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PROTECT

Protection of the Environment from Ionising Radiation in a Regulatory Context

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Deliverable 4
Evaluation of approaches for protecting the environment from ionising radiation in a regulatory context

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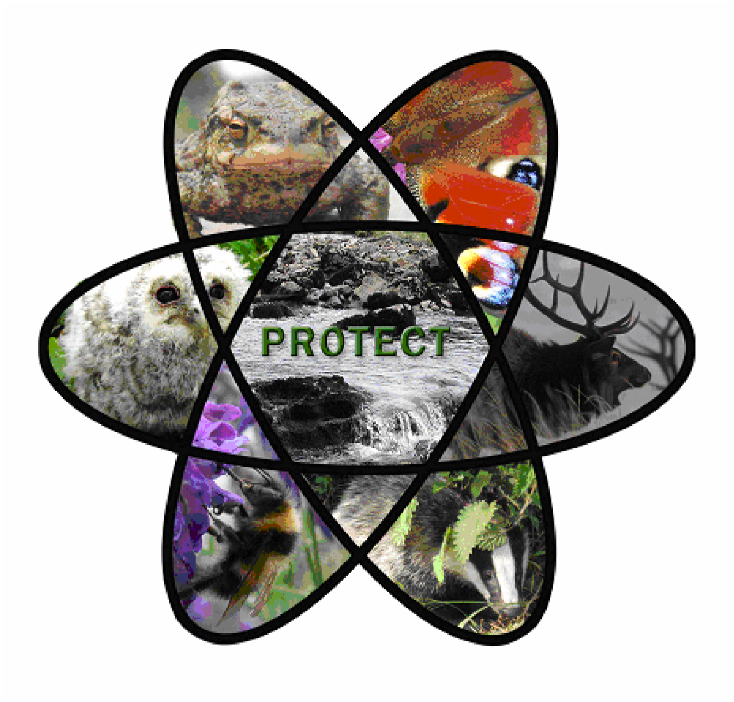
The EU EURATOM funded PROTECT project (FI6R-036425) will evaluate the different approaches to protection of the environment from ionising radiation and will compare these with the approaches used for non-radioactive contaminants. This will provide a scientific justification on which to propose numerical targets or standards for protection of the environment from ionising radiation.



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Executive Summary

In response to international recommendations, and to address the requirements of existing national legislation in some countries, a number of approaches have been developed specifically to estimate the exposure of non-human biota to ionising radiation. Some of the approaches are currently being used within the national regulatory frameworks of some countries, including EC member states. This report describes activities conducted to: evaluate the practicability of existing and developing approaches; consider the acceptability and relevance of current approaches compared to the needs of industry and regulators and the different situations it may need to address; test available approaches against any relevant ICRP recommendations or outputs from PROTECT; and assess the availability, usability and transparency of available approaches to groups other than those involved in their development.

The three most comprehensive approaches which are freely available for use, and which are being used by organisations other than their developers, are RESRAD-BIOTA (implementing the USDoE 'graded approach), EA R&D 128 (developed for use in England and Wales) and the ERICA Tool (developed under EURATOM funding). Consequently, some emphasis is placed on these three approaches.

There is likely to be a significant future requirement for such tools as a consequence of revised ICRP Recommendations and EC and International Safety Standards. The existence of currently available assessment tools considered here will reduce the cost to any further industry users/regulators who may need to demonstrate protection of the environment in response to international guidelines and resultant national legislation. However, currently none of the available approaches is comprehensive and, as a consequence, parts of different approaches are often being combined for use in some assessments.

Evaluations by PROTECT support the conclusions of the IAEA EMRAS BWG and others, that the transfer components of the assessment tools add most to the overall uncertainty in predictions.

