been recommended by the Nordic Council of Ministers, with the magnitude of analysis being determined by the magnitude of the predicted trade-offs [Hokkanen and Pellinen, 1997]. Thus, the nature of the assessment should be based on the nature of the problem; if the impacts of the decision are minor, then a relatively simple analysis may suffice. However, there may be a need for more comprehensive analysis in cases where there is likely to be a significant trade-off between cost and benefit, with significant cost implications for a range of industries and other stakeholders, and if there are controversial trade-offs between environmental impacts and human health. This approach is consistent with the ERICA Tiered Approach recommendations.

Box 8.1

Social criteria defined by the Environment Agency (England and Wales):

- promote health, safety and wellbeing (including consideration of health, liveability and crime);
- help meet social needs (improvement in goods and services, contribution to urban and rural regeneration);
- promote fairness and social cohesion (promote equal opportunities and social justice, support the development of social capital or robust communities);
- demonstrate corporate social responsibility (external and internal responsibilities);
- increase stakeholder, citizen and community participation (by increasing engagement, developing partnerships, supporting external activities);
- help develop a learning culture (capacity building) by increasing staff skills and knowledge of social issues and developing new areas of knowledge and practice.

Box 8.2

Criteria applied by Environment Canada for chemical risk management:

- the implications for competitiveness of the industry concerned (and minimisation of financial burden);
- the provision of incentives for creativity and innovation in the development and implementation of cleaner technologies;
- the ease of enforceability and compliance;
- the need to allow for economic growth within the framework of environmental requirements;
- the speed with which environmental objectives may be reached;
- fairness and the degree to which the measure will impose an unfair burden on certain sectors or stakeholders;
- intrusiveness and flexibility and the interaction between regulatory and industry responsibilities;
- the intensiveness and availability of necessary data;
- the compatibility with existing or other initiatives;
- public acceptability.

Box 8.3

EC rationale for developing risk reduction strategies:

- the severity and extent of the risk;
- the scale of the drawbacks;
- the balance between the likely advantages and drawbacks;
- the information available within reasonable cost and a reasonable time frame;
- the level of uncertainty surrounding the likely advantages and disadvantages.

Box 8.4

- *CEA* is based on the principles of economic appraisal. It may be used to identify the most cost-effective way of achieving a predefined target at the least cost (but it will not provide information about, for example, whether the benefits gained by an action outweigh the costs).
- *CBA* is based on the principles of welfare economics, and is based on the assumption that values (for example, for risk avoidance) can be determined from individuals' willingness to pay to achieve them. This offers the potential for direct comparison of the implications of regulatory decisions, for example, but concerns are often expressed about the validity of converting some aspects of decision-making into monetary terms, particularly those connected to non-tradable goods such as health and environmental integrity. As a consequence, semi-quantitative approaches to its application have evolved.
- *MCA* is based on utility theory (and the identification of means that achieve the most overall utility or benefit). It specifically allows for the multi-faceted nature of decision-making, by allowing qualitative and quantitative factors to be included in the analysis. It potentially allows the impact and the importance assigned to it to be distinguished from one another. The sensitivity of the decision to variations in the importance assigned to different factors can therefore be determined, thereby potentially facilitating transparent decision-making. However, there are often difficulties in defining scoring and weighting schemes and ensuring that factors are not double-counted. The techniques applied range from simple checklists to trend analysis and intricate mathematical procedures.

8.4 Outcomes of the assessment

Faced with the outcome of the assessment, the user of the ERICA Integrated Approach may wish to consider some or all of the factors reviewed above in the post-assessment decision-making. In doing so, it might be helpful to return to the generic ICRP exposure situations introduced in Chapter 2, that is, planned exposure situations, existing exposure situations (from past and current practices), and emergency exposure situations (from accidents). Table 8.2 lists a number of possible decisions or actions relating to hypothetical outcomes of the assessment. as well as to the above mentioned exposure situations for consideration and for further elaboration by the user of the ERICA Integrated Approach. The user may benefit from consulting ERICA D8 [2007] for further information.

Table 8.2: Examples of possible decisions or actions based on the assessment, organised according to the generic ICRP exposure situations.

Assessment outcome	Planned exposure	Existing exposure	Emergency exposure
Of concern	Are there overriding priorities that mean that the practice should be started (cost-benefit analysis)? Perspective of other risks Reconsider the proposal Reconsider decision Say no to the practice Select a different site Would more data help?	Consider changes of current practice to re-optimise the process Consider ecological value of present site Monitoring Perform cost-benefit analysis Shut down existing practice Would remediation do more good than harm?	Consider ecological value of present site Monitoring Perform cost-benefit analysis Would remediation do more good than harm?
Insufficient confidence	Ask experts for help/review Perform cost-benefit analysis Proceed with additional controls imposed and review the practice and/or assessment at defined time intervals Re-iterate the assessment Say no to the practice Undertake a multi-criteria decision analysis Would more data be helpful and are they available?	Consider assessment of other stressors Consider changes of current practice to re-optimise the process Consider ecological value of present site Monitoring Perform cost-benefit analysis Proceed with additional controls imposed and review practice/assessment after defined time intervals Say no to the practice Shut down existing practice Would remediation do more good than harm?	Consider ecological value of present site Consider timescales Monitoring Perform cost-benefit analysis Would remediation do more good than harm?
Negligible concern	Proceed but consider other factors such as cost, best available technique, human exposure, optimisation and monitoring	Consider if monitoring and controls for human exposure are required No intervention for biota	Monitoring No action from environmental point of view

ERICA Deliverables

D1	Copplestone, D (Ed) (2005) Progress on the production of the web-based effects database: FREDERICA. ERICA Deliverable D1.EC Contract N°FI6R-CT-2004-508847.
D2	The prototype of the ERICA Tool (2006) Available on www.erica-project.org. To be replaced by the final version of the ERICA Tool in February 2007, on the same website. EC Contract N°FI6R-CT-2004-508847.
D4a	Copplestone D, Björk M and Gilek M (Eds) (2005) Ecological risk characterisation: An interim method for the ERICA Integrated Approach. ERICA Deliverable D4a. EC project Contract N°FI6R-CT-2004-508847.
D4b	Björk M and Gilek M (Eds) (2005) Overview of ecological risk characterisation methodologies. ERICA Deliverable D4b. EC project Contract N°FI6R-CT-2004-508847.
D5	Garnier-Laplace J and Gilbin R (Eds) (2006) Derivation of predicted no effect dose rates values for ecosystems and their sub-organisational level exposed to radioactive substances. ERICA Deliverable D5. EC project Contract N°FI6R-CT-2004-508847.
D5 - Annex A	Garnier-Laplace J and Gilbin R (Eds) (2006) Guidelines for the design and statistical analysis of experiments on chronic effects of radioactive substances. ERICA Deliverable D5 Annex B - Public. EC project Contract N°FI6R-CT-2004-508847.
D5 - Annex B	Gilbin R and Oughton D (Eds) (2006) Experiments on chronic exposure to radionuclides and induced biological effects on two invertebrates (earthworm and daphnid). Results and discussion. ERICA Deliverable D5 Annex B - Public. EC project Contract N°FI6R-CT-2004-508847.
D7a – Part 1	Oughton D, Zinger I, Bay I, Børretzen P, Garnier-Laplace J, Larsson CM and Howard B (2004) First EUG event - Part 1: Discussion of ERICA work plan. ERICA Deliverable D7a – Part 1. EC project Contract N°FI6R-CT-2004-508847.
D7a – Part 2	Oughton D, Zinger I, Bay I and Larsson CM (2004) First EUG event - Part 2: Briefing notes on assessment frameworks and knowledge gaps. ERICA Deliverable D7a – Part 2. EC project Contract N°FI6R-CT-2004-508847.
D7b	Oughton D, Zinger I and Bay I (2004) Briefing notes from the second thematic EUG event. Part 1: Ionising radiation and other contaminants and Part 2: Contribution to deliverable D4 on risk characterisation. ERICA Deliverable D7b. EC project Contract N°FI6R-CT-2004-508847.
D7c	Zinger I (Ed) (2005) Transcripts from the first generic EUG event: Ecological risk assessment and management. ERICA Deliverable D7c. EC project Contract N°FI6R-CT-2004-508847.
D7c – Annex 1	Zinger I (Ed) (2005) Added written comments from the Freising questionnaire. ERICA Deliverable D7c Annex 1. EC project Contract N°FI6R-CT-2004-508847.
D7d	Copplestone D, Zinger I and Oughton D (Eds) (2005) Transcript from the third thematic EUG event: Decision-making and stakeholder involvement. ERICA Deliverable D7d. EC project Contract N°FI6R-CT-2004-508847.
D7e	Oughton D and Breivik H (Eds) (2005) Scientific uncertainties: Transcript from the

EUG workshop. ERICA Deliverable D7d. EC project Contract N°FI6R-CT-2004-508847.

D7f Forsberg ME and Oughton D (Eds) (2006) The ERICA consensus seminar. ERICA Deliverable D7f. EC project Contract N°FI6R-CT-2004-508847.

Consensus Document Consensus Document (2006). EUG Event – Stavern June 2006. EC project Contract N°FI6R-CT-2004-508847.

D7g Zinger I, Vetikko V, Sjöblom KL, Jones S, Hubbard L, Copplestone D, Michalik B, Prlic I and Momal P (2007) Summary of the EUG event on: Management, compliance and demonstration. Deliverable D7g. EC project Contract N°FI6R-CT-2004-508847.

D7h Zinger I (Ed) (2007) EUG Tool Testing Event. Deliverable D7h. EC project Contract N°FI6R-CT-2004-508847.

D7i Jones S (Ed) (2007) Local Stakeholder EUG Event. Deliverable D7i. EC project Contract N°FI6R-CT-2004-508847.

D8 Zinger I, Copplestone D, Brown J, Sjöblom KL, Jones S, Pröhl G, Oughton D and Garnier-Laplace J (2007) Considerations for applying the ERICA Integrated Approach. Deliverable D8. EC project Contract N°FI6R-CT-2004-508847.

D8 - Annex A Copplestone D (Ed) (2007) Review of international legal instruments that may influence decision-making. Deliverable D8 Annex A. EC project Contract N°FI6R-CT-2004-508847.

D9 Beresford N and Howard B (Eds) (2005) Application of FASSET framework at case study sites. Deliverable 9. EC project Contract N°FI6R-CT-2004-508847.

D10 in progress, to be published in February 2007.

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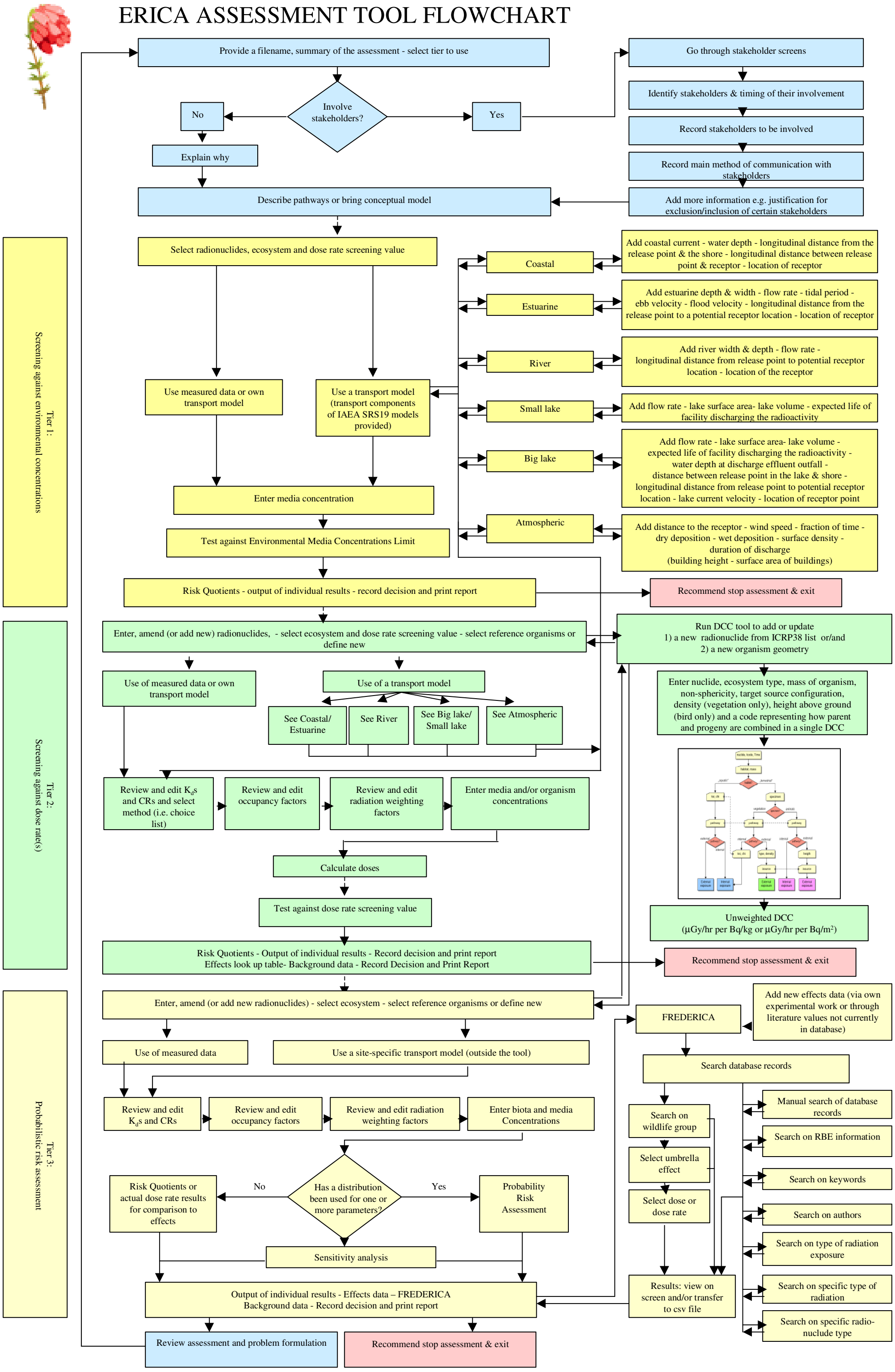
Appendix 1: ERICA Assessment Tool Flowchart

ERICA ASSESSMENT TOOL FLOWCHART



Appendix 2: Decisions to be taken within the ERICA Tool regarding parameter selection and data input

What decision is taken?	Where is this in the ERICA Tool?	What are the choices	Strengths	Weaknesses
Appropriate data entry (screening Tier 1) for retrospective assessment	Screen 1 assessment context (Tier 1)	Use maximum media activity concentration value derived from an empirical dataset.	Most defendable approach – empirical data, therefore no assumptions required with respect to behaviour and fate of radioactivity in the environment. Provides an integrated view of contamination levels.	There will be a cut-off where too few empirical data exist to perform an analysis using the user-defined option. Reasonable data coverage in time and space may be required to ensure that a maximum value is acquired.
		Use input value based on activity concentrations at the edge of the dispersion zone.	Maximum measurement at the end of the discharge pipe is overly conservative.	May be perceived not to be as conservative as it might be.
		Select the tool default transport model (based on IAEA, 2001).	Provides a quick and easy method to establish whether a problem might exist.	Output from this generic screening model may not reflect the real contamination levels. Problems related to time-integrated contamination levels.
		Select user-defined transport model and enter data based on simulation output.	May predict quite realistic activity concentration data.	Problems related to time-integrated contamination levels although simulating over long time periods may mitigate the situation.
Appropriate data entry (screening Tiers 1 & 2) for prospective assessment	Screen 1 assessment context (Tier 1 & 2)	Select the tool default transport model (based on IAEA, 2001).	Established internationally recognised methodology. Provides consistency, allowing comparison between different assessments.	May be overly conservative.
		Select user-defined transport model and enter data based on simulation output as media activity concentration.	User may feel more confident for his particular case. A site-specific model should provide the best estimate of contamination levels for this type of assessment.	Requires some consideration of the most appropriate scenario for prediction – in particular, issues related to spatial and temporal averaging.

What decision is taken?	Where is this in the ERICA Tool?	What are the choices	Strengths	Weaknesses
		Enter proxy data that are based on expert judgement, for example comparison with the contamination surrounding existing sites with similar technical specification, authorisation limits and receiving environment.	Based on real-world conditions. Reasonable semi-empirical approach.	May be perceived not to be as conservative as it might be.
Appropriate data entry (screening Tier 2) for retrospective assessment	Screen 1 assessment context (Tier 2)	Use representative empirical activity concentration data for environmental media and biota.	Most robust defendable approach – empirical data therefore no assumptions required with respect to behaviour and fate of radioactivity in the environment.	Relatively complicated set of rules governing which data take precedence. For example, data available for organism A, B and sediment: which value(s) should be used to derive water concentrations? A further weakness might be insufficient data.
		Select the tool default transport model (based on IAEA, 2001) to derive media concentrations.	Provides a quick and easy method to establish whether a problem might exist.	Will tend to provide conservative activity concentrations in environmental media.
		Select user-defined model and enter data based on simulation output.	May predict quite realistic activity concentration data.	
Assessor faced with multi-contaminants (including non-radioactive substances)	The assessment tool deals with radioactive contaminants only	Use the ERICA Tool and whatever method is appropriate for the other stressor and combine with the ERICA assessment.	Assessment can be conducted addressing both sets of stressors.	Difficult to interpret.

What decision is taken?	Where is this in the ERICA Tool?	What are the choices	Strengths	Weaknesses
Assessor faced with multiple sources	Screen 1 assessment context	Run through the assessment numerous times in accordance with the more complicated scenario, then add all components.	Considers all sources and impacted environment. Allows identification of the dominant source and most vulnerable environmental receptor.	Difficult to acquire all the necessary data.
		Select the dominant/most relevant source and ignore the others.	Simplifies the problem.	May lead to an underestimation of the total risk. May not be credible to stakeholders.
Selection of dose rate screening value	Screen 1 assessment context	Use the default ERICA screening values.	Values derived based on analyses of latest current available data and established statistical methods [ERICA D5 Annex A, 2006].	Data frozen in time and maybe become outdated by new research.
		Select a user defined screening value.	Dose rate screening level might be more acceptable because it falls in line with national legislation or guidance and/or internationally-accepted recommendations.	Screening values may not account for the most up-to-date environmental radiobiological data.
		Do not use a screening value.	May not be needed by assessor.	Cannot do a Tier 1 assessment using the ERICA Tool.
Selection of DCCs	Either through creating own organism or through the edit database option	Select ERICA default DCCs.	ERICA DCCs have been derived using state-of-the-art methods as used within the field of ecodosimetry. The methods have been validated and are consistent with those being adopted by international advisory groups such as the ICRP	Use of default DCCs based on reference organism geometries may not be compatible with the actual organisms under study. This problem can be mitigated by using the DCC interpolation module in the tool if considered necessary.
		Select user-defined DCCs.	The assessor may feel more comfortable with values that have been derived explicitly for his/her purposes using familiar methodologies.	User-defined DCCs may not be transparently documented as those provided. If you edit the default databases, it may become unclear which numbers are being used in the assessment.

What decision is taken?	Where is this in the ERICA Tool?	What are the choices	Strengths	Weaknesses
Selection of DCCs	Either through creating own organism or through the edit database option	Use the 'create' organism function.	Uses the ERICA method and may be more appropriate to the species being assessed.	
Application of risk quotients (Tier 1) - EMCLs		Use ERICA's method of summing over risk quotients.	The ERICA RQ methodology calculates RQ for one reference media only. In summing RQs, the lowest radionuclide specific EMCL value (which will return the highest radionuclide specific RQ value) is selected for each radionuclide Although this approach might also be deemed overly-conservative, this approach is fairly consistent with other assessment approaches in that it provides only a single EMCL value for each radionuclide and does not lead to the suggestion that there is greater detail of information than actually available. Fulfils the criteria to be highly conservative within Tier 1.	No organism-specific assessment – may identify the most exposed organism.
		Use other methods to sum over risk quotients.	Other RQ summation methodologies exist, such as those applied at Tier 2. Also others (US DoE, 2002; Garisto et al., 2005) that add EMCLs for two reference media such as sediment and water.	Depends on approach but, for example, the practice of summing RQs for different media types is considered overly-conservative.
Application of risk quotients (Tier 2) – dose rates	Tier 2	Use ERICA's method of summing over risk quotients.	The ERICA RQ summation method treats each reference organism on an individual basis, testing whether the sum of all radionuclides for that particular organism is less than one. This approach is considered to offer the greatest realism to the assessment and avoid any unnecessary conservatism.	The approach is unconventional – differs somewhat to approaches taken elsewhere.

What decision is taken?	Where is this in the ERICA Tool?	What are the choices	Strengths	Weaknesses
Application of risk quotients (Tier 2) – dose rates	Tier 2	Use other methods to sum over risk quotients.	Other RQ summation methodologies exist.	When information is provided specifically in relation to the types of organisms present at a site, any approach that does not treat risk quotients on an organism-by-organism basis might be considered overly conservative. Would need to be done outside of the Tool.
Selection and revision of radioecological parameters (K_ds and CRs)	Tier 2 dialogue screen entitled "Radioecological parameters"	Select ERICA default CRs and K_ds.	The CRs used in the ERICA default database are comprehensive, drawing on an extensive review of published literature and characterised by statistical information. According to Sheppard (2005), the inherent variability of transfer parameters is so large that generic data may be the best choice for application in risk assessments.	In studies where the environment is characterised by parameters that clearly deviate from generic conditions (in the case of freshwater environment this might, for example, be for assessments involving extremely nutrient poor, oligotrophic or nutrient rich, eutrophic, lakes) the application of generic values is likely to be inappropriate
		Input user-defined CRs and K_ds.	In cases where there are statistically-significant differences between site-specific and generic data, the application of site-specific data may be justified. Especially for ERICA, site-specific K_ds might be more suitable owing to the fact that ERICA K_ds are mostly poorly defined statistically – essentially recommended values have been provided and exponential or probability distribution functions applied for want of more detailed collated statistical information.	The application of site-specific data is often not justified, especially in cases where datasets are small.
Selection and revision of occupancy factors	Tier 2 dialogue screen entitled "Occupancy factors and radiation weighting factors"	Use ERICA default occupancy factors.	Default occupancy factors have been selected to maximise the dose, such as those selected for the location in the habitat where highest doses might be expected.	The selection of the default occupancy factor will lead to an overestimation of the dose rate in some cases.

What decision is taken?	Where is this in the ERICA Tool?	What are the choices	Strengths	Weaknesses
Selection and revision of occupancy factors	Tier 2 dialogue screen entitled "Occupancy factors and radiation weighting factors"	Input user-defined occupancy factors.	Application of realistic occupancy factors, where appropriate, will lead to less conservative dose estimates.	Need to obtain life history data.
Revision of radiation weighting factors	Tier 2 dialogue screen entitled "Occupancy factors and radiation weighting factors"	Use ERICA default radiation weighting factors.	Default values of 10 for alpha, 3 for low beta and 1 for γ,β used. These might be considered conservative values – recent reviews on the subject suggest that a α weighting factor of around 5 might be most appropriate for population deterministic and stochastic endpoints (Chambers et al., 2006).	The radiation weighting factors used in ERICA have been adopted from FASSET. They have always been considered provisional values, applied for demonstration purposes only – their application therefore is arguably unsubstantiated.
		Input user-defined radiation weighting factors.	The assessor can account for the most recent radiobiological research related to this theme. Furthermore, the assessment can be tailored to a specific problem context. Radiation weighting factors are known to be endpoint, species and dose rate specific. Could use published reviews (Chambers et al., 2006).	The choice of the radiation-weighting factor needs to be justified.
Choice of Tier 3 parameters		Choices as per Tier 2.		
Tier 3 probabilistic parameters	Tier 3	Use single values.	Pdfs may not be available.	Loose benefit of Tier 3 functionality.
		Use pdf.	Probabilistic analysis conducted with sensitivity analysis.	User has to be able to derive appropriate pdfs. Sufficient data may not be available.

Appendix 3: Information on three relevant projects

FASSET (2000-2003)

FASSET: Framework for Assessment of Environmental Impact

Executive summary of the FASSET Final Technical Report

Background and project organisation

Radiological protection has traditionally focused on the protection of man. For the past decade, the limitation to human health protection has been increasingly questioned and the requirement for an internationally agreed rationale to the protection of the environment to ionising radiation is now recognised, *for example* as reflected in the ongoing revision of the Recommendations of the International Commission on Radiological Protection. The FASSET project (contract N°: FIGE-CT-2000-00102) was launched in November 2000 under the EC 5^{th} Framework Programme, to develop a framework for the assessment of environmental impact of ionising radiation in European ecosystems. It involved 15 organisations in seven European countries, and set out to organise radioecological and radiobiological data into a logic structure that would facilitate the assessment of effects on non-human biota resulting from known or postulated presence of radionuclides in the environment.

The FASSET project was divided into four work packages (WP), with the following broad objectives:

- WP1 – Dosimetry. To provide radiation dosimetry models for a set of reference organisms relevant to different exposure situations.
- WP2 – Exposure. To assess transfer, uptake and turnover of radionuclides in European ecosystems and identify components of the ecosystems where exposures (external and internal) may be high.
- WP3 - Effects. To critically examine reported data on biological effects on individual, population and ecosystem levels, as a point of departure for characterising the environmental consequences of, *for example*, a source releasing radioactive substances into the environment.
- WP4 - Framework. To review existing frameworks for environmental assessment used in different environmental management or protection programmes and to integrate project findings into an assessment framework.

In WP2, seven European ecosystems were considered, four of them terrestrial and three of them aquatic. A list of generic *reference organisms* was drawn up on the basis of expert judgement of exposure situations in the selected ecosystems. A number of novel modelling approaches were applied in the work, and resulted in a Handbook that compiles relevant information for the initial stages of the impact assessment.

The identification of reference organisms served as starting points for the development of dosimetric models in WP 1. For a variety of reference geometries, dosimetric conversion factors were computed, in several cases involving Monte Carlo calculations, and tabulated in the Handbook.

WP3 considered general ‘umbrella’ effects that, when manifested in an individual, may have an impact at population level or at higher levels of the organisational hierarchy. A database was also assembled, compiling data from the literature for a number of wildlife groups for each of these four umbrella effects (FRED – The FASSET Radiation Effects Database).

WP4's main task was to organise the work from the above three work packages into a framework for impact assessments, which would take into account experiences from existing systems for environmental risk assessment. The formulation of the FASSET assessment context was also part of this WP, which helped define the remit of the framework.

The FASSET project produced a total of six report deliverables, D1-D6. The final deliverable, D6, describes the FASSET framework and draws on information produced under the other five deliverables. Complete documentation on the FASSET project can be found on FASSET's website (www.fasset.org).

The progress and dissemination of results were further carried out by presentations at major international conferences and by publications into the scientific literature. It also help support the development of international initiatives, and lead to the commissioning of further research, *for example* under the EC 6th Framework Programme.

The FASSET Framework – an overview

The assessment framework developed under FASSET includes the following fundamental elements: source characterisation; description of seven major European ecosystems; selection of a number of reference organisms on the basis of prior ecosystem and exposure analysis; environmental transfer analysis; dosimetric considerations; effects analysis; and, as an integral part of the aforementioned steps, general guidance on interpretation, including consideration of uncertainties and possibilities to extrapolate from existing data to areas where data are absent or scarce. The project has used existing information, supplemented by the development of models, by Monte Carlo calculations, and by building an effects database (FRED, the FASSET Radiation Effects Database). An overview is given below, with reference to the different FASSET Deliverables (*cf*. also Figure 1).

Source characterisation

The initial phase of the assessment involves the characterisation of the radionuclide input in the environment. A set of radionuclides from 20 elements was selected for inclusion within the Framework, on the basis of being routinely considered in assessments and emergency planning for accidental releases; representing a range of environmental mobilities and biological uptake rates; being of both anthropogenic and natural radionuclides; and, being representatives of α-, β- and γ-emitters [D1].

Furthermore, a preliminary flowchart for the screening of radionuclides and a description of criteria useful in the process has been described. This guidance was based on a number of criteria used to define the source term, physical characteristics, environmental fate, biological activity and chemical characteristics, as discussed in [D2].

Ecosystem characterisation and selection of 'reference organisms'

The Framework includes information on seven European ecosystems to allow for identification of maximally exposed ecosystem components [D1]. The ecosystems considered were as follows.

- *Forests*: land with tree crown cover of more than 10 %, an area of more than 0.5 ha and with trees, which are able to reach a minimum *in situ* height of 5 m at maturity.
- *Semi-natural pastures and heathlands*: including mountain and upland grasslands, heath and shrub lands, saltmarshes and some Arctic ecosystems.
- *Agricultural ecosystems*: including arable land, intensively managed pastures and areas used for fruit production.
- *Wetlands*: areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish, or salt.
- *Freshwaters*: all freshwater systems, including rivers and lakes.

- *Marine*: the North-Eastern section of the Atlantic Ocean and its marginal seas.
- *Brackish waters*: the non-tidal, shallow Baltic Sea; organisms are immigrants from either marine or freshwater systems.

The ecosystems overview enabled identification of a number of reference organisms, based on habitat and feeding habits, as well as bioaccumulation and biomagnification [D1]. The Framework defines the reference organism as: *"a series of entities that provide a basis for the estimation of radiation dose rate to a range of organisms which are typical, or representative, of a contaminated environment. These estimates, in turn, would provide a basis for assessing the likelihood and degree of radiation effects"*. In total, *ca* 30 reference organisms have been chosen. It should be noted that these 'organisms' are not equivalent to specific species – they rather represent biological components of importance for the functioning of each ecosystem, and thus they are suitable targets for impact assessments.

Environmental transfer and dosimetry

A number of radionuclide transfer models developed for the seven major European ecosystems have been used for calculation of external and internal radionuclide concentrations. Furthermore, calculations and tabulations have been made to allow conversion of external and internal concentrations to absorbed dose (rate), including those resulting from natural background radiation for a number of ecosystems. The Conversion factors for estimates of dose rates have involved Monte Carlo calculations and the definition of a number of representative geometries for different reference organisms. Data have been compiled in a Handbook on the initial assessment stages [D5], as well as in a separate report on dosimetry [D3].

Effects analysis

The Framework centres the effects analysis on individuals, accepting that effects must materialise in individuals *before* they can become manifested within the ecosystems. In order to organise the available knowledge on radiation effects, it was decided that the Framework would concentrate on four effects categories, or 'umbrella effects'.

- *Morbidity* (including growth rate, effects on the immune system, and the behavioural consequences of damage to the central nervous system from radiation exposure in the developing embryo).
- *Mortality* (including stochastic effect of somatic mutation and its possible consequence of cancer induction, as well as deterministic effects in particular tissues or organs that would change the age-dependent death rate).
- *Reduced reproductive success* (including fertility and fecundity).
- *Mutation* (induced in germ and somatic cells).

[D4] reviews the current knowledge on radiation effects on biota, grouped under 16 wildlife groups, which are broadly comparable with the chosen reference organisms. The report is supported by the FASSET Radiation Effects Database (FRED). The database contains approximately 25 000 data entries from more than a thousand references. The reviewed effects data give few indications of readily observable effects at chronic dose rates below 100 µGy/h. However, it is advised that using this information for establishing environmentally 'safe' levels of radiation should be done with caution, considering that the database contains large information gaps for environmentally relevant dose rates and ecologically important wildlife groups. Assessors are encouraged to use the database as a starting point, and seek the original papers to extract more detailed information.

The FRED contains only limited data that enable the derivation – or even discussion – of radiation weighting factors. The recommendation is that assessors, as a part of a sensitivity analysis, make a judgment whether the weighting factor matters in each particular case.

Uncertainties and interpretation

The Framework contains general advice as to the interpretation and handling of uncertainties associated with the assessment. For a number of radionuclides, transfer and effects data are lacking or scarce, necessitating information to be extrapolated from 'known' data, and involving a substantial component of expert judgment.

Outlook

On the basis of the FASSET experience, and other recent projects, it can be concluded that there is substantial agreement in terms of conceptual approaches between different frameworks currently in use or proposed, and that differences in technical approaches can largely be attributed to the differences between ecosystems of concern, or to different national legal requirements. Furthermore, sufficient knowledge appears to be available to support robust, scientifically-based assessments following the FASSET framework structure, although significant data gaps exist, *for example* concerning environmental transfer of key nuclides and effects data for key wildlife groups at environmentally relevant dose rates.

Future challenges lie in the development of an integrated approach where decision-making can be guided by sound scientific judgements, which requires, *inter alia*: filling of gaps in basic knowledge of relevance to assessment and protection; development of risk characterisation methodologies; development of user-friendly assessment tools; and stakeholders involvement, including the development of supporting communication strategies.

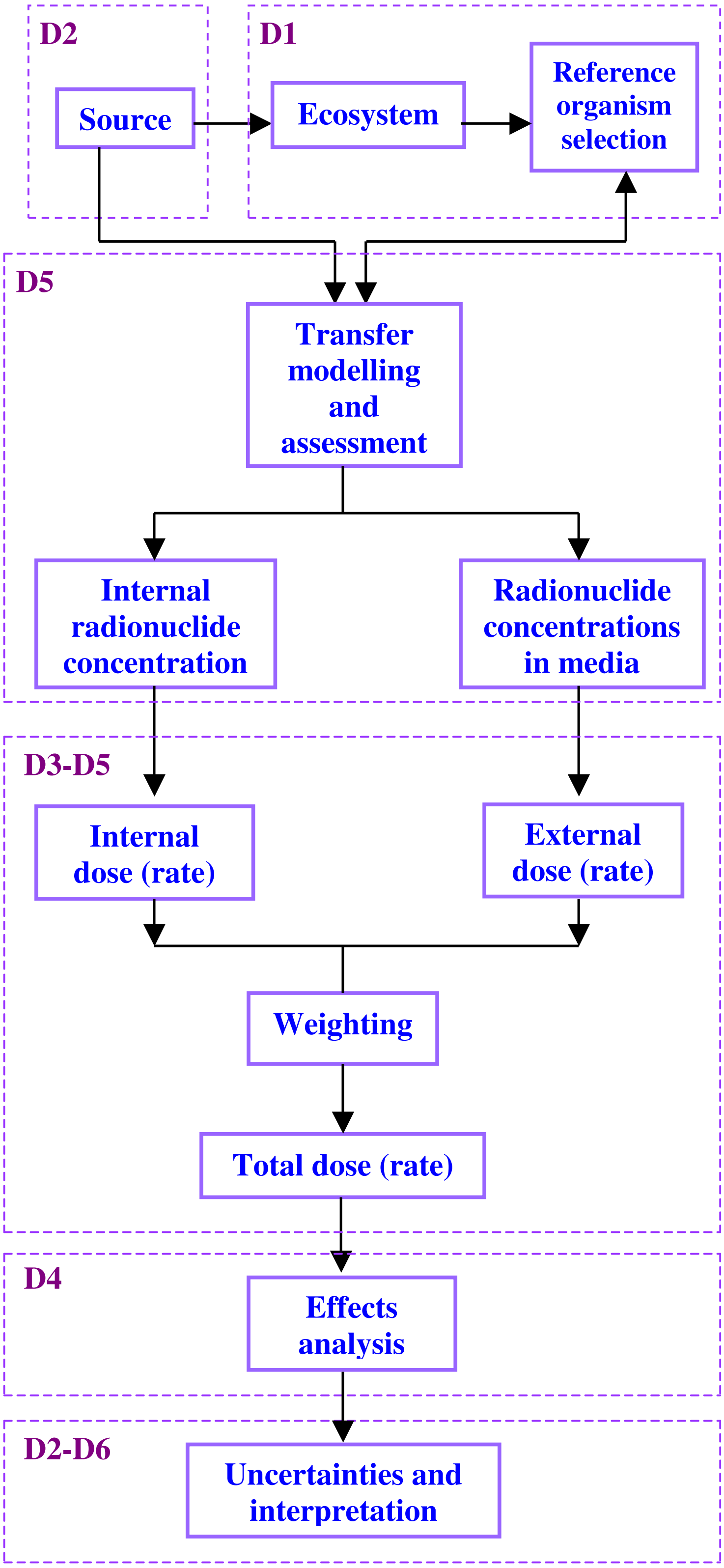


Figure 1 *Sequential organisation of the Framework elements, as developed by the FASSET Project, with reference to the sources of detailed information in the different FASSET Deliverables.*

EPIC (2000-2003)

EPIC: Environmental Protection from Ionising Contaminants in the Arctic

<u>Executive summary of D6</u>*: The "EPIC" impact assessment framework: Towards the protection of the Arctic environment from the effects of ionising radiation*

A Deliverable Report for EPIC (Environmental Protection from Ionising Contaminants in the Arctic). Funded under the European Commission's Inco-Copernicus Programme.Contract No: ICA2-CT-2000-10032. Edited By: JE Brown, H Thørring and A. Hosseini [2003].