Of the three most developed approaches freely available to any user, EA R&D128 could be described as the most basic and the developers state an intention to adopt parameters from the ERICA Tool. However, it is the only one of the three approaches to consider radioisotopes of noble gases which can constitute an important component of airborne releases from nuclear power plants. The RESRAD-BIOTA package is designed as a screening tool with, in effect, a requirement for site specific data at anything above the initial screening levels. However, the tool does contain allometric models enabling the user to define transfer to terrestrial/riparian mammal and bird species of interest (including the creation of simple foodchains). The ERICA Tool has the most developed CR-based transfer databases for a wide range of reference organisms arguably giving it a better basis to conduct prospective (when site specific data will not be available) assessments. It also considers the largest number of radionuclides having the ability to estimate dose conversion coefficients values for most radionuclides included within ICRP Publication 38.The ERICA Tool may also provide the most appropriate platform to implement the ICRP framework when it becomes available (the ERICA Tool already includes all of the adult life stages of the ICRP proposed Reference Animals and Plants and the ICRP have adopted the same dosimetric methodology as used in the ERICA Tool). However, the ERICA Tool lacks the functionality of RESRAD-BIOTA provided by its allometric models and ability to consider contaminated water intake by terrestrial animals. If organisms are to be assessed at the level of species (e.g. as in the Canadian 'valued ecosystem component' approach) then robust generic approaches to deriving transfer need to be further developed (e.g. allometric models for animals or phylogenetic approaches for plants).

Both RESRAD-BIOTA and the ERICA Tool continue to be maintained and developed; in the case of the ERICA Tool this is currently being conducted by a number of the original developing organisations without additional funding. Given the more comprehensive nature of the ERICA Tool we recommend its use for chronic exposure assessment within EC member states. However, it may be necessary to use it in conjunction with other models including the allometric modelling functionality of RESRAD-BIOTA. Our recommendation is only valid with the assumption that there is continued development and maintenance of the ERICA Tool and its databases.

There may be requirements to conduct temporal and/or spatial assessments, capabilities which the three models considered in most detail in this report do not have. Some dynamic models have been developed. For spatial assessments, the USEPA SADA model enables screening tier assessments to be conducted spatially (utilising parameters from RESRAD-BIOTA), and parameters from both the FASSET and ERICA Tool have been implemented in geographical information systems. Similarly, if packages such as RESRAD-BIOTA and the ERICA Tool do not have the required flexibility in the dosimetric assessment components there are other bespoke dosimetry tools available which may have the required flexibility, although these may not have been as independently assessed to date as the more generic tools.

Perhaps the most important criteria for the assessment tools, such as RESRAD-BIOTA or the ERICA Tool, is that they can be used with confidence in screening tier assessments. However, the comparison of screening tier predictions presented in this report does not promote the level of confidence required with large differences in output between the three approaches evaluated. If these models are to be (increasingly) used for regulatory assessment the reasons for such large variation in basic screening tier outputs needs to be more fully understood and any deficiencies addressed. This emphasises the importance of continuing the work of groups such as the IAEA EMRAS BWG and further funding for this still developing area of radiological protection.

All the major international organisations (i.e. ICRP, EC, IAEA and UNSCEAR) have draft documents in progress on this area. As these become available the requirements for assessment tools and their development may further evolve.

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1. Introduction

In response to international recommendations (e.g. ICRP 2007a), and to address the requirements of existing national legislation in some countries, a number of approaches have been developed specifically to estimate the exposure of non-human biota to ionising radiation. Some of these approaches are being used within the national regulatory frameworks in some countries (e.g. the USA, England and Wales, Canada, Sweden and Finland). This report describes activities conducted within Workpackage 2 of the PROTECT project with the objectives to:

- evaluate the practicability of existing and developing approaches
- consider the acceptability and relevance of current approaches compared to the needs of industry and regulators and the different situations it may need to address
- test available approaches against any relevant ICRP recommendations or outputs from PROTECT
- assess the availability, usability and transparency of available approaches to groups other than those involved in their development

The work has, in part, been achieved through consultation with tool developers and users including at two of the workshops held within the PROTECT project (Beresford et al. 2007a; 2008a). A draft version of this report was made available for comment on the PROTECT website and this final version takes into account comments received (comments received and responses to them can be found on: http://www.ceh.ac.uk/protect/outputs/[1]).

This report will concentrate on approaches which have been developed, or proposed, for use in exposure assessment and risk estimation. It will not consider approaches available to analyse effects data to determine numerical benchmark values which are considered within a separate PROTECT report (Andersson et al. 2008a).

[1]In some instances responses were discussed with the originators of the comments during the preparation of this final report version.

2. Overview of existing approaches

The IAEA initiated the Biota Working Group (BWG) within its Environmental Modelling for Radiation Safety (EMRAS) programme in response to the need for a forum to compare and improve the growing number of models/approaches, either already developed or under development, to estimate the exposure of wildlife to ionising radiation. In total, 15 approaches were applied in the modelling exercises of the BWG (Beresford et al. submitted). These ranged from freely available assessment tools considering multiple ecosystems and enabling at least exposure (dose) and risk to be estimated, through moderately comprehensive in-house approaches (which may or may not be encapsulated within a model), to more specific dosimetric or transfer tools, including adaptation of existing models developed for human exposure estimates. The methodologies evaluated by the BWG include most of those we are aware of that are being applied by regulators and industry to conduct assessments to meet national requirements.

Table 2.1 presents a summary of the approaches which are being used, or have been proposed for use, in radiological environmental assessment including those approaches participating within the BWG and additional models identified during the course of PROTECT. In addition to a brief overview of each approach, the table provides: information on software and documentation availability; details of uses of the approach in a regulatory context (we have not made reference to their additional application as research and teaching tools); and a note on application within the BWG evaluations. The outputs of the BWG evaluation of many of the approaches listed within Table 2.1 are discussed in the section 3.1.

The three most comprehensive approaches which are freely available for use, and which are being used by organisations other than their developers, are RESRAD-BIOTA, EA R&D 128 and ERICA. Consequently, some emphasis is placed on these three approaches in the subsequent text.

One aim of PROTECT was to consider chemical assessment models which may be applicable to radiological assessments. One such model identified is the SADA (Spatial Analysis and Decision Assistance) software package developed for US agencies and which already has some radiological assessment capabilities (SADA is included Table 2.1). The SADA package allows a unified framework wherein screening ecological risk assessment for non-radioactive stressors can be derived alongside screening assessments for radionuclides, and integrated human and ecological risk assessments can be conducted. We also considered the ARAMS (Adaptive Risk Assessment Modeling System; see http://el.erdc.usace.army.mil/arams/) a modelling analysis package which integrates multimedia and multi-pathway fate/transport, exposure, intake/uptake, and effects of military relevant compounds to assess human and ecological health impacts/risks associated with chronic exposure. However, we could find no current functionality in ARAMS to conduct radiological environmental risk assessments (it has some human radiological assessment capabilities).

2.1 Basic common components of the different approaches

The more comprehensive assessment approaches use some form of tiered (iterative) assessment which is consistent with approaches used for other stressors. In the case of RESRAD-BIOTA and the ERICA Tool, the tiers are inbuilt into the software; in other cases (e.g. R&D128 and the AECL approach) the approaches are applied in a manner consistent with a tiered approach. Such tiered assessments begin with a highly conservative 'screening tier' and progress, if required, to more refined assessment. This procedure is described further within section 3.2.

2.1.1 Organisms

Terms are used for the organisms being assessed in the different approaches, include: 'reference organism', 'representative species', 'feature species' and 'receptor'. In many, although not all approaches, these terms are used for a set of default organisms (e.g. FASSET, EPIC, ERICA, RESRAD-BIOTA and R&D 128) for which default transfer parameters values and/or models, geometries and associated dosimetry coefficients, habitat assumptions etc. are provided. In selecting these reference organisms a number of factors have generally been considered so that they represent or encompass various criteria such as: organisms likely to be amongst the most exposed; different trophic levels; species of protected status; and organisms sensitive to radiation. However, in other approaches species may be chosen both from a scientific point of view and from a public interest perspective and are classified in Canada as 'valued ecosystem components'. This differs from the concept of reference organisms, as in Canada the focus has been on species of interest locally (although in selecting these, consideration is given to ensuring a cross-section of exposure pathways, trophic positions, radionuclides etc. are included) (Beresford et al. 2007a).

2.1.2 Transfer

Many of the approaches predict radionuclide activity concentrations in animals and plants from media activity concentrations using equilibrium concentration ratios (CR), where for terrestrial ecosystems:

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

Exceptions common to a number of different approaches are for chronic atmospheric releases of ^{3}H and ^{14}C (and in some approaches radioisotopes of P and ^{35}S) where:

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

For aquatic ecosystems:

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

In aquatic ecosystems, many approaches also use distribution coefficients (K_d) to describe the relative activity concentrations of sediment and water:

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

Because of the generic nature of how organisms are defined in many of the approaches (e.g. terrestrial mammal, benthic fish etc.), recommended CR values may be based upon many studies for different species (e.g. see Beresford et al. 2008c and Hosseini et al. 2008 for a description of the ERICA CR databases) or a value for one species may be proposed as representative for many species (e.g. EA R&D128 (Copplestone et al. 2001)). Much of the data available for some organisms are from measurements of tissues entering the human foodchain which have had to be manipulated to provide whole body CR values. Not all approaches use CR models, some use, or incorporate, allometric approaches for vertebrate organisms which relate body mass to either (i) radionuclide transfer from the diet or (ii) radionuclide biological half-life (e.g. Higley et al. 2003; Garisto et al. 2007) (other parameters such as dietary intake may also be determined using allometric expressions).