This report provides an overview of the EPIC environmental impact assessment framework in its entirety and explores how the advances made in the project may provide input towards the development of criteria and standards ensuring protection of the Arctic environment from ionising radiation. Where relevant, the methodologies employed by environmental impact assessment systems for non-radioactive contaminants are discussed from the perspective of compatibility. In the introductory part of the report, the requirement for environmental protection is considered through an analysis of international conventions, agreements and legal issues. The need to relate the system to established underlying principles including conservation, sustainability and maintenance of biodiversity is also emphasised.

The EPIC system consists of problem formulation stage and primarily of an assessment methodology that will allow an assessor to quantify the probable effect of radiation exposure to selected biota following a defined release of radionuclides. Pure decision and management issues fall beyond the scope of our assessment as these involve judgements of a societal, political etc. nature. The considerations afforded the system development have also been limited in a geographical context, i.e. to the European Arctic, and to a suite of 13 radionuclides selected to be broadly representative of:

(i) routine release scenarios from power plants and reprocessing facilities,

(ii) accidental releases and

(iii) naturally-occurring or technologically enhanced naturally occurring (TENORM) radionuclides.

Three ecosystem types have been studied, i.e. terrestrial, freshwater and marine and the starting point for the assessment has been selected to be a unit concentration of a specified radionuclide in the environment with emphasis placed upon food chain transfer as oppose to physical transport processes.

Earlier in the EPIC project, lists of reference organisms were constructed based on the application of selection criteria including: Ecological niche, intrinsic radiosensitivity, radioecological sensitivity, distribution and amenability to research and monitoring. The generic reference organism lists have been used as a basis for deriving appropriate environmental transfer data information and selecting suitable target geometries/phantoms for dosimetric modelling. With respect to these points, it became apparent that the identification of actual species (or in some cases families or classes of organisms) representing each of the broadly defined groups would be helpful in some instances. Basic ecological information needs to be collated for each of the selected flora and fauna. The specific organism attributes that should be considered relate directly to the subsequent assessment of exposure. For example, information should be provided on habitat and, where applicable, the fractional occupancy of various organisms in their habitats. Guidance on the types of ecological information required for reference fauna has been provided in this report. For the purpose of illustration Life History data sheets have been presented in Appendix 1.

Several approaches have been employed in order to consider the transfer of radionuclides in the Arctic environment. In the first instance, datasets providing information on concentration ratios/factors (CR/CF) have been collated for reference organism types and the suite of EPIC radionuclides. This exercise has allowed data gaps to be identified. In cases where data coverage is poor or non-existent, other methodologies have been employed in the process of providing estimates. Such methods have included the application of allometric relationships and the biokinetic models. Recommended values have been provided for terrestrial and marine environments in Appendices 3 and 4, respectively. Limitations in the application of concentration ratios have been explored. These essentially relate to problems in applying the method where sources to a compartment are numerous and the unsuitability of applying the approach to non-equilibrium situations. In light of these problems, further work was conducted in the development of fully dynamic models as exemplified by the modification of an existing radiological model "ECOMARC" to allow activity concentrations in a herbivorous (reindeer) and carnivorous mammal (nominally a wolf) to be derived.

The method for deriving absorbed doses is based on an approximation describing the dose distribution defined using Dose attenuation function and Chord distribution functions. External doses to organisms from radionuclides present in soil or in the water column are calculated using a variant of a simple formula for a uniformly contaminated isotropic infinite absorbing medium: This approach neglects density differences between the organism and the medium. A two-step method has been used for the estimation of external exposures at the interface of environments with different densities. In the first step, the kerma in a specified location (above the soil/air interface, in soil at the given depth) is derived. In the second step, the ratio of the dose in an organism and the kerma is calculated for the different organisms and radionuclides. A computer model with a user-friendly interface has been developed to allow such calculations to be conducted. Radionuclide specific Dose Conversion Factors (DCFs) have been generated for all reference organism groups and a large suite of radionuclides including the 13 radionuclides selected within EPIC and radionuclides from ^{238}U and ^{232}Th decay series. Within this report, weighted DCFs have been derived using provisional weighting factors of 3 for 3H and 10 for alpha radiation. These DCF values are presented in Appendix 2 of this report.

The approach taken within EPIC with regards to analyses of dose-effects relationships was to collate and organise data around the reference organism categories and to focus on dose-rates and biological endpoints that are of relevance from the perspective of environmental protection. Data of dose-effects relationships on radiation effects in biota available from Russian and other former Soviet Union sources have been collated. The compiled data are concentrated on the effects in radiosensitive species in terrestrial and aquatic ecosystems, such as mammals, fish, and sensitive groups of plants (for example pines). Data have been organised under "umbrella" end-point categories, namely: morbidity, reproduction, mortality, cytogenetic effects, ecological effects, stimulation effects and adaptation effects. A general conclusion can be made, that the threshold for deterministic radiation effects in wildlife lies somewhere in the range 0.5-1 mGy d^{-1} for chronic low-LET radiation. However, although minor effects on morbidity in sensitive vertebrate animals are observed at the dose range specified above, populations of highly productive vertebrate organisms are viable at dose rates in the order 10 mGy d-1. Preliminary scales defining the severity of radiation effects at different levels of chronic exposure for different organisms groups have been constructed. In addition, background dose-rates have been calculated for reference organisms in terrestrial, freshwater and marine ecosystems although some of the values generated have been based on very limited data sets.

There are currently no radiation dose limits in place for Arctic environments. In order to assess the potential consequences of exposures to radiation on non-human biota, arguably, two points of reference may be used. These are (a) natural background dose rates and (b) dose rates known to have specific biological effects on individual organisms. The information collated within the EPIC project is consistent with this and, therefore, allows an evaluation of potential effects from a given dose-rate to be made without explicitly providing dose-limits. Furthermore, the generalised conclusions, within EPIC, regarding the threshold dose-rates at which various effects are observed are consistent with earlier studies. From the available information it is, therefore, not possible to justify any Arctic specific dose-standards at the present time. It should be noted, however, that the data set upon which such a conclusion is drawn is limited in scope and the hypothesis relating to whether there is a unique expression of radiation-induced biological damage under Arctic conditions remains to be properly tested.

The EPIC environmental impact assessment framework is generally compatible with systems being developed elsewhere including those applicable for non-radioactive substances. The reference organism approach has now been advocated by a number of international authorities on this subject including the International Commission on Radiological Protection (ICRP), the International Atomic Energy Agency (IAEA) and the International Union of Radioecology (IUR). Similar methodologies have also been applied in a recent EC study looking at impact of radionuclides in European marine areas, i.e. The Marina II study.

At the end of this report, areas of information deficiencies are identified and recommendation made for further development of this system. In particular, these relate to the development of better transfer data, through empirical data collation and modelling, in the Arctic environment, dose reconstruction of numerous data entries in the EPIC dose-effects database and the more detailed exploration of dose-effects on Arctic species (at present most of the available information relates to boreal species).

PROTECT (2006-2008)

PROTECT: Protection of the Environment from Ionising Radiation in a Regulatory Context

www.ceh.ac.uk/protect

The EC EURATOM funded **PROTECT** project (FI6R-036425) aims to evaluate different approaches to protecting the environment from ionising radiation.

We will compare these approaches with those used for non-radioactive contaminants, which will allow us to suggest numerical target values and develop standards for protecting the environment from ionising radiation. To achieve this we will work with the International Commission on Radiological Protection, the International Atomic Energy Agency, regulators, industry and other interested parties. The outputs will help to inform a future revision of the EC Basic Safety Standards.

Work Plan

There are four work packages associated with the project:

WP1: Environmental protection concepts

WP2: Assessment approaches: practicality, relevance and merits

WP3: Requirements for protection of the environment from ionising radiation

WP4: Management and progress assessment

During the course of the project we will run a number of workshops for interested parties from regulatory organisations, NGOs, industry and the research community.

Work Package 1

Drawing on the experiences of key stakeholders from regulatory organisations, NGOs and industry (nuclear and chemical) in different member states, this WP will:

- gather information on the current regulatory approaches to both chemical and radioactive substances in member states;
- critically review the biological and ecological endpoints of protection currently used and the similarities and differences between approaches for chemical and radioactive substances.

Work Package 2

This WP will bring together those organisations using or developing ways of protecting the environment from ionising radiation in order to:

- evaluate whether existing and developing approaches are practical;
- consider how acceptable and relevant the approaches are to regulators and industry (identified by WP1);
- apply numerical target values recommended by WP3 and others;
- assess the user-friendliness of the approaches to potential users;

Application of the available approaches to case studies will be used to help achieve these objectives.

Work Package 3

To propose numerical target values for protection of the environment from ionising radiation to ensure compliance with protection goals. This WP will:

- define appropriate levels of protection, taking into account European legal requirements and existing practices for other hazardous substances;
- propose target values for both dose and activity concentrations to ensure protection level compliance.

Consult with regulators, industry, NGOs and other experts to identify areas of consensus and make recommendations for numerical target values in the future.

Summary

PROTECT will:

- evaluate the current regulatory approaches to chemical and radioactive substances, recommend how standards should be set and establish how to assess these approaches;
- evaluate different approaches for protecting the environment from ionising radiation;
- propose an appropriate level of protection and numerical target values;
- record views from the consultation exercise
- make recommendations for the future.

Consortium

- Centre for Ecology and Hydrology: Co-ordinator of the project
- Swedish Radiation Protection Authority
- Environment Agency
- Norwegian Radiation Protection Authority
- Institute for Radiological Protection and Nuclear Safety

Note that all deliverables from the ERICA project will be transferred to the PROTECT website www.ceh.ac.uk/protect as of March 2007.

EUROPEAN COMMISSION
Community Research

ERICA

(Contract Number: FI6R-CT-2004-508847)

D-ERICA Annex A:

Uncertainty matrix applicable to the ERICA Tool

Editor: **Copplestone D**

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Dissemination Level		
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RE	Restricted to a group specified by the partners of the [ERICA] project	
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www.erica-project.org	1	electronically as pdf on the public area

ERICA (Environmental Risk from Ionising Contaminants: Assessment and Management) will provide an integrated approach to scientific, managerial and societal issues concerned with the environmental effects of contaminants emitting ionising radiation, with emphasis on biota and ecosystems. The project started in March 2004 and is to end by February 2007.

Erica Tetralix L.

Contract No: **FI6R-CT-2004-508847**
Project Coordinator: **Swedish Radiation Protection Authority**

Contractors:

Swedish Radiation Protection Authority	SSI
Swedish Nuclear Fuel and Waste Management Company	SKB
Facilia AB	Facilia
Södertörn University College	SUC
Norwegian Radiation Protection Authority	NRPA
Research Centre in Energy, Environment and Technology	CIEMAT
Environment Agency	EA
University of Liverpool	UNILIV
Natural Environment Research Council, Centre for Ecology and Hydrology	NERC
Westlakes Scientific Consulting Ltd	WSC
Radiation and Nuclear Safety Authority	STUK
Institute for Radiological Protection and Nuclear Safety	IRSN
GSF - National Research Center for Environment and Health, GmbH	GSF
Norwegian University of Life Sciences (previously NLH)	UMB
Electricité de France	EDF

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Executive Summary

This report extends the text published in Section 3.4 of the ERICA deliverable D8 - Considerations for applying the ERICA Integrated Approach (Zinger *et al.*, 2007).

Practical options for dealing with data gaps and uncertainties

The most appropriate practical approaches for dealing with uncertainties and gaps in data will depend upon the assessment context and on the form of the type of uncertainty concerned – whether it primarily arises from incomplete knowledge (which can be addressed by additional research) or from natural variability (which cannot be reduced by additional research).

In order to assist the assessor, key practical options available for dealing with knowledge gaps and uncertainties, when applying the ERICA Tool, have been identified within matrix. The types of issues, options exist and their strengths and weakness are outlined. This matrix is provided in the Annex 2 of D8, and some of the main features are outlined below for ease of reference.

The options matrix

This matrix is intended to provide the user of the tool with options for dealing with uncertainties – its focus is thus on the application of the ERICA tool rather than on the uncertainties inherent in the development of the tool and the underlying models. The structure of the matrix is as follows:

Table 1: Structure of the options matrix.

Issue	Description	Types of uncertainty	Options	Strengths	Weaknesses
		U or V or DG*			

***Uncertainty (U):** arises from imprecision due to lack of information, expert judgement and/or measurement errors and could be reduced with increased knowledge and/or experimentation. **Variability (V):** otherwise referred to as natural variability and results from heterogeneity. Variability is inherent and cannot be eliminated in general. **Data Gap (DG).**

The types of issue for which decisions may be required have been grouped into the various steps involved in conducting an assessment:

- source characterisation, including source monitoring, radionuclide selection and discharge routes;
- ecosystem analysis, involving both biota and environmental characterisation;
- environmental transfer, which incorporates the transfer of radionuclides from environmental media to organisms and the subsequent assessment of internal and external dose rates;
- effects analysis; and,
- interpretation and evaluation.

Each issue has been classified in terms of the general type of uncertainty it represents. However, it is recognised that the type of uncertainty associated with an issue may vary depending on both the context of the assessment and the tier being applied.

The matrix information is intended to help the assessor to identify the practical options for coping with an incomplete data set – arising from uncertainty or variability – and to make choices on the basis strengths and weaknesses associated with them (including issues such as stakeholder acceptance, resource implications and the extent of expert consultation likely to be required). The extent to which different options are applicable or feasible will be determined by the primary type and characteristics of uncertainty concerned. Some general considerations are outlined below.

- Measurement or data uncertainties – can be reduced by further measurement to a certain extent, although errors in measurement and uncertainties arising from natural variability will remain following additional measurements.
- Scenario uncertainties – or incomplete information about the situation to be assessed – may be reduced in some cases (for short-term retrospective assessments for example additional measurements may provide additional information). However, these types of uncertainty are generally accounted for by making alternative assumptions about the situation, e.g. maximising assumptions (as implied by the semi-quantitative treatment defined by the scenario sub dimension of the level of uncertainty defined by Walker and van der Sluijs).
- Conceptual uncertainties – arising from the conceptualisation of natural processes into simplified functions, e.g. the consideration of complex dynamic environmental processes as transfer coefficients between simplified environmental compartments. This type of uncertainty is fundamental to the process or situation being modelled and it is difficult to consider in a purely numerical way. It may correspond to uncertainties in the context of expert judgement – and relate to knowledge uncertainties, recognised ignorance.
- Model uncertainties – relate to uncertainties in the numerical implementation of the conceptual model – the uncertainties in the model may be studied (and to some extent reduced) by numerical means, for example by undertaking verification and validation exercises. The applicability of model parameters may be improved by additional measurements – but variability uncertainty will remain.
- Parameter (or data) uncertainty – is often difficult to distinguish from model uncertainty. Such uncertainties may be reduced by undertaking focused experimental work but uncertainties related to natural variability will remain.

The options referred to in Appendix 1 of this Annex 2 provide practical alternatives for deriving specific parameters, in the absence of a full dataset. Some general features are summarised below.

Table 2: Summary of practical options for dealing with data gaps and uncertainties.

Options	**Strengths**	**Weaknesses**
Ignore process or source of uncertainty of concern	Easy to apply	Provides no information about the likely importance of process or uncertainty. Likely to be difficult to justify to stakeholder groups
Maximising assumptions about the relevant parameter	Easy to apply – provides an upper estimate of the likely influence of parameter or uncertainty	Could lead to significant overestimation and unnecessary concerns
Additional literature research with application of single value parameters	Confidence in results of additional literature search.	Rather resource-intensive and requires specialist knowledge to make use of primary literature information. Does not necessarily reduce uncertainties arising from variability/site-specific issues or allow uncertainties to be quantitatively assessed.

Options	Strengths	Weaknesses
Site-specific or relevant experimentation – to derive single value (site specific) parameters	Greater confidence that parameters are applicable to the site being considered – should reduce uncertainties primarily to intrinsic local variability.	Very resource-intensive; high level of expert input required to design and perform site-specific survey to provide representative input. Single-value parameter derivation does not provide for a sensitivity or uncertainty analysis.
Additional literature research to develop distribution of relevant parameters (for inclusion in sensitivity and uncertainty analysis)	Greater confidence that uncertainties are included as an intrinsic part of the assessment; provides basis for sensitivity analysis which could provide basis for focusing effort for more detailed uncertainty.	Resource-intensive and specialist input needed to undertake search and develop necessary distributions.
Application of expert elicitation techniques to derive a parameter distribution	When well structured – the approach can add to buy-in and increase confidence in results	Expert planning required to ensure consistency of results.
Site specific or relevant experimentation to derive distributions of relevant parameters (for inclusion in sensitivity and uncertainty analysis)	The most comprehensive treatment of parameter uncertainty possible – may add to confidence in results	Very resource intensive, the site-specific research, interpretation of experimental results and the application and interpretation of uncertainty analysis results will require detailed expert input.

Example of use of the uncertainty matrix

The uncertainty matrix described above also provides a practical framework for recording the uncertainty-related decisions. A simplified version is given as an example in Table 3.

Table 3: Example of use of the uncertainty matrix.

Location		**Type of uncertainty**			**Nature of uncertainty**		
		Statistical	**Scenario - range**	**Ignorance**	**Knowledge-related**	**Inherent variability**	**Quality of knowledge base**
Assessment Tool							
Model Parameters	CRs	Site specific concentration ratios (e.g. in Tier 3)			Conceptual and model uncertainties related to the use of simple equilibrium factors to model complex dynamic process - apply to any use of CRs	Appropriate sampling and analysis	Good - specific to situation being considered
		Generic data for Cs-137 and Sr-90 distribution data and statistics available			As above	Site-specific applicability unknown	Much of CR database related to human modelling requirements
			Choice of CRs based on expert judgement and extrapolation methods, e.g. on trace or chemically similar elements		As above	Significant - related to site-specific variation and variations in radionuclide/organism characteristics	Depends on radionuclide and organisms involved - may vary between moderate and poor
				For many other radionuclides, or maximising assumptions			Poor knowledge base

Location		Type of uncertainty			Nature of uncertainty		
		Statistical	Scenario - range	Ignorance	Knowledge-related	Inherent variability	Quality of knowledge base
	Kds	Site-specific data			Model and conceptual uncertainties related to use of distribution coefficient apply to use of site-specific and generic values	High degree of variability for different sites due to selinity, redox, sediment load etc.	Good knowledge base if site-specific analysis appropriate
			Single-value ranges of Kd values generally available (e.g. IAEA)			See above	Moderate-poor depending on radionuclide
	DCC		Organism-specific geometry applied (Tier 3)		Applicability of whole body coeficients due to heterogeneity in dose distribution for some radionuclides		Best available
			Application of generic geometry and DCC values			Significant - due to variations in size and shape of organism and target-source configurations	Applicability will depend on the organism concerned
	Weighting factors	For gamma and beta radiation	For alpha - due to internal incorporation			Variation in biological effectiveness of different radiation types in inducing different biological endpoints	Knowledge base varies depending on organism and biological effect type

Location		Type of uncertainty			Nature of uncertainty		
		Statistical	**Scenario - range**	**Ignorance**	**Knowledge-related**	**Inherent variability**	**Quality of knowledge base**
	Occupancy factors		Ranges of values based on observations for generic species	Applicability to specific species (and specific life stages) unknown		Significant variations with climate and organism	Generally unspecific database of information
Model inputs	Radionuclides	Discharge and monitoring information available for some sites and radionuclides			The chemical form of the radionuclide may not be known in detail	Temporal and spatial variability	Well known - scientific judgements
	Activities		Given incomplete information on radionuclides present - assumptions and ranges necessary		Exact nature of radionuclides may not be known		
	Reference organism		semi-quantitative judgements on reference organisms applicability to species of concern			Natural variability difficult to accommodate in simple assessment	Varies from good/moderate to poor - depending on information available for given species and organism.
Outputs	Effects analysis	For some effects and organisms			Related to type of effect - individual or population; use of laboratory information to the field;	Natural variation in sensitivity of different organisms and species; analysis of experimental protocols	Good for some species and endpoints - poor for others

Location		Type of uncertainty			Nature of uncertainty		
		Statistical	**Scenario - range**	**Ignorance**	**Knowledge-related**	**Inherent variability**	**Quality of knowledge base**
			For some effects and organisms derived from information on analogue organisms		Information available for sub-set of organisms	See above	Poor for many organisms
	Derivation and application of dose rate or concentration benchmarks	For species where distribution information exisits - possible to use species sensitivity distributions to derive 'no effects' levels			Multiple stressor or inter-organisms events may affect sensitivity that are not taken into account	Natural variability in sensitivity (see 'effects analysis')	Subjective valuation related to the percentiles used for benchmarks
				Where effects information is sparce - uncertainties may be taken into account by application of safety factors		See above	Poor scientific basis for decisions

Appendix 1: Uncertainty matrix applicable to the ERICA Tool

*** Three types of uncertainties: (U) uncertainty/ (V) variability / (DG) data gap**

Issue	Description	Type*	Options	Strengths	Weaknesses
Source characterisation					
Source monitoring					
Discontinuous emissions monitoring	Emissions may be variable, which is not reflected in emissions monitoring programme	U/V	**Tier 1**: Assume maximum activity concentration detected or modelled/predicted to apply for the entire period of assessment	Conservative approach not requiring additional resources	This typically conservative approach may result in assessments exceeding action levels in circumstances where a more realistic assessment would suggest there was no need for concern
			Tier 2: Undertake monitoring of discharge or source of activity in the environment to gather more specific information	More accurate assessment of levels of activity entering or present in the environment on which to base assessment	Resource-intensive survey work likely to require expert consultation
			Tier 2: Undertake modelling study based on understanding of general discharge behaviour to determine likely concentration ranges within environmental compartments	Not resource intensive and allows informed judgement of likely consequences of variation in emissions	Not as robust as conducting discharge monitoring
			Tier 3: Undertake more detailed assessment of the variability of discharges with time and undertake assessment that takes account of temporal variability (e.g. based on more appropriate averaging but continuing to apply equilibrium assumptions if appropriate)	Reasonable approach where discontinuity does not significantly influence exposure or effects analysis (e.g. in relation to the life-time or occupancy of the biota group concerned)	Resource-intensive and requiring expert consultation

Issue	Description	Type*	Options	Strengths	Weaknesses
Transient conditions and temporal variability	Transient, non-equilibrium conditions may influence the activity present and transfers and uptakes (e.g. from unplanned release, or short-term exposure during particular season that is particularly relevant to the assessment of biota effects)	V/U	**Tiers 2 and 3**: Consider the appropriate temporal averaging appropriate for the biota concerned and undertake appropriate measurements	Confident that temporal averaging will reflect organisms of concern, leading to more accurate exposure and effects analysis	Resource-intensive and requiring expert consultation
			Tier 3: Take account of the transient conditions by applying dynamic environmental transfer modelling external to the ERICA tool	More accurate assessment of levels of activity in biota of concern leading to more accurate effects analysis	Resource-intensive. Data on exposure and effects are not always sufficient to support dynamic modelling. Requires consultation Data may be unavailable in the literature to enable dynamic models for the particular situation to be developed/applied
Environmental activity concentrations (measured or modelled) do not take account of spatial variability	Sampling locations may not be representative of environmental contamination	U	**Tier 1**: Assume maximum activity concentration detected or modelled/predicted to apply	Simple screening approach. May be sufficient for low concentration sources	Conservative approach likely to lead concentration 'limiting' values being exceeded unnecessarily
			Tier 2 may be necessary to interpolate concentration at site of interest using dispersion assumptions.	Easy to apply (models form part of ERICA tool)	Uncertainties and variability in activity concentrations will remain that are not assessed in this process

Issue	Description	Type*	Options	Strengths	Weaknesses
			Tier 3: Survey of spatial distribution and extent of biota and specific allowance in assessment. Assess dose based on frequency of occurrence within the area of interest	Accurate assessment of exposure and effects that is more representative of the location of interest; uncertainty and sensitivity analysis allows importance of spatial variability to be studied	Resource-intensive and requiring expert consultation
			Tier 3: Enter values beyond a discharge point that provide a more representative value for calculation of population relevant exposures.	Accurate assessment of exposure and effects that is more representative of the location of interest.	Resource-intensive and requiring expert consultation
There may be contributions from more than one source (e.g. contamination from other source or from past discharge)	Radionuclides may be deposited in the environment from more than one source; consideration of a single source (e.g. on the basis of current discharges alone) may lead to impacts being underestimated	U	**Tier 2**: Evaluate the existing dose rate arising from all sources based on information available in literature (e.g. on the activity concentrations existing in the area of interest)	Limited additional resource implications, provides confidence that additional sources taken into account	The information available in the literature will be generic in nature and not necessarily applicable to the specific area of interest. This approach does not provide quantitative evaluation of uncertainties.
			Tier 2: Undertake assessment for each site and combine results	Complete assessment with the same level of consideration for each	More resource-intensive than consideration of a single site, there may be problems involved in combination of results
			Tiers 2 and 3: Undertake environmental sampling programme that takes account of contributions from all sources in the area of interest	Confidence that this approach will reflect the specific nature of the multiple sources existing in the area	Sampling, design and interpretation of results would require expert consultation, does not take quantitative account of uncertainties

Issue	Description	Type*	Options	Strengths	Weaknesses
			Tier 3: Undertake site-specific assessment and uncertainty analysis	Confidence that this approach will reflect the specific nature of the multiple sources existing in the area, and allow for uncertainties in a quantitative manner (assuming other parameters are dealt with in a proportionate manner).	Resource intensive and requiring expert consultation
Unknown source term	Contamination may result from diffuse releases or from historic activities	DG/U	**Tier 1**: Apply conservative assumptions on the presence and activity concentrations of radionuclides at the site of interest		Expert judgement required. Subject to error
			Tier 2: Review available information on past activities / possible sources of contamination to identify possible radionuclides and activity concentrations		Could result in an inaccurate / incomplete assessment. May be resource intensive if modelling required to determine activity concentrations
			Tier 3: conduct environmental monitoring to determine radionuclides present and activity concentrations in environmental media	confidence that assessment will be based on site-specific data	Resource intensive.
Radionuclide					
Radionuclide may not exist in ERICA database	An assessment of impacts of a radionuclide not present in the ERICA database may be required	DG	**Tier 1**: Go to **Tier 2**	Approach does not require additional resource	Significant uncertainties will exist in the application of this information
			Tiers 2 and 3: Use ERICA tool to access information from ICRP 38 on relevant radionuclide transformations, energy and intensity of emissions for the radionuclide of interest and use this information (together with geometry information for biota) to assess dose rates. CR data will also be required.	Easy to apply (models form part of ERICA tool)	Likely to be incomplete assessment (external dose only); expert analysis will be necessary

Issue	Description	Type*	Options	Strengths	Weaknesses
Speciation of radionuclide	Chemical form of radionuclide may affect transfer, uptake, metabolism and internal distribution - the form and effect on transfer may be unknown	U/DG	**Tier 1** concentrations will be based on generic assumptions that encompass a range of different physico-chemical forms where possible for a radionuclide.	Easily applied approach	Data may lead to overestimation (although there is also the potential for underestimation if the radionuclide is present in an unusual form)
			For **Tier 2** gather information (e.g. from literature, operator information) on the chemical form to influence choice of parameters of concern, e.g. CR and Kd.	Not significantly more work than using default information	More likely to be representative of the nuclides under consideration
			Tier 3: Take account of the range of parameter values due to speciation in defining uncertainty distributions	This approach allows the sensitivity of results to the range of input parameters to be studied (to focus further work, e.g. measurement programmes)	The definition of distributions may require consultation with an expert
			For **Tier 3**, the form of radionuclides determined by measurement and choice of appropriate parameter distributions to form basis of uncertainty analysis	The assessment will be more situation-specific	It may be resource-intensive to obtain spatial/temporally representative information
Radionuclides in source or discharge unknown	Discharges or monitoring results may be reported as total alpha/beta and radionuclide contributions are unknown	DG	**Tier 1** - assess using worst case substitution (e.g., assume 100% alpha is Pu-239, 100% beta is Cs-137), taking account of site knowledge on likely radionuclide emissions)	This provides an easy scoping assessment	This approach may lead to 'limiting concentrations' being exceeded unnecessarily. May require expert consultation.
			Tier 2: Obtain more information on the radionuclides (e.g. from past site experience)	This approach is likely to be more accurate than application of default conservative assumptions while not being resource-intensive	The approach may not be accurate if there has been a significant change in release or source characteristics

Issue	Description	Type*	Options	Strengths	Weaknesses
			Tier 3 - Conduct emissions and/or environmental measurements to determine radionuclides present	Measurement data for the environmental medium of concern will provide the most accurate assessment of the radionuclides present (and their quantities)	Resource-intensive. It may be difficult to obtain measurement results in environmental materials that exceed detection limits. Sampling programme design and performance would require consultation with an expert
Activity concentrations present in the environment unknown	Activity concentrations in the environment are required for an assessment to be conducted - often this information is interpolated from information on releases to the environment	DG	**Tier 1**: Assume maximum expected concentration in water or soil (from previous experience, authorisation assessments or other relevant information)	Simple screening approach. May be sufficient for low concentration sources	May be over-conservative leading to 'limiting concentrations' being exceeded unnecessarily. Inherent uncertainty in the assessment may reduce stakeholder confidence
			Tier 1: If discharge rates are known, apply IAEA SRS19 model to estimate environmental concentrations.	Easy to apply	Model is not site-specific so may result in degree of uncertainty
			Tier 1: Estimate the activity concentration at location(s) of interest from discharge information, using dispersion models included in ERICA Assessment tool	This is a useful approach where there is some but incomplete information available (e.g. activity concentrations at point of release but not at the location of biota of interest)	The dispersion assumptions used in this approach do not take account of site-specific topography or surface water conditions.
			Tier 2: Estimate the activity concentration at location(s) of interest from discharge information, using dispersion models included in ERICA Assessment tool	This is a useful approach where there is some but incomplete information available (e.g. activity concentrations at point of release but not at the location of biota of interest)	The dispersion assumptions used in this approach do not take account of site-specific topography or surface water conditions.

Issue	Description	Type*	Options	Strengths	Weaknesses
			Tiers 2 and 3: Undertake environmental monitoring at the location of the biota of interest	This is potentially the most accurate approach on which to base dose rate or risk assessments	Relatively resource-intensive and it may be difficult to obtain measurement results in environmental materials that exceed detection limits. Sampling programme design would require consultation with an expert.
			Tiers 2 and 3: Conduct robust dispersion modelling taking account of site specific conditions	Provides potentially more accurate assessment of dispersion	Can be resource intensive where models have not been calibrated for the characteristics of the area in question
	Monitoring results are below limit of detection (LoD)	U	**Tiers 2 and 3**: Where all results are consistently below the limit of detection, assume radionuclide is not present.	This approach is easy to apply	This approach may lead false negative results
			Tiers 2 and 3: Where a proportion of results are below the limit of detection, assume concentration is half the value of the LoD	This approach reflects the expected statistical distribution of results around the LoD, and allows all radionuclides with positive measurement results to be taken into account	This result may result in false positive results
Radionuclides give rise to progeny of potential importance	It is necessary to take progeny into account that may result in additional impacts to biota.	U/DG	**Tier 1**: Apply concentration levels that effectively disregard the in-growth of progeny	Easily applied approach that is useful for scoping purposes	The concentration limiting value may underestimate overall impact e.g. where sedentary biota close to discharge point are continuously exposed to short-lived radionuclides
			Tier 2: Apply concentration levels that effectively disregard the in-growth of progeny	Easily applied approach that is useful for scoping purposes	The concentration limiting value may underestimate overall impact e.g. where sedentary biota close to discharge point are continuously exposed to short-lived radionuclides

Issue	Description	Type*	Options	Strengths	Weaknesses
			Tier 3: Consider the sensitivity of results to changing assumptions regarding the production and behaviour of radioactive progeny	More complete analysis that will provide the most comprehensive treatment of progeny	Resource-intensive, more complex assessment likely to require expert consultation (e.g. regarding the balance between effective and radioactive half-lives and relevance to life time of biota of interest etc).
Discharge routes					
Impacts on biota in more than one medium/ecosystem	Releases into a medium may have an impact on another. Impacts may be underestimated if impacts on only one ecosystem is considered	DG/U	**Tier 1**: Assume that a single ecosystem is affected (e.g. that into which material is discharged)	Ease and rapidity of assessment. Where assessment indicates no impact on biota in the receiving environment, there can be reasonable certainty that secondary environments would be unaffected.	Incomplete assessment - biota in 'secondary' media may be more significant or more sensitive
			Tiers 2 and 3: Consider impacts on all potentially affected ecosystems, run ERICA for each one and combine as appropriate	This provides a more complete assessment of impact	This approach would require results to be assessed for each ecosystem in turn (and occupancy weighted for biota that exist in more than one ecosystem)
Completeness of conceptual model	All processes involved in the transfer of radioactivity to the environment / biota of concern may not have been considered	U/DG	**Tier 3**: Test predictions from conceptual model to environmental observations	Enables accuracy of model to be verified	Resource intensive.

Issue	Description	Type*	Options	Strengths	Weaknesses
Ecosystem analysis ***Biota characterisation*** Data on presence of species within an ecosystem are unavailable	Presence of sensitive species within the potential impact zone are unknown	DG	**Tier 1**: Use maximum soil, water or sediment concentrations and take 'pessimistic' view that the species are present and assume that at least one organism from the broad suite of ERICA reference organisms is a reasonable surrogate for the actual species present.	Ease and rapidity of assessment - valuable for scoping purposes	The implicit assumption that an assessment species is present may be unreasonable; the overestimation implicitly in the approach may raise unnecessary concerns. The assumption of the presence of particularly sensitive species may result in 'limiting concentrations' being exceeded unnecessarily.
			Tier 2: Identify generic species within the ecosystem type and conduct broad-ranging assessment	Use of default data provides ease of assessment and confidence that choice is based on expert opinion	Generic parameters may not be representative of the designated species present
			Tier 2: Assume the presence of sensitive species and construct a geometry and transfer data relevant for the organism using the 'add organism' functionality	Increases confidence that important biota have been included.	May require expert consultation
			Tiers 2 and 3: Gather information about the species present (and the designation of species and habitats) in the impact zone	This information is readily available and allows more informed development of assessment approach and a focus on designated species	The review and application of site specific information on species type may require consultation with an expert

Issue	Description	Type*	Options	Strengths	Weaknesses
Site designated on basis of habitat qualities rather than species	An assessment may be required to ensure protection of important sites designated for reasons other than the presence of sensitive biota	DG	**Tier 1**: Apply concentration levels that implicitly assume the presence of a generic species relating to the relevant ecosystem type	Ease and rapidity of assessment - valuable for scoping purposes	The species on which this approach is implicitly based may not be representative of the species the designated habitat
			Tier 2: Identify key generic components of the habitat and undertake assessment for these	Simple assessment method that provides assurance that the types of species in the designated area have been considered	This approach will require a review of specific information relating to the habitat. It may also require consultation with experts and stakeholder/conservation groups to ensure acceptability
			Tier 2 and 3: Apply safety factor in applying effects analysis that takes account of uncertainties in extrapolation from population responses to those occurring at higher levels of organisation (see below)	Allows more specific consideration of implications of ecosystem effects	Likely to require consultation with an expert - additional uncertainties will exist that need to be considered
			Tier 3: Identification of species or other assessment endpoint of interest in consultation with stakeholders	Assessment will address specific endpoints of concern to stakeholders	Stakeholder involvement process may be time-consuming and will require expert facilitation
Biodiversity status unknown	Biodiversity rather than specific species/habitats may be of importance	DG	**Tier 1**: Apply concentration levels that implicitly assume the presence of a species for assessment	Ease and rapidity of assessment - valuable for scoping purposes	The species on which this approach is implicitly based may not be representative of the species for which the area is designated
			Tier 2: Identify key species and habitats that have been designated on biodiversity grounds and undertake assessment for these	Simple assessment method that provides assurance that the types of species in the designated area have been considered	This approach will require a review of specific information relating to the habitat. It may also require consultation with experts and stakeholder/conservation groups to ensure acceptability

Issue	Description	Type*	Options	Strengths	Weaknesses
			Tier 2 and 3: Apply safety factor in applying effects analysis that takes account of uncertainties in extrapolation from population responses to those occurring at higher levels of organisation (see below)	Allows more specific consideration of implications of ecosystem effects	Likely to require consultation with an expert - additional uncertainties will exist that need to be considered
Significance of biota unknown (e.g. designation status)	Where sensitive species are identified, the significance of designation (e.g. locally important/internationally important) may affect the level to which an assessment should be conducted.	DG	**Tier 1**: Apply concentration levels that implicitly assume the presence of a species for assessment	Ease and rapidity of assessment - valuable for scoping purposes	The species on which this approach is implicitly based may not be representative of the species for which the area is designated
			Tiers 2 and 3: Gather information about the species present (and the type of designation of species or habitat, as appropriate)	This information is readily available and allows more informed development of assessment approach and a focus on designated species	The review and application of site specific information on species type may require consultation with an expert
Biota habit data unavailable	Information on the food preferences of identified organisms and occupancy factors within ecosystem compartments are unknown	DG	**Tier 2**: Apply generic habit data for biota type from the ERICA database	Ease of application. Confidence that data has been derived on the basis of expert opinion	The data may not be directly applicable to the biota concerned (significance depends on the designation of biota and predicted dose rates)
			Tier 2: Conduct review to identify similar species and use 'add organism' functionality to assess differences in factors applied.	Increased confidence in assessment through variability analysis	Resource intensive and may require expert consultation

Issue	Description	Type*	Options	Strengths	Weaknesses
Geometry of identified biota unknown	Information on the geometry of species and location in surrounding medium is required to assess external dose to biota	DG/V	**Tiers 2 and 3**: Assume 100% occupancy in environmental media to which organism will be maximally exposed (e.g. soil / sediment)	Ease of application. Conservative approach.	Could be considered overly conservative.
			Tier 3: Carry out ecological survey to determine site specific data for assessment	Confidence that data will be applicable to the site in question (and applicability demonstrable to stakeholders)	Resource-intensive survey work will need to be undertaken by or in consultation with expert
			Tier 1: Apply concentration levels that implicitly assume the presence and default geometry of assessment species	Ease and rapidity of assessment - valuable for scoping purposes	The species on which this approach is implicitly based may not be representative of the biota of interest
			Tiers 2 and 3: Gather information on the geometry of biota of interest from literature (at key life stages) and undertake assessment based on this information using data from ERICA or other databases	Database of information available reducing the effort required	Consultation required in defining life-stage that is likely to be of interest (related to effects and radionuclides of concern)
			Tier 3: Undertake uncertainty analysis that takes account of the range of likely geometries	Allows more specific consideration of the likely impact of uncertainties in geometry to be assessed	Resource-intensive and requiring expert consultation.
			Tier 3: Undertake survey of the biota of interest to make more accurate assessment of geometry	More specific to situation being considered	There will be uncertainties related to the natural variability, and design, survey and analysis would also require expert consultation. Resource-intensive.

Issue	Description	Type*	Options	Strengths	Weaknesses
Environment characterisation					
Soil properties/water chemistry unknown	Behaviour of radionuclides within an ecosystem will be dependant upon factors such as pH, oxidation state etc	U/DG / V	**Tier 1**: Apply concentration levels calculated based on generic assumptions regarding soil and water properties	Ease and rapidity of assessment - valuable for scoping purposes	The parameters used in the assessment of concentration values may not be applicable to the environment under consideration (e.g. where characterised by extreme pH, or unusual soil types are present)
			Tier 2: Collect information on the general soil and water characteristics from locally available information & apply appropriate environmental parameters from literature sources in the assessment	Relatively easy assessment that takes account of the type of environmental conditions existing	Information may not be available for the specific radionuclide/biota/environment-type combination
			Tiers 2 and 3: Undertake limited survey to determine soil type/water chemistry characteristics at location of concern and use transfer parameter data for these characteristics (from literature sources)	Provides specific information related to the area of interest with limited additional expenditure	Survey work and interpretation are likely to require consultation with expert
			Tier 3: Undertake survey of environmental characteristics and behaviour of radionuclides of concern and measurement of activity concentrations in environmental media closely related to the primary biota of interest	Provides specific information related to the area of interest, which may be used in probabilistic assessment if appropriate	Sampling programme, survey work and interpretation will be resource-intensive and require consultation with expert

Issue	Description	Type*	Options	Strengths	Weaknesses
Level of background radiation unknown	Level of background radiation will affect the overall dose received by biota	DG	**Tier 1**: Ignore background (or for NORMs do not differentiate between background and man-made contributions)	Easy to apply	The validity of the approach will depend upon the way in which 'concentration limiting values' have been defined
			Tier 2: Derive background doses to biota from information on the average natural background doses experienced by humans in the area and literature-based information for the type of biota of concern	The easiest approach to estimate background doses to biota	Literature information on human and biota background doses will be based on averages that may not be applicable to the biota or area of concern
			Tiers 2 and 3: Derive background dose to biota from data from literature for similar biota and types of environment	Greater specificity of data at moderate effort	The background doses in the area under consideration may vary significantly from information available in literature sources
			Tier 3: Undertake survey to determine the background radiation doses experienced by biota of interest	Demonstrable confidence that data relates to location (and biota) of interest	Resource-intensive survey work will need to be undertaken by or in consultation with expert
Environmental transfer					
Environmental transport					
Dispersion and deposition factors unknown	Radionuclide specific factors unknown - this information is necessary for the calculation of environmental concentrations	DG	**Tier 1**: Ignore deposition and dispersion characteristics by using maximum concentration information for aquatic scenarios (e.g. at point of discharge)	Easy approach to apply - useful for scoping assessment	This approach is likely to lead to significant overestimation of environmental activity concentrations
			Tier 1: Apply IAEA SRS19 model and default parameters to calculate environmental concentrations.	Easy approach to apply.	Does not take account of site specific dispersion

Issue	Description	Type*	Options	Strengths	Weaknesses
			Tier 2: Generic values may be used from existing tools (including ERICA)	Likely to be more realistic than assuming no dispersion without requiring significant additional work	Continuing uncertainty in detailed pattern of contamination.
			Tier 3: undertake monitoring programme to identify environmental concentrations at locations of interest (such that dispersion and deposition data are not required)	Demonstrable confidence that data relates to location of interest	Resource-intensive survey work will need to be undertaken by or in consultation with expert. The natural variability in dispersion and deposition are likely to give rise to difficulties in sampling to ensure representative results
Activity concentrations present in environment unknown	Activity concentrations in the environment are required for an assessment to be conducted - often this information is interpolated from information on releases to the environment or activity concentrations in other media (e.g. water, soil and sediment)	DG	**Tier 1**: Assume maximum expected concentration in water or soil (from previous experience, authorisation assessments or other relevant information)	Simple screening approach. May be sufficient for low concentration sources	May be over-conservative leading to 'limiting concentrations' being exceeded unnecessarily. Inherent uncertainty in the assessment may reduce stakeholder confidence
			Tier 2: Estimate the activity concentration at location(s) of interest from other information, using dispersion models included in ERICA Assessment tool	This is a useful approach where there is some but incomplete information available (e.g. activity concentrations at point of release but not at the location of biota of interest)	The dispersion assumptions used in this approach do not take account of site-specific topography or surface water conditions.

Issue	Description	Type*	Options	Strengths	Weaknesses
			Tiers 2 and 3: Undertake environmental monitoring at the location of the biota of interest	This is potentially the most accurate approach on which to base dose rate or risk assessments	Relatively resource-intensive and it may be difficult to obtain measurement results in environmental materials that exceed detection limits. Sampling programme design would require consultation with an expert.
			Tiers 2 and 3: Conduct robust dispersion modelling taking account of site specific conditions	Provides potentially more accurate assessment of dispersion	Can be resource intensive where models have not been calibrated for the characteristics of the area in question
Kd is unavailable for radionuclide(s) of concern	This information is important for defining the relative amounts of the nuclide in water and sediment	DG	**Tier 2**: Survey recent literature and apply Kd for the radionuclide of concern if available	This approach allows recent information to be taken into account without site-specific survey work	Kds vary significantly depending upon location. It is therefore quite possible that the data in the literature will not be applicable to the situation under consideration
			Tier 2: Extrapolate from information for chemical analogues	This approach may be useful where assessments relate to unusual radionuclides	Kds vary significantly depending upon location. It is therefore quite possible that the data in the literature will not be applicable to the situation under consideration
			Tiers 2 and 3: undertake monitoring programme to measure Kd values	Demonstrable confidence that data relates to location of interest	Resource-intensive survey work will need to be undertaken by or in consultation with expert
Site specific Kd not available for radionuclide	Kd dependant upon soil/sediment/water chemistry	DG/U	**Tier 1**: Apply 'concentration limiting values' that implicitly include default Kd assumptions for the given radionuclide	Easy approach to apply and confidence that default data have been derived on the basis of expert opinion. Useful for scoping assessment	Kds vary significantly depending upon location. It is therefore quite possible that the default data are not applicable to the situation under consideration
			Tier 2: Apply default Kds from literature (including ERICA documentation)	Easy approach apply	Kds vary significantly depending upon location. It is therefore quite possible that the data in the literature will not be applicable to the situation under consideration

Issue	Description	Type*	Options	Strengths	Weaknesses
			Tiers 2 and 3: Undertake measurements to determine appropriate site-specific Kds	Demonstrable confidence that data relates to location of interest	Resource intensive in order to ensure that the data are representative of the appropriate conditions
			Tier 3: Gather information on the likely distribution of Kd values to form part of probabilistic analysis	Allows significance of results to the uncertainty in Kds to be studied	Likely to require consultation with experts
Adequacy of models uncertain	Assessment models may not take account of all factors within a system of interest	U	**Tier 2**: Identify and document uncertainty		
			Tier 3: Conduct inter-comparison, for example between site-specific models and default models within ERICA	Provides greater confidence in model outputs	Resource intensive.
Insufficient information on the relationship between habitat and biota monitoring data due to mobility of fauna	Sampled biota may not have been in contact with areas of contamination, site specific CRs may be inaccurate	V/DG	**Tier 2**: Use occupancy data to modify dose rate estimate	Simple approach not requiring additional survey work or other resources	This approach may lead to underestimation of internal dose rate due to oversimplification of distribution of contamination
			Tiers 2 and 3: Undertake a more detailed survey of the spatial range of biota and the extent of contamination. Use these data in exposure assessment	Provides more accurate assessment of exposure	Resource-intensive and requiring expert consultation (e.g. in design and performance of survey work).

Issue	Description	Type*	Options	Strengths	Weaknesses
			Tier 3: Undertake more detailed assessment of the variability of environmental concentration, and of the home range of fauna. Overlay home range data with spatial map of contamination to define degree and modify occupancy factors accordingly.	Provides more accurate assessment of exposure; the distribution information may be used to determine the importance of these uncertainties to the assessment results as a whole	Resource intensive and requiring expert consultation
Concentration Ratio (CR)					
No CR available for organism (for a given radionuclide) in ERICA Assessment Tool	CRs are necessary to estimate internal activity concentrations and doses from general activity concentrations in the environment, i.e. in water or soil	DG	**Tier 1**: The 'limiting' concentration values applied in this tier will be calculated on the basis of default derived CRs	This option is easy to apply; High degree of confidence that values are derived from expert knowledge; Derivation method documented.	Not possible for user to study the sensitivity of results to changing CR assumptions; The applicability of CR may be difficult to defend to non-specialists.
			Tier 2: Review literature for recent CR data and apply if relevant	The review and application of specific and recent information will improve confidence in the assessment	Resource-intensive approach that may require consultation with expert
			Tier 2: Calculate external dose rates only; .	This option is easy to apply and will be a reasonable assumption for many radionuclide/organism combinations for which external dose is the dominant exposure pathway, e.g. gamma emitters and soil invertebrates and zooplankton	This approach may lead to significant underestimation of dose rates for some radionuclides.
			Tier 2: Apply maximum CR or value of 1	Easily applied and provides estimate of dose rate with internal component maximised	Likely to be very conservative for most radionuclides

Issue	Description	Type*	Options	Strengths	Weaknesses
			Tiers 2 and 3: Apply CR available for taxonomically similar organism	May be relatively straightforward approach that is easy to justify	Depending on the data available, it may be a more complex decision that may require expert consultation
			Tiers 2 and 3: Apply CR from data for stable isotope	High confidence that the CR will relate closely to the chemical characteristics of the nuclide concerned	Data for stable isotopes may exhibit non-linear transfer behaviour (i.e. CRs are lower at higher concentrations
			Tier 2 or 3: Select CR from analogue (biogeochemically similar) radionuclide	Easily applied for groups of radionuclides with similar environmental characteristics (e.g. actinides)	Extension of this approach beyond defined chemical groups (e.g. actinides) will require consultation with an expert
			Tiers 2 and 3: Application of Allometric Extrapolation Methods	Expert consultation required	
			Tier 2 or 3: Collection of site-specific information	Confidence that the CF will relate to the specific organism and environment (if used in conjunction with generic information). The approach will be particularly important where the radionuclide or environmental conditions are unusual or extreme.	Resource-intensive and, if used in isolation, there may be significant uncertainties resulting from limited sample size and inherent variability of environmental transfers (particularly for bioaccumulation factors for fish tissue)
			Tier 3: Gather information on the distribution of CR values from site-specific information and use this as part of an uncertainty analysis	Allows the significance of these uncertainties to the results to be evaluated	Resource-intensive, expert consultation likely to be required in undertaking appropriate survey work and in undertaking and interpreting results of uncertainty analysis.

Issue	Description	Type*	Options	Strengths	Weaknesses
CR does not take account of natural variability in radionuclide uptake through food preferences etc	Inherent variability in natural populations cannot be accurately modelled by the use of one default CR	V	**Tier 1**: The 'limiting' concentration values applied in this tier will be calculated on the basis of default derived CRs	This option is easy to apply; High degree of confidence that values are derived from expert knowledge; Derivation method documented.	Not possible for user to study the sensitivity of results to changing CR assumptions; The applicability of CR may be difficult to defend to non-specialists.
			Tier 2: Review available literature for information on the variability in CR for biota of interest and apply as appropriate	Data likely to be generally representative of biota of interest; limited resource implications	CRs will still be subject to variability; this approach does not provide a natural basis for uncertainty or sensitivity analysis to determine importance of this variability
			Tier 3: Review information in recent literature on natural variability in CRs to use as basis for uncertainty analysis	Allows sensitivity of results due to variability to be determined (and the basis for prioritisation for further study)	Not site-specific; expert consultation likely to be required
			Tier 3: Collect information on natural variability from site-specific survey information and undertake uncertainty analysis	This approach allows the specifics of the situation to be taken into account, and the influence of uncertainties in CRs to form an explicit part of the assessment	Resource-intensive; The sampling design, performance and interpretation would require expert consultation; the results of the uncertainty analysis may require expert consultation
CR does not take account of natural variability in environmental	Different soil/sediment/water properties will affect CR such as organic content, pH etc	V	**Tier 1**: The 'limiting' concentration values applied in this tier will be calculated on the basis of default derived CRs	This option is easy to apply; High degree of confidence that values are derived from expert knowledge; Derivation method documented.	Not possible for user to study the sensitivity of results to changing CR assumptions; The applicability of CR may be difficult to defend to non-specialists.

Issue	Description	Type*	Options	Strengths	Weaknesses
parameters such as sediment/soil characteristics			**Tier 2**: Review available literature for information on the variability in CR for sediment/soil characteristic of location of interest and apply relevant data in the assessment	Data likely to be generally representative of sediment/soil characteristics of interest; limited resource implications	CRs will still be subject to variability; this approach does not provide a natural basis for uncertainty or sensitivity analysis to determine importance of this variability
			Tier 3: Review information in recent literature on natural variability in CRs due to soil/sediment characteristics to use as basis for uncertainty analysis	Allows sensitivity of results due to variability to be determined	Not site-specific; expert consultation likely to be required
			Tier 3: Collect information on natural variability from site-specific survey information and undertake uncertainty analysis	This approach allows the specifics of the situation to be taken into account, and the influence of uncertainties in CRs to form an explicit part of the assessment	Resource intensive; The sampling design, performance and interpretation would require expert consultation; the results of the uncertainty analysis may require expert consultation
CR not applicable to ecosystem under assessment	Default CR was not derived for the media in question (e.g. river water opposed to lake, estuary opposed to marine)	U	**Tier 1**: The 'limiting' concentration values applied in this tier will be calculated on the basis of default derived CRs (for a generic ecosystem that may similar to that of interest	This option is easy to apply; High degree of confidence that values are derived from expert knowledge; Derivation method documented.	Not possible for user to study the sensitivity of results to changing CR assumptions; The applicability of CR may be difficult to defend to non-specialists.
			Tier 2: Derive appropriate CR from information on the relative values of the CRs in different ecosystems for the biota and radionuclide under consideration	Relatively limited resource requirements	Prone to error - the variation of radionuclide behaviour in different environments is more complex than linear scaling may allow
			Tier 2: Review available literature for information on CRs for the ecosystem of interest and apply relevant data in the assessment	Data likely to be generally representative of ecosystem of interest; limited resource implications	CRs will not represent site-specific features of the ecosystem

Issue	Description	Type*	Options	Strengths	Weaknesses
			Tier 3: Collect information on CR for radionuclide and default biota in ecosystem of interest	This approach allows the specific characteristics of the ecosystem to be taken into account	Resource intensive; the sampling design, performance and interpretation would require expert consultation; the results of the uncertainty analysis may require expert consultation
Default CR uncertain	lack of data for the derivation of default CR values within ERICA tool required data manipulation (e.g. extrapolation of single tissue concentration data to whole organism concentrations, application of soil depth and density data to convert Bq/m2 data to Bq/kg etc) leading to uncertainties in applicability of default factors.	U	**Tier 1**: The 'limiting' concentration values applied in this tier will be calculated on the basis of default derived CRs	This option is easy to apply; High degree of confidence that values are derived from expert knowledge; Derivation method documented.	Not possible for user to study the sensitivity of results to changing CR assumptions; The applicability of CR may be difficult to defend to non-specialists.
			Tier 2: Select most appropriate ERICA CRs using selection criteria made available in the tool	Limited resource requirements. Enables most applicable selection criteria to be selected for the particular assessment. User-defined CR values can be entered where site-specific values are available.	
			Tier 3: Derive site specific CR	Increases confidence in applicability of CR value	Resource intensive. Approach cannot be applied to rare or endangered species
			Tier 3: Run assessment with various CR values to determine sensitivity of dose to changes	Increased confidence in assessment through variability analysis	Resource intensive, requires multiple assessments to determine variability

Issue	Description	Type*	Options	Strengths	Weaknesses
Whole organism concentration data unavailable	CRs are required on basis of whole organism concentrations for assumption of uniform distribution within the ellipsoid geometry	DG	**Tiers 2 and 3**; Apply most applicable ERICA default CR values	High degree of confidence that values are derived from expert knowledge. Derivation method documented.	Doesn't allow for site-specific factors to be taken into account.
			Tiers 2 and 3: Apply assumptions used by experts in derivation of ERICA default CRs to available site-specific data	Enables site-specific factors to be taken into account	Resource intensive. Could be open to greater criticism from stakeholders.
Accumulation of radionuclides within biota tissues	Methodology requires assumption of uniform distribution within the ellipsoid geometry so does not take account of accumulation within organs.	U	**Tiers 2 and 3**: Where organ of accumulation could result in greater effect that that estimated (e.g. reproductive organs), run assessment using geometry applicable to the organ in which accumulation occurs.	Increased confidence that impact will not be underestimated	Requires additional assessment and more considered interpretation of results
Reference organism					
Reference organisms are not applicable to the ecosystem requiring assessment	Biota present within a site cannot be assessed due to lack of a suitable reference organism within the habitat type	DG	**Tier 1**: Apply 'limiting concentration levels' that implicitly assume the presence of a reference organism for defined ecosystem types	Ease and rapidity of assessment - valuable for scoping purposes	The implicit assumptions underlying the specification of the reference organism may be applicable to the species present in the habitat of interest
			Tier 2: Identify Reference Organism analogue for the biota of interest and apply relevant parameters (e.g. most suitable geometry and taking account of mass/volume) in assessment	Data likely to be generally representative of biota of interest; limited resource implications	Specifics of reference organism assumptions may not be applicable to biota of interest

Issue	Description	Type*	Options	Strengths	Weaknesses
			Tiers 2 and 3: Identify geometry related to biota (and life-stage of interest), assess external rates using the DCC tool	Relates to specific characteristics of the biota of interest	Resource intensive; expert consultation necessary for calculations
Reference organisms not representative of those species requiring protection under European and National legislation	Lack of specific reference organisms for internationally important species as designated under both national and international legislation may lead to their exclusion from assessments	DG	**Tier 1**: Apply 'limiting concentration levels' that implicitly assume the presence of a reference organism for defined ecosystem types (using DCC Tool)	Ease and rapidity of assessment - valuable for scoping purposes	The implicit assumptions underlying the specification of the reference organism may be applicable to the species present in the habitat of interest
			Tier 2: Interpolate from existing information based on available reference species with similar attributes (using DCC Tool)	Relatively easy to apply; possible to take account of general characteristics of the biota of interest (e.g. life cycle, habits for organism type)	Data not specific to biota of interest; Applicability may be difficult to demonstrate
			Tier 3: Gather information on the geometry and behaviour of the organism of interest and apply the most applicable geometry from the default set of reference organisms and undertake uncertainty analysis to account for any variation in geometry between default and actual organism.	More accurate assessment that takes account of the specific nature of the species concerned without need for site-specific monitoring	The default data will not fully represent the characteristics of the species concerned.
			Tier 3: Collect information for relevant biota of interest and use this information to undertake assessment (with help of DCC Tool)	Specific to the biota of interest	Resource-intensive; all stages of assessment require expert consultation

Issue	Description	Type*	Options	Strengths	Weaknesses
Natural variability in mass/volume not reflected in reference organism geometry	External doses may be over/under estimated depending on variation in biota/reference organism geometries	V	**Tier 1**: Apply 'limiting concentration levels' that implicitly assume the characteristics of a reference organism for defined ecosystem types	Ease and rapidity of assessment - valuable for scoping purposes	The implicit assumptions underlying the specification of the reference organism may be applicable to the species present in the habitat of interest
			Tier 2: Review available literature for information on the variability in biota geometry and apply data as appropriate	Data likely to be generally representative of biota of interest; limited resource implications	Geometry will still be subject to variability; this approach does not provide a natural basis for uncertainty or sensitivity analysis to determine importance of this variability
			Tier 3: Review information in recent literature on natural variability biota geometry to use as basis for uncertainty analysis	Allows sensitivity of results due to variability to be determined	Resource-intensive. Not site-specific; expert consultation likely to be required
			Tier 3: Collect information on biota geometry and undertake uncertainty analysis	This approach allows the specifics of the situation to be taken into account, and the influence of uncertainties in CRs to form an explicit part of the assessment	Resource-intensive and difficult to design and undertake. The sampling design, performance and interpretation would require expert consultation; the results of the uncertainty analysis may require expert consultation

Issue	Description	Type*	Options	Strengths	Weaknesses
Species identified for assessment span more than one ERICA ecosystem	Biota may spend time in more than one ecosystem (e.g. transition zones such as marsh areas where exposures could be high due to nuclide accumulation) or there may be different biota that need to be assessed in different ecosystems	DG/U	**Tier 1**: Apply 'limiting concentration levels' in the primary ecosystem of concern (e.g. that into which radionuclides are discharged)	Ease and rapidity of assessment - valuable for scoping purposes	Incomplete assessment which may result in significant errors due to important biota groups not being included in the assessment
			Tier 2: Consider biota present in different ecosystems and assess based on assessed dose rates in each ecosystem or occupancy-weighted sum of dose rates, as appropriate	Errors reduced by taking account of combinations of ecosystems; easily applied if information available for biota-type in ERICA-defined ecosystems	Requires multiple runs of ERICA Tool and the combination of results external to tool
			Tier 3: Undertake site-specific assessment of biota that takes account of multiple ecosystem occupancy and different biota present in different ecosystems	Specific to ecosystems of interest	Resource-intensive
Geometry does not take account of varying geometries of different biota life stages	Different life stages may vary in their sensitivity to the effects of radiation exposure	V	**Tier 1**: Apply 'limiting concentration levels' that implicitly assume the characteristics of a reference organism for defined ecosystem types	Ease and rapidity of assessment - valuable for scoping purposes	juvenile stages may be maximally exposed due to habits and geometry, which may be underestimated through use of reference organism approach based on adult stage
			Tiers 2 and 3: Investigate effects data to determine the most sensitive life-stage to help guide information gathering with respect to geometry	Allows a more focused approach	Resource-intensive and interpretation of the corresponding effects data likely to require expert consultation

Issue	Description	Type*	Options	Strengths	Weaknesses
			Tiers 2 and 3: Collect information from literature on the geometry of the biota of interest under various life-stages and use to undertake assessment using the DCC Tool and combine as appropriate	Errors reduced by taking account of combinations of ecosystems; easily applied if information available for biota-type in ERICA-defined ecosystems	Requires multiple runs of ERICA Tool and the combination of results external to tool
Suitable geometry data not available for user-defined species of interest	Accurate dimensions for ellipsoid axes and mass not available on which to calculate user-defined geometry	DG	**Tier 3**: Identify most applicable data and apply expert judgement to define those for which data are lacking	Easy to apply	Subject to error and uncertainty
			Tier 3: Monitor species of interest to derive required data	Enables high degree of certainty in derived data and enables variability in dimensions and mass to be taken into account	resource intensive
<u>Dose Conversion Coefficient (DCC)</u>					
No external DCC for radionuclide/organism	External dose cannot be calculated for the radionuclide/organism combination	DG	**Tier 2**: Apply information from radionuclide/reference organism combinations that are likely to have similar external DCCs	Easy to apply; useful as initial scoping approach	Assessment based on external dose alone (significant error where internal doses likely to be significant); interpolation on more than one parameter is prone to error
			Tiers 2 and 3: Collect information from literature on the geometry of the biota of interest and use to undertake assessment using the DCC tool	Undertake specific assessment based on generic geometry information included in ERICA Tool	May require expert consultation
			Tier 3: Conduct dose rate measurements at the site of interest	Data specific to site of interest	May be incomplete assessment if internal dose is likely to be significant contributor to dose; Design, sampling and interpretation will require expert consultation

Issue	Description	Type*	Options	Strengths	Weaknesses
Variability in organism dimensions and mass	Reference geometry is not precise for a specific organism leading to uncertainty in the DCC	V	**Tier 3**: Assign probability distributions	Allows variability to be taken into account	
Organ specific information	Organ-specific dose rates may be necessary for accurate assessment of effects e.g. where reproduction is the primary endpoint of concern	DG	**Tier 1**: Apply 'limiting concentration levels' that implicitly assume effects related to dose rates to whole body	Ease and rapidity of assessment - valuable for scoping purposes	Errors in assessment of effects (e.g. if reproduction is the primary endpoint of concern)
			Tier 3: Undertake specific dose rate assessment based on whole body and/or organ-specific information and prediction of effects based on information in FREDERICA	Accounts for effects at an organ-specific level	Potentially resource-intensive. Limited information likely available to support dose rate calculation or effects analysis. Expert consultation necessary
No DCC for internal exposure	Internal dose cannot be calculated for the radionuclide/organism combination without DCC for activity concentrations internal to the organism	DG	**Tier 2**: Ignore internal dose component and calculate dose rates based on external dose alone	Simple to apply where external DCCs exist	Dose may be under estimated due to exclusion of either internal or external dose from calculations
			Tiers 2 and 3: Gather information from literature, specify organ size and shape and use ERICA Assessment Tool to derive DCC for internal exposure	More complete assessment that takes account on internal dose component	Expert consultation necessary to determine data requirements and apply model

Issue	Description	Type*	Options	Strengths	Weaknesses
Ecosystem					
Ecosystem to be assessed is not covered by ERICA	Not all important habitats can be accurately assessed using the assessment method - e.g. salt marshes	DG/U	**Tier 1**: Apply 'limiting concentration levels' in the ERICA ecosystem closest to that of interest	Ease and rapidity of assessment - valuable for scoping purposes	Errors in assessment likely to arise due to the inability to take account of ecosystem specifics (e.g. salinity, occupancy)
			Tier 2: Gather information from literature on the likely difference in environmental behaviour between ERICA defined-ecosystem and the ecosystem of interest and apply appropriate factors	Relatively easy to apply while allowing partial account of characteristics of ecosystem of interest	Information likely to be limited and to require expert consultation
			Tier 3: Undertake site-specific surveys to gather information necessary for assessment	Demonstrably confident that information specific for ecosystem	Resource-intensive - requiring expert consultation and involvement
Effects analysis					
No effects data for wildlife group of interest	Lack of effects data will reduce the level to which it is possible to make specific statements about the acceptability, or not, of a given situation	DG/U	**Tier 2**: Compare calculated dose with the lowest causing effect in all biota categories	Cautionary approach - where calculated dose is below all effects data there can be confidence in the conclusion of no impact	The effects data will not necessarily be representative of the biota under consideration. Possible over-estimation
			Tiers 2 and 3: Extrapolate effects data for similar organisms (and take account of uncertainties by using appropriate safety or extrapolation factor)	Allows effects to be evaluated without the need for additional effects studies or site-specific surveys (NB: it will not be possible to collect specific data for protected species the use of information for analogous species is likely to be the only option in most cases)	There will be significant uncertainties associated with extrapolating information from one species to another. Simple extrapolation factors are a semi-quantitative conservative approach to taking account of uncertainties

Issue	Description	Type*	Options	Strengths	Weaknesses
			Tiers 2 and 3: Extrapolate effects data for similar organisms using information from the FREDERICA database to construct species sensitivity distribution for appropriate taxonomic group	Refined quantitative analysis of extrapolation between species	Other uncertainties remain (SSD will only taken account of extrapolation between species).
			Tier 3: Conduct survey and analysis to develop effects analysis information that is more relevant to the group of interest	Demonstrates completeness of assessment (assuming that a proportionate approach is applied to all parameters in the assessment)	The collection of more representative wildlife group or site-specific information will need to be undertaken by experts. Uncertainties will still exist due to the extrapolate information for protected species; uncertainty analyses would also require significant expert consultation.
Multi-stressor context	The presence of additional non-radioactive stressors may result in a given dose rate having a greater or lesser effect than predicted (if the environment is under significant stress)	DG/U	Additional safety factors may be used (in all Tiers) to take this issue into account and ensure conservatism	Allows a semi-quantitative assessment of the effect of multiple stressors for limited additional resource	The safety factor approach is arbitrary and a significant source of uncertainty only partially taken into account
			Tier 1: Mention the possibility of additional stressors but do not make any quantitative assessment of combined stress	This demonstrates that other issues have been considered but does not require additional assessment resources	This does not provide a complete assessment
			Tier 1: Undertake assessment of the impact of radionuclides using ERICA and identify other stressors present and apply Environmental Quality Standards for these pollutants	This demonstrates that other issues have been considered and requires limited additional assessment resources	This approach does not provide a combined assessment of impact

Issue	Description	Type*	Options	Strengths	Weaknesses
			Tier 3: Use information on the contaminants present in the environment and from literature sources to derive probability distributions that account for the uncertainty in effects due to the presence of additional stressors	Distribution information will allow the significance of this source of uncertainty to be evaluated	Resource-intensive survey work likely to require expert consultation
			Tier 3+: Assess the combined impact of environmental stressors using biomarker methods (in consultation with relevant expert)	This approach has the potential to provide a complete assessment that addresses all stressors on biota under consideration	Very resource-intensive. There remain significant uncertainties regarding the interpretation of biomarker results. For example the extent to which they relate to health impacts exhibited in individuals or populations, and in the identification of relative importance of different types of stress. This approach may imply significant research involvement
Toxic radionuclides (e.g. U) not accounted for by dose	Increased impact may occur where radionuclides present both radio- and chemical toxic effects	U	All tiers: Ignore the potential for toxic impacts and apply 'limiting concentration levels' that implicitly to the ERICA ecosystem closest to that of interest	Ease and rapidity of assessment - valuable for scoping purposes to indicate radiological impacts	Could lead to significant underestimation of potential effects for some radionuclides (e.g. uranium)
			All tiers: Conduct review to determine whether toxicity likely to occur at media concentrations calculated	Demonstrates that potential toxic effects have been considered without significant increase in effort	Only qualitative consideration of potential effects (not possible to comment on antagonistic or synergistic impact)

Issue	Description	Type*	Options	Strengths	Weaknesses
Application of weighting factors uncertain	RBE of alpha radiation on non-human biota uncertain - for non-human biota RBEs for alpha and beta radiation vary between species, life stages, endpoints and exposure regime	U	**Tier 1**: Apply 'limiting concentration levels' that implicitly include default weighting factor assumptions	Ease and rapidity of assessment - valuable for scoping purposes to indicate radiological impacts	Does not provide basis for considering relative importance of uncertainties in weighting factors to other assessment issues
			Tiers 2 and 3: Calculate and present dose rates separately for high and low LET radiation	Transparent approach that allows users to understand the contribution of different types of radiation, and to externally apply weighting factors as appropriate	Dose rate results do not provide complete indication of potential effects - additional interpretation is required
			Tiers 2 and 3: Apply various weighting factors in order to determine impact on calculated doses	Allows statements to be made regarding the importance of results to with respect to weighting factors	There is the potential for overestimation of doses from alpha radiation by use of very high weighting factors
Application of acute/chronic effects data	Effects information is generally available for high doses and dose rates - it may be necessary to extrapolate these data to chronic/low dose rate situations	U	**Tier 1**: Apply 'limiting concentration levels' that implicitly include default assumptions to provide screening values for both acute and chronic situations	Ease and rapidity of assessment - confidence that effects data judgements have been made on the basis of expert opinion	It is not possible to make specific statements regarding the applicability of effects data to the situation under consideration
			Tier 2 : Calculation of dose rates to biota of interest using the standard features of the assessment tool; review information available in the FREDERICA data base (or from more recent publications if available) on effects for the biota type and make qualitative statement about applicability to situation being considered	Demonstrates that this issue has been considered with relatively limited effort; provides an additional basis for determining whether **Tier 3** assessment is required	This allows only qualitative consideration of one of the most significant uncertainties related to effects analysis

Issue	Description	Type*	Options	Strengths	Weaknesses
Extrapolation required between individual effects and population	There is often more information available on individual responses rather than on populations. It may be necessary to extrapolate from information on individuals to assess population-related effects	DG/U	**Tiers 2 and 3**: Application of extrapolation factor or safety factor by determining relationship between chronic and acute effects within FREDERICA database for alternative biota categories	Relatively simple quantitative evaluation of chronic effects from acute data which could provide information needed for uncertainty analysis (safety factors of power of 10 often applied; where several extrapolation multiple factors will be applied).	Some expert judgement will be needed to apply such factors
			Tier 3: Take account of uncertainty in extrapolation from acute to chronic effects in the specification of distribution on the probability of effects, as part of uncertainty analysis	Demonstrates completeness of assessment (assuming that a proportionate approach is applied to all parameters in the assessment)	Resource-intensive requirements for specification and application of uncertainty analysis; consultation with an expert necessary
			Tiers 2 and 3: Apply safety factor to allow for the uncertainty in extrapolating from individual to population responses	Relatively simple quantitative evaluation (safety factors of power of 10 often applied; where several extrapolation multiple factors will be applied).	Some expert judgement will be needed to apply such factors
			Tiers 2 and 3: Apply population dynamic modelling approach (e.g. Leslie Matrix) to predict population response	More accurate assessment of potential population effects without detailed survey requirements	Analysis will need to be performed by an expert
			Tier 3: Take account of uncertainty in extrapolation from acute to chronic effects in the specification of distribution on the probability of effects, as part of uncertainty analysis	Demonstrates a relatively complete assessment possibly without the need for additional survey work (assuming that a proportionate approach is applied to all parameters in the assessment)	Resource-intensive requirements for specification and application of uncertainty analysis; consultation with an expert necessary

Issue	Description	Type*	Options	Strengths	Weaknesses
			Tier 3: Specific experimental study, including the consideration of population dynamics	A complete assessment of the likely effects on a population level	There will still be uncertainties involved in the effects analysis (e.g. due to species extrapolation and dose rates) due to experimental design requirements. Population dynamic information may be difficult to collect. Such experiments would need to be performed by experimental scientists.
Reliability of effects data unknown	Test conditions on which effects data are reported are not known (e.g. proportion of the population tested, genetic factors etc) leading to uncertainty in their reliability	U	**Tiers 2 and 3**: Apply safety factor to allow for the uncertainty	Relatively simple quantitative evaluation (safety factors of power of 10 often applied; where several extrapolation multiple factors will be applied).	Some expert judgement will be needed to apply such factors
Basis for organism effects data uncertain	Life stage of test organism on which effects data are available is not reported leading to uncertainties in the interpretation of effects results (sensitivity of life-stage unknown)	U	**Tiers 2 and 3**: Apply safety factor to allow for the uncertainty	Relatively simple quantitative evaluation (safety factors of power of 10 often applied; where several extrapolation multiple factors will be applied).	Some expert judgement will be needed to apply such factors
Extrapolation of population information to higher organisational levels	Derived benchmarks are based on ecotoxicity data observed at the individual level	U	**Tiers 2 and 3**: Application of safety factor to take account of extrapolation to higher levels of organisation and ensure conservative approach	Allows effects to higher organisational levels to be taken into account in simple approach	Safety factors will tend to overestimate effects

Issue	Description	Type*	Options	Strengths	Weaknesses
			Tier 3: Undertaken predator/prey modelling to refine benchmarks and application of ecologically relevant weight to each trophic level	Improves realism of approach (where the ecosystem is well characterised)	Will require consultation with an expert
Application of laboratory information	Extrapolation between laboratory and field data will not take account of multi-stressor effects or differences in sensitivity between laboratory and field organisms	U	**Tiers 2 and 3**: Apply safety factor to allow for the uncertainty in extrapolating from individual to population responses	Simple approach that allows effects data to be derived from the widest database of information available	There will be uncertainties resulting from application of laboratory data to field situations due to additional stresses in field conditions (e.g., competition, predation, effects from other pollutants) but safety factors tend to be conservative
			Tiers 2 and 3: Review information available in ERICA database and other literature sources to determine whether it would be possible to apply a factor to allow for extrapolation errors	Simple semi-quantitative approach providing some allowance for this source of uncertainty and the basis for further study (e.g. consideration of uncertainty analysis)	The relationship between effects under field and laboratory conditions is likely to be complex and vary for different species. There is unlikely to be information sufficient to support the use of a single factor. Expert interpretation will be required.
			Tier 3: Take account of uncertainty in extrapolation from laboratory to field effects studies in the specification of distribution on the probability of effects, as part of uncertainty analysis	Demonstrates completeness of assessment (assuming that a proportionate approach is applied to all parameters in the assessment)	Resource-intensive requirements for specification and application of uncertainty analysis; consultation with an expert necessary

Issue	Description	Type*	Options	Strengths	Weaknesses
Implications of bystander effects, secondary responses and genomic instability	Such effects may lead to additional uncertainties assessing effects on individuals from radioactive and chemical pollutants, particularly at low dose rates	U	**Tiers 2 and 3**: Do not take account of these effects in quantitative assessment but make statement regarding this type of uncertainty	Demonstrates that issues have been considered at minimal additional effort	May reduce confidence in assessment results (where other sources of uncertainty are generally likely to be more significant)
			Tier 3: Allow for uncertainties in effects analysis due to such effects from information available in literature	Demonstrates completeness of assessment (assuming that the approach to other uncertainties is similarly detailed)	Difficult to incorporate simply in uncertainty analysis. Information available on the level of uncertainty associated with such effects would need to be interpreted by an expert and the results are likely to be difficult to explain to non-specialists
Interpretation and Evaluation					
Generic 'Benchmarks' do not take account of site-specific issues in the assessment	All generic criteria or benchmarks are derived on the basis of assumptions that may not apply to the situation in question	U/V	**Tier 1**: Apply 'limiting concentration levels' defined in the ERICA tool and comment on uncertainties involved	Confidence that these values will have been derived based on expert opinion	Simple application of these levels does not allow uncertainties to be specifically addressed
			Tier 2: Apply 'benchmark' directly but comment on the uncertainties involved	Simple approach not requiring additional resources	No account of uncertainties. This may lead to the results being questioned.
			Tier 2: Apply safety factor to 'benchmark' dose rate to account for uncertainty	Simple approach to apply that takes account of uncertainty	Specification and application of safety factors is arbitrary and likely to be conservative (e.g., in comparison with values based on species sensitivity distribution information

Issue	Description	Type*	Options	Strengths	Weaknesses
			Tier 2: Derive benchmark based on predicted no-effects dose(rate) levels identified from FREDERICA database	More specific account of the form of information available for the particular biota group	Data requirements more extensive than safety factor approach. Data evaluation and interpretation are complex requiring consultation with experts
			Tiers 2 and 3: Derive benchmarks based on species sensitivity distribution based on a percentile of the SSD for a subset of the FREDERICA database (for particular taxonomic grouping)	More specific account of the form of information available for the particular biota group	Data requirements more extensive than safety factor approach. Data evaluation and interpretation are complex requiring consultation with experts
			Tiers 2 and 3: Derive a 2 tier benchmark approach based on two different criteria for the percentage of species protected	Initial lower trigger level allows more structured decision with regard to the extent of impact and the specific effects on ecosystem stability and biodiversity effects	Resource-intensive approach requiring expert consultation
			Tier 3: perform assessment that includes uncertainty analysis and species sensitivity distribution information (related to the appropriate trophic level)	More accurate statement of the implications of the assessment (including possibility of taking account of organ-specific responses and specific trophic/taxonomic groups)	Specification of parameter distributions and analysis will need to be performed by an expert
Assumptions implied in defining a criterion may not be applicable to the situation under consideration	The criterion may relate to a pathway or organism that is not present	U	**Tier 2**: Modify benchmarks to more closely reflect the situation under consideration (e.g. biota or habits considerations) using information available in the FREDERICA database.	Benchmark will more clearly relate to specifics of situation	Requires consultation with an expert (and appropriate stakeholders and authorities)
			Tier 3: Perform more site-specific assessment to determine the likely effects from information from the FREDERICA database	Results more representative of the current state of knowledge about the organism concerned	More resource-intensive - likely to be warranted only if concentrations significant or there is stakeholder concern

Issue	Description	Type*	Options	Strengths	Weaknesses
Treatment of natural background in deriving benchmarks	There may be errors associated with the treatment of natural background due to uncertainty in conditions in which experimental effects data have been derived	U	**Tiers 2 and 3**: Derive benchmarks or effects data based on laboratory studies where background is excluded include natural background in the assessment of exposure (dose rate)	Confidence that data set consistent with consideration of total exposure; single value benchmarks may be defined	Reduction in the dataset used to define benchmarks, uncertainties still remain that will need to be addressed (e.g. by safety factors), expert consultation required
			Tiers 2 and 3: Apply 'added risk approach' that involves in assessment the component of dose or concentration above background for comparison	Similar to approach adopted for humans, background may be used as additional comparator	Exposure analysis potentially more complex requiring evaluation of local background for subtraction from measured data; uncertainty remains about applicability of effects information

EUROPEAN COMMISSION

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ERICA

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D-ERICA Annex B:
Glossary

Editors: David Copplestone and Irene Zinger

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ERICA (Environmental Risk from Ionising Contaminants: Assessment and Management) concerns an integrated approach to scientific, managerial and societal issues concerned with the environmental effects of contaminants emitting ionising radiation, with emphasis on biota and ecosystems. The project started in March 2004 and ended by February 2007.

Erica tetralix L.

Contract No: **FI6R-CT-2004-508847**

Project Coordinator: **Swedish Radiation Protection Authority**

Contractors:

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Swedish Nuclear Fuel and Waste Management Company	SKB
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Electricité de France	EDF

Annex to D-ERICA: Glossary

The aim of this extended glossary and abbreviation list is to enable the ERICA Consortium to use the same terminology and abbreviations when writing the project various deliverables. Its purpose is to ensure consistency and avoid misunderstandings during discussions at various meetings, including during the EUG events, where a number of professionals from a wide range of background meet.

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List of Abbreviations **18**

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Glossary

Absorbed dose	Quantity of energy imparted by ionising radiation to unit mass of matter such as tissue. Unit gray, symbol Gy. 1 Gy = 1 joule per kilogram.
Accuracy	Qualitative concept describing the closeness of the agreement between the result of a single measurement or calculation and the true or accepted value of the measurand (see precision). The tendency of values of an estimator to come close to the quantity they are intended to estimate. See also Precision.
Activity concentration	The activity per unit mass or volume in which the radionuclides are essentially uniformly distributed, *e.g.* Bq kg^{-1}, Bq l^{-1}.
Air kerma	The kerma value for air. Under charged particle equilibrium conditions, the air kerma (in gray) is numerically approximately equal to the absorbed dose in air (in gray). See also kerma.
ALARA principle	"As low as reasonably achievable", refers to actions directed to limiting doses to individuals, the number of exposed individuals, and the probability of receiving a dose.
Allometric	Correlation of changes in any organism part (*i.e.* contaminant concentration) to organism size and metabolic needs.
Assessment criteria	Preparation of a procedure for summarising the results of the evaluation and takes, as input, management criteria specific to a particular environment which may influence the relative importance of different quality characteristics (ISO 9126).
Assessment endpoint	The biological effect inferred from the measurements or predictions and which the assessment framework is designed to study. An explicit expression of an ecological value to be protected.
Assessment factor	See safety factor
Assessment framework	Identification and demarcation of the assessment boundaries. In FASSET, the FASSET assessment framework contains the process from problem formulation through to characterisation of the effects of radiation on individuals. The overall assessment system describes the tools, methods and information flow used to carry out the impact assessment.
Assessor	The person using the ERICA integrated approach.
Authorisation	The granting by a regulatory body or other governmental body of written permission for an operator to perform specified activities.
Background	The doses, dose rates or activity concentrations associated with natural sources or any other sources in the environment that are not amenable to control.
Benchmark	Concentration, dose or dose rate that are assumed to be safe based on exposure–response information (*e.g.* ecotoxicity test endpoints).

Beta Distribution	Flexible, bounded Probability Distribution Function described by two shaped parameters. It is commonly used when a range of the random variable is known.
Bioaccumulation	The process whereby an organism accumulates substances in living tissues to concentrations higher than those existing in the surrounding media (*e.g.* soil, water and water).
Bioassay	A test to determine the relative strength of a substance by comparing its effect on a test organism with that of a standard preparation.
Bioavailability	Term used to describe the way contaminants are absorbed by humans and other animals.
Biodiversity	The number and abundance of species found within a common environment. This includes the variety of genes, species, ecosystems, and the ecological processes that connect everything in a common environment.
Biological half-life	The time required for a biological system (*e.g.* an animal) to eliminate, by natural processes, half the amount of a substance that has been absorbed into that system.
Biomagnification	Situations where the concentration of certain substances increase as one moves higher up the food chain.
Biomass	The total weight of all living organisms in a biological community.
Biosphere	That part of the environment normally inhabited by living organisms. In practice, the biosphere is not usually defined with great precision, but is generally taken to include the atmosphere and the Earth's surface, including the soil, surface water bodies, seas and oceans and their sediments. There is no generally accepted definition of the depth below the surface at which soil or sediment ceases to be part of the biosphere, but this might typically be taken to be the depth affected by basic human actions, particularly farming. In waste safety in particular, the biosphere is normally distinguished from the geosphere.
Biota	The animal and plant life of a given region.
Common Locations CLs	Use of the Kruskal-Wallis statistic to identify changes in the distribution of y across the range of individual xi's.
Common means CMNs	Use of the F-statistic to identify changes in the mean value of y across the range of individual xi's.
Common Medians CMDs	Use of the $\chi 2$ statistic to identify changes in the median value of y across the range of individual xi's.
Conceptual model	Representation of the environmental system and of the physico-chemical and biological processes that determine the transport/transfer of contaminants from sources through environmental media to receptors within the system.
Confidence	Is used to represent trust in a measurement or estimate.
Confidence interval	An interval for which one can assert with a given probability, called the degree of confidence or the confidence coefficient that it will contain the true value of the parameter it is intended to estimate. The endpoints of a confidence interval

	are referred to as the (upper and lower) confidence limits; they are generally values of random variables calculated on the basis of sample data.
Consensus building	Process aimed to reach agreement on particular points through informed debate and discussion. The aim is to produce an output that all stakeholders involved can agree with and sign up to. This is different to consultation where areas of disagreement are bound to remain because consultation is really about finding out the different opinions and views so that the decision makers can consider all aspects when making decisions. In contrast, consensus building attempts to bring all parties to some form of agreement. For example, it might be possible to get consensus on what might considered to be a trivial exposure to ionising radiation for non-human species or that the assessment tool was fit for purpose. Whilst the aim of the process might be to come to some form of consensus, this is not always possible. In these cases, the reasons for disagreement should be recorded as it might shed light on key issues for consideration by decision-makers.
Consultation	A process that can be used for the purpose of discussion on, for example, appropriate input values into the assessment and for gaining an understanding of the stakeholders' points of view and arguments.
Contaminant	Any physical, chemical, biological, or radiological substance or matter that has a potentially adverse effect on air, water, or soil, with the implication that the amount is measurable.
Correlation	In general, the term denotes the relationship (association or dependence) between two or more qualitative or quantitative variables. See also CC (Correlation Coefficient).
Correlation coefficient CC	A measure of the linear relationship between two quantitative variables. It is denoted by the letter r and its values range from -1 to +1, where 0 indicates the absence of linear relationship, while -1 and +1 indicate, respectively, a perfect negative (inverse) and a perfect positive (direct) relationship.
Cumulative Distribution Function CDF	F(x), expresses the probability the random variable X assumes a value less than or equal to some value x, F(x)=Prob(x. x). For continuous random variables, the cumulative distribution function is obtained from the probability density function by integration. In the case of discrete random variables, it is obtained by summation.
Cytogenetic effect	An observed effect in chromosomes that can be correlated with adverse hereditary effects (effects that are inheritable and appear in the descendants of those exposed) or genetic effects.
Dispersion model	Model for the representation of the spreading of contaminants in air (aerodynamic dispersion) or water (hydrodynamic dispersion) resulting mainly from physical processes affecting the velocity of different molecules in the medium.
Distribution Function	A function whose values F(t) are the probabilities that a random variable assumes a value less than or equal to t.
Dose	See absorbed dose
Dose rate	Dose (normally absorbed dose) received over a specified unit of time.

Dose-effect	A biological effect at the molecular, cellular, tissue or whole body level of organisation following exposure of a contaminant that, in the case of ERICA, would be ionising radiation.
Dose-response	A correlation between a quantified exposure (dose) and the proportion of an exposed population that demonstrates a specific effect (response).
Driving force	An influence that causes change, *e.g.* legislation.
Ecological impact	The total effect of an environmental change, natural or man-made, on the community of living things.
Ecological receptor	Living organisms at various organisation level (*i.e.* ecosystems, communities, populations, individual organisms (except humans – note that humans are included when the term "environmental receptors" is used) potentially exposed to and adversely affected by stressors because they are present in the source(s) and/or along stressor migration pathways.
Ecosystem	The interacting system of a biological community and its nonliving surroundings.
Effect	A biological change caused by exposure to a contaminant.
Effective Concentration(x) EC_x, ED_x, EDR_x	The concentration of a substance that is estimated to cause some sub-lethal toxic effect on x % of the test organisms under specified conditions. The duration of the exposure must be specified. The concentration of a substance that is estimated to cause an effect *x* on the test organisms under specified conditions. The duration of the exposure must be specified. *x* is defined as the percent change in the (average) level of the endpoint considered $x\% = 100\left(\frac{y(EC_x)}{y(0)} - 1\right)\%$. The same definition can apply for the Dose (*ED_x*) or the dose rate (*EDR_x*). Currently, these parameters are estimated by modelling (concentration-effects, dose-effects or dose rate-effect modelling).
Endpoint	In the context of ERICA an endpoint can be described as the biological effect or type of biological effects of concern at the end of the assessment. Alternatively it may be whatever the end of the assessment is agreed to be (for example it might be the requirement of legislation for example to protect a particular species.
End-Users Group EUG	End-Users Group, formed under ERICA to provide advice to the ERICA Consortium from the perspective of being users of ERICA outputs.
Engagement	A general term to cover information provision, information feedback, involvement and consultation and extended involvement (Institute of Environmental Management and Assessment, 2002).
Environment	Water, air, land, plants and man and all other organisms living therein, and the inter-relationships that exist among them.
Environmental Impact Statement EIS	An Environmental Impact Statement is a document providing information for decision makers on the positive and negative effects of an action, practice or policy, which identifies and evaluates the environmental impacts of the hazard

EIS	source and feasible alternatives, including taking no action.
Environmental justice	Often used interchangeably with the term environmental equity, refers to the distribution and effects of environmental problems and the policies and processes to reduce differences in who bears environmental risks. In a general sense, it includes concern for disproportionate risk burden placed upon any population group, as defined by gender, age, income, race, nationality or generation.
Environmental Media Concentration Limit	The environmental media concentration limit is defined as the Predicted no Effects dose rate or screening dose-rate (µGy h^{-1}) divided by the value F which is the dose rate that an organism will receive for the case of a unit concentration in environmental media (µGy h^{-1} per Bq l^{-1} or kg of medium). In other words this is the environmental concentration of a radionuclide which would give rise to a dose rate of concern.
Environmental quality criteria	The levels of pollution and lengths of exposure, above which adverse effects may occur on health and welfare.
Environmental quality standards	The level of pollutants prescribed by law or regulation that cannot be exceeded during a specified time in a defined area.
Exposure	The co-occurrence or contact between the organism of interest (see receptor) and the stressor (*e.g.*, radiation or radionuclide).
Exposure assessment	The process of measuring or estimating the intensity, frequency, and duration of exposures to an agent currently present in the environment or of estimating hypothetical exposures that might arise from the release of new chemicals into the environment.
Exposure pathway	A route by which radiation or radionuclides can reach humans and cause exposure – an exposure pathway may be very simple, *e.g.* external exposure from airborne radionuclides, or a more complex chain.
False positive	A false positive is where the assessment result indicates that the assessment is satisfactory and meets the assessment criteria specified in the problem formulation stage of the assessment but in reality there is a risk of harm in the environment.
Fecundity	The survival of offspring.
Fertility	The ability to produce offspring.
FRED	FASSET Radiation Effects Database, see www.erica-project.org.
FREDERICA	Database that stems from the FASSET Radiation Effects Database (FRED), which was supplemented during the ERICA project (hence the name FREDERICA) with new data, including some from the FP5 EPIC project.
Gaussian distribution	See Normal Distribution
Hazard	A condition or physical situation with a potential for an undesirable consequence, such as harm to health or the environment. The term is used to indicate the likelihood that a contaminant will cause an adverse effect, to man or the environment, under the condition in which it is

	produced or used. Thus, the hazard is a function of two broad considerations, the potential of the contaminant to harm biological systems and its potential for exposure such that the adverse effect can occur.
Hazard analysis	Procedure used to (1) identify potential sources of hazardous materials from fixed facilities or transportation accidents; (2) determine the vulnerability of a geographical area to a release of hazardous materials; and (3) compare hazards to determine which present greater or lesser risks to an individual, population, or ecological community.
Hazard identification	Recognising that a hazard exists and trying to define its characteristics. The process of determining whether exposure to an agent can cause an increase in the incidence of an adverse health or environmental effect.
Indicator organisms	A species, whose presence or absence may be characteristic of environmental conditions in a particular area of habitat.
Information provision	Can be considered more or less a one-way process (although the stakeholders might also provide specific information to the assessment). Dissemination of information related to the project and associated processes may include the use of leaflets, websites, public relations and media, open house, exhibitions, dissemination of project information and of process information, seminars to explain issues and announcements.
Kerma	The quantity K, defined as: $$K = \frac{dE_{TR}}{dm}$$ where, dEtr is the sum of the initial kinetic energies of all charged ionising particles liberated by uncharged ionising particles in a material of mass dm. Unit: Gray (Gy).
Licence	1) A legal document issued by the regulatory body granting authorisation to perform specified activities related to a facility or activity. 2) Any authorisation granted by the regulatory body to the applicant to have the responsibility for the siting, design, construction, commissioning, operation or decommissioning of a nuclear installation. 3) Any authorisation, permission or certification granted by a regulatory body to carry out any activity related to management of spent fuel or of radioactive waste.
Linear Energy Transfer. LET	A measure of how, as a function of distance, energy is transferred from radiation to the exposed matter. Radiation with high LET is normally assumed to comprise of protons, neutrons and alpha particles (or other particles of similar or greater mass). Radiation with low LET is assumed to comprise of photons (including X-rays and gamma rays), electrons and positrons.
Lognormal Distribution	The distribution of a variable whose logarithm is normally distributed.
Lowest observed effect	The lowest observed effect concentration in a toxicity test that causes a statistically significant effect in comparison to the controls.

concentration LOEC	
Measurement endpoint	Measured or predicted value that an assessment produces. A measurable response to a stressor that is quantifiably related to the assessment endpoint.
Median	The median value of a sample is the value that divides an ordered sample into two equal halves. If there are 2n + 1 observations, the median is taken as the (n+1)th member of the ordered sample. If there are 2n it is taken as being halfway between the nth and (n+1)th.
Monte Carlo Analysis / Simulation	It is a computer-based method of analysis developed in the 1940's that uses statistical sampling techniques in obtaining a probabilistic approximation to the solution of a mathematical equation or model. It is a method of calculating the probability of an event using values, randomly selected from sets of data repeating the process many times, and deriving the probability from the distributions of the aggregated data. Monte Carlo simulation is a method for *iteratively* evaluating a deterministic model using sets of random numbers as inputs. This method is often used when the model is complex, nonlinear, or involves more than just a couple uncertain parameters. A simulation can typically involve *over 10,000 evaluations* of the model. Monte Carlo simulation methods are applied to studying systems with a large number of degrees of freedom as disordered materials, strongly, and geometrical structures. Monte Carlo methods are used to model phenomena with significant uncertainty in inputs. In radiation protection, they are broadly applied to simulate radiation transport from radiation sources to defined targets.
Morbidity	A loss of functional capacities generally manifested as reduced fitness, which may render organisms less competitive and more susceptible to other stressors, which may reduce life span.
Morbidity	A loss of functional capacities generally manifested as reduced fitness, which may render organisms less competitive and more susceptible to other stressors, thus reducing the life span.
Mortality	Death; the death rate; ratio of number of deaths to a given population.
Natural background	See background
No observed effect concentration	NOEC is the highest concentration in a toxicity test not causing a statistically significant effect compared with the controls.
Non-parametric approach	Approach that does not depend for its validity upon the data being drawn from a specific distribution, such as the normal or lognormal; a distribution-free technique.
Normal	Probability distribution for a set of variable data represented by a bell shaped

Distribution	curve symmetrical about the mean. Also known as Gaussian distribution.
Parametric	Category of statistical tests based on the following assumptions: (i) data are normally distributed, (ii) variance is homogeneous, (iii) about 25 samples for each variable analysed, (iv) relations among variables are linear.
Partial Correlation Coefficient	PCC is a statistic that is calculated to measure the association between two variables after controlling (or adjusting) for the effects of one or more additional variables.
Partial Rank Correlation Coefficient PRCC	Measures the degree of relation between two variables, when a third variable is held constant. Estimates non-linear monotonic relationship and gives the unique contribution of an input parameter to the resultant dose.
Permission	See licence
Permit	See licence
Pollution	The presence of matter or energy (*e.g.* smoke, gas, hazardous or noxious substances, light, heat, litter or a combination thereof) in sufficient quantities and of such characteristics and duration as to produce, or likely to produce, undesired environmental effects.
Precautionary approach	A precautionary approach is the method or procedure that has been developed to implement the precautionary principle.
Precautionary principle	In order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation. (UNCED, Rio principle 15, 1992.)
Precision	The closeness of the agreement between the results of a group of independent measurements or calculations, obtained by applying a given procedure under stipulated conditions. The smaller the random part of the errors, which affect the results, the more precise the procedure is. On the contrary, systematic errors may give precise but not accurate data (see accuracy). The precision of an estimator is its tendency to have its values cluster closely about the expected value of its sampling distribution; thus, it is related inversely to the variance of this sampling distribution - the smaller the variance, the greater the precision.
Probabilistic assessment	Assessment where probability distributions are assigned to model parameters and a probability distribution of the assessment endpoint is obtained by performing Monte Carlo simulations (this is the way is done in the ERICA tool) or by other methods for uncertainty propagation.
Probability Density Function of a continuous random variable	PDF is a function that can be integrated to obtain the probability that the random variable takes a value in a given interval.
Problem	Defined as the first step of any risk assessment and is intended to identify the

formulation	context and purpose of the assessment framework. This should include ecological, political and societal issues related to questions being addressed, and integrate the process of choosing appropriate assessment endpoints, identifying sources and describing the environment.
Prospective assessment	A prospective assessment is an assessment that is conducted to determine the impact of a practice or process that has not yet commenced.
Quantile	A generic name for statistics such as deciles, percentiles, and quartiles. The q^{th} quantile of a list ($0 < q <= 1$) is the smallest number such that the fraction q or more of the elements of the list are less than or equal to it, *i.e.* if the list contains n numbers, the q^{th} quantile, is the smallest number Q such that at least $n \times q$ elements of the list are less than or equal to Q.
Radiation weighting factor	The value of a radiation weighting factor represents the relative biological effectiveness of the different radiation types, relative to X- or gamma-rays, in producing endpoints of ecological significance. Its value represents the relative biological effectiveness of the different radiation types, relative to X- or gamma-rays, in producing endpoints of ecological significance.
Radioactive material	1) Material designated in national law or by a regulatory body as being subject to regulatory control because of its radioactivity. 2) Any material containing radionuclides where both the activity concentration and the total activity in the consignment exceed the values specified in paragraphs 401–406 of "Regulations for the Safe Transport of Radioactive Material, 1996 Edition (As Amended 2003) Requirements Details". IAEA Safety Standards Series No. TS-R-1 2004. Some States use the term radioactive substance for this regulatory purpose. However, the term radioactive substance is also sometimes used to indicate that the scientific use of radioactive (see radioactive material (1)) is intended, rather than the regulatory meaning of radioactive (see radioactive material (2)) suggested by the term radioactive material. It is therefore essential that any such distinctions in meaning are clarified.
Radioactive substance	See radioactive material (1). It should be noted that radioactive substance is sometimes used to indicate that the scientific use of radioactive is intended, rather than the regulatory meaning of radioactive.
Radioecological sensitivity	A combination of features that include the exposure situation and biology of an organism, that contributes to the sensitivity of the organism to presence of radioactive substances in its environment.
Radionuclide	An unstable nuclide that undergoes spontaneous transformation, emitting ionising radiation.
Random Error	Result of a measurement minus its expected value. Random error is equal to absolute error minus systematic bias. Because only a finite number of measurements can be made, it is possible to determine only an estimate of random error.
Receptor	See ecological receptor

Reference organism	A series of entities that provide a basis for the estimation of radiation dose or dose rate to a range of organisms that are typical, or representative, of a contaminated environment. These estimates, in turn, could provide a basis for assessing the likelihood and degree of radiation effects.
Relative Biological Effectiveness RBE	For a given type of radiation, the Relative Biological Effectiveness (RBE) is defined as: $$RBE = \frac{\text{Dose of the reference radiation needed to produce the same effect}}{\text{Dose of the given radiation needed to produce a given biological effect}}$$
Response	The proportion or absolute size of an exposed population that demonstrates a specific effect. May also refer to the nature of the effect.
Retrospective assessment	A retrospective assessment is an assessment that is conducted to determine the impact of a practice or process which has already started and is either still operational or has ceased operation.
Risk	A statistical concept describing the expected frequency or probability of undesirable effects arising from exposure to a contaminant. A measure of the probability that damage to life, health, property, and/or the environment will occur as a result of a given hazard. A technical estimation of risk is usually based on the expected value of the conditional probability of the event occurring times the consequence or magnitude of the event given that it has occurred.
Risk assessment	A qualitative or quantitative evaluation of the risk posed to human health and/or the environment by the actual and/or potential presence of pollutants. It includes problem formulation, exposure and dose-response assessment and risk characterisation.
Risk characterisation	The synthesis of information obtained during risk assessment for use in management decisions. This should include an estimation of the probability (or incidence) and magnitude (or severity) of the adverse effects likely to occur in a population or environmental compartment, together with identification of uncertainties.
Risk communication	The exchange of information about health or environmental risks among risk assessors and managers, the general public, news media, interest groups, etc.
Risk evaluation	A component of risk assessment in which judgments are made about the significance and acceptability of risk.
Risk management	The selection and practical implementation of regulatory and non-regulatory responses to risk. Practical implementation of procedures, actions or policies to mitigate, reduce, remove or monitor health or environmental risks.
Risk Quotient	A risk quotient is a measure of the risk caused by each contaminant to an organism. For radioactive substances it is defined by the activity concentration of a given radionuclide in soil, water or air divided by the environmental media concentration limit for that radionuclide.
Safety factor	Measure of degree of uncertainty, caused by lack of effects data. For example, an estimated lowest observed effect concentration may, as a precautionary

	approach, be divided by a safety factor (normally within the range 10 - 10 000) to safeguard against harmful effects, where the magnitude of the safety factor reflects the degree and type of uncertainty (*e.g.*, lack of chronic exposure data, lack of data for different taxonomic groups or trophic levels, etc.). Also known as assessment factor.
Sensitivity Analysis	The systematic investigation of the reaction of the simulation and response to either extreme values of the model's quantitative factors (parameter and input variables) or to drastic changes in the model's quantitative factors (modules). So the focus is not on marginal changes in inputs.
Source	Anything that may cause radiation exposure — such as by emitting ionising radiation or by releasing radioactive substances or materials — and can be treated as a single entity for protection and safety purposes.
Spearman Rank Correlation Coefficient	RCC is usually calculated on occasions when it is not convenient, economic, or even possible to give actual values to variables, but only to assign a rank order to instances of each variable. It may also be a better indicator that a relationship exists between two variables when the relationship is non-linear.
Species Sensitivity Distribution SSD	The SSD method estimates the doses (or dose rates) below which 95 % (for example) of species in the aquatic/terrestrial ecosystem should be protected (HD_5 or HDR_5 – Hazardous Dose giving 50 % effect to 5 % of species or Hazardous Dose Rate giving 10 % effect to 5 % of species). The final benchmark screening values (PNED or PNEDR) are obtained by applying a safety factor (SF) of between 1 and 5 to take on board remaining extrapolation uncertainties (*e.g.* the irradiation pathway that could lead to a dominant internal dose by α or β emitters). In summary: $PNED(R) = \frac{HD(R)_5}{SF}$ In ERICA, SSD built on ecotoxicity data obtained from the mathematical processing of the effects data within the FRED, and averaging per umbrella effect for each species (geometric mean per umbrella effect for each species, species weighted in the distribution, no weight per taxonomic group).
Stakeholder	Stakeholder: anyone who has an interest in or considers themselves to have an interest in the issue and therefore it goes beyond "representatives" of groups to include "interested members of the public" (Institute of Environmental Management and Assessment, 2002).
Standardised Rank Regression Coefficient. SRRC	Estimates non-linear monotonic relationship and provides "shared" contribution of an input parameter to the resultant dose.
Standardised Regression Coefficient SRC	The regression coefficient that would result from data that have been standardised.
Statistical Independence SI	Use of the χ2statistic to identify non random joint distributions involving y and individual xi's.

Sustainability	The ability of an ecosystem to maintain ecological processes and functions, biological diversity, and productivity over time.
Synergism	An interaction between two substances that results in a greater effect than both of the substances could have had acting independently.
Systematic error (Bias)	(i) In problems of estimation, an estimator is said to be biased if its expected value does not equal the parameter it is intended to estimate. (ii) In sampling, a bias is a systematic error introduced by selecting items from a wrong population.
Threshold	A pollutant concentration (or dose), below which no deleterious effect occurs.
Tier	The common denominator in tiered approaches are that complexity and realism increases with higher tiers and that the decision to continue from one tier to the next is based on identification of hazard to ecological receptors.
Toxicant	A substance that kills or injures an organism through chemical or physical action or by altering the organism's environment; for example, cyanides, phenols, pesticides, or heavy metals; especially used for insect control.
Triangular Distribution	A distribution with a triangular shape. It is characterised by its minimum, maximum and mode (most likely) values. It is often used to represent a truncated log-normal or normal distribution if there is little information available on the parameter being modelled.
Uncertainty	Statistical term that is used to represent the degree of accuracy and precision of data. It often expresses the range of possible values of a parameter or a measurement around a mean or preferred value. Uncertainty is a statistical term that is used to represent the degree of accuracy and precision of data. It often expresses the range of possible values of a parameter or a measurement around a mean or preferred value. Parameter, associated with the result of a measurement or calculation that characterises the dispersion of the values that could be attributed to the measurand.
Uncertainty analysis	In uncertainty analysis values of the model inputs are sampled from pre-defined distributions to quantify the consequences of the uncertainties in the model inputs, for the model outputs. So in uncertainty analysis the input variables range between extreme values investigated in sensitivity analysis.
Validation	The establishment of sound approach and foundation. The legal use of validation is to give an official confirmation or approval of an act or product.
Variability	This refers to observed differences attributable to true heterogeneity or diversity in a population or parameter. Sources of variability are the result of random processes. Variability is usually not reducible by further measurement or study, but can be characterised.
Variance	The variance of a sample is (i) the square of the standard deviation (ii) the second central moment of a population.

List of Abbreviations

ALARA	As low as reasonably achievable
BAT	Best Available Technology
BPEO	Best Practicable Environmental Option
CC	Correlation coefficient
CDF	Cumulative Distribution Function
CLs	Common Locations
CMDs	Common Medians
CMNs	Common Means
CTV	Chronic Toxicity Value
ECx	Effective Concentration at value x
EIA	Environmental Impact Assessment
EIS	Environmental Impact Statement
EMCL	Environmental Media Concentration Limit
EQS	Environmental Quality Standard
ERA	Ecological Risk Assessment
ERICA	Environmental Risk from Ionising Contaminants: Assessment and Management
EUG	End Users Group
EUG	ERICA End Users Group
FRED	FASSET Radiation Effects Database, see www.erica-project.org
FREDERICA	Database that stems from the FASSET Radiation Effects Database (FRED), which was supplemented during the ERICA project (hence the name FREDERICA) with new data, including some from the FP5 EPIC project.
LC	Lethal Concentration
LET	Linear Energy Transfer.
LOAEL	Lowest Observed Adverse Effect Level
LOEC	Lowest Observed Effect Concentration
MPC	Maximum Permissible Concentration (RIVM)
NAWQC	National Ambient Water Quality Criteria
NOAEL	Lowest Observed Adverse Effect Level
NOEC	No Observed Effect Concentration
NORM	Naturally Occurring Radionuclides
PBT	Persistent, Bioaccumulative and Toxic substances.
PCC	Partial Correlation Coefficient.

PDF	Probability Density Function
PNEDR	Predicted No-Effect Dose Rate
PRCC	Partial Rank Correlation Coefficient
QSAR	Quantitative Structure-Activity Relationship
RBE	Relative Biological Effectiveness
RCC	Spearman Rank Correlation Coefficient.
RQ	Risk Quotient
SI	Statistical Independence.
SLC	Screening Level Concentration
SRC	Standardised Regression Coefficient.
SRRC	Standardised Rank Regression Coefficient
SSD	Species Sensitivity Distribution
TEL	Threshold Effects Level
TeNORM	Technologically Enhanced Naturally Occurring Radionuclides
TGD	Technical Guidance Documents
TLD	Thermo-luminescent Dosimeter
TU	Toxic Unit