The allometric approach is an example of methods developed to try to address the large number of radionuclide-organism combinations needed. In some approaches (notably EA R&D128 and ERICA), where data to derive CR values were not available, 'guidance' methodologies were derived to estimate default CR values. These range from, for instance, the use of allometric and other models through to using CR values for biogeochemically similar radionuclides (e.g. applying a value derived for Am as the Pu CR) or similar organisms (e.g. applying a CR value derived for terrestrial mammals to estimate the activity concentration of terrestrial birds) (Copplestone et al. 2003; Beresford et al. 2008c).

The freely available tools ERICA, RESRAD-BIOTA and EA R&D128 all allow the user to input either their own CR values or measurements of the activity concentration in biota (although not in the initial screening tiers of RESRAD-BIOTA and ERICA).

An overview of the methods used to estimate whole-body activity concentrations by a number of the approaches listed in Table 2.1 can be found in Beresford et al. (2008b).

2.1.3 Dosimetry

For dosimetry assessment, all approaches use a simplification, representing whole organisms by simple shapes (most typically as ellipsoids). Absorbed dose rates (Gy per unit time) are estimated using dose conversion coefficients (DCCs), which relate unweighted absorbed dose rate to the activity concentration in an organism or media. Vives i Batlle et al. (2007) present an overview of the derivation of DCC values by many of the approaches listed in Table 2.1. Briefly, potential differences between approaches include: the number of radionuclide daughter products included in the derivation of the parent DCC; media and tissue density; uniformity of contamination in media (including e.g. depth of soil or water column); nuclide library information (e.g. number of α-, β- or γ-decays used for a given radionuclide); and the degree of absorption of internal and external radiation assumed. Multiplicative radiation weighting factors are used to derive equivalent dose rates for α- and β-emitters and the value of the radiation factor varies between approaches. Assumptions with regard to estimating dose rates may vary with level of assessment with some approaches. For instance, for initial screening assessments RESRAD-BIOTA conservatively assumes a very small organism to estimate external exposure and a very large organism to estimate internal exposure thus maximising the estimated dose rate.

Two of the approaches listed in Table 2.1 (EDEN and EPIC DOSES-3D) are bespoke dosimetric tools which enable dose rates, or DCC values, to be estimated for a range of organism shapes and/or sizes. The ERICA Tool, in addition to having default geometries and associated DCC databases, also has the functionality to allow users to define their own organism, although with some constraints of size.

Table 2.1. Summary of approaches used or proposed for the radiological assessment of wildlife. Links to the software and documentation for many of these approaches can also be found on http://www.ceh.ac.uk/protect/pages/env_protect_radio.html.

Approach	Short description	Documentation/availability	Application in assessments*	Evaluated by IAEA EMRAS BWG**
Tools/approaches enabling multiple aspects of exposure assessment to be conducted and which are freely available to any user				
EA R&D 128	The approach and associated spreadsheet tools have been developed by the England & Wales Environment Agency (EA) primarily to assess compliance with the EC Habitats Directive in England & Wales. The tools include coastal, freshwater and terrestrial ecosystems. The approach uses 'reference organisms' to represent biota and covers 16 and 18 radionuclides in aquatic/terrestrial ecosystems respectively. The tool uses an equilibrium based approach and default databases contain parameters for concentration ratios (CRs) for each reference organism geometry/radionuclide (obtained using guidance where there are gaps in the literature), weighting factors, occupancy factors and dose conversion coefficients (DCCs). DCCs are estimated using energy absorbed fraction functions calculated separately for photons and electrons. Organisms are defined as three-axis ellipsoids, assuming uniform distribution of internally incorporated radionuclides.	Two reports described methodology: Copplestone et al. (2001); Copplestone et al. (2003). Dosimetric calculations are further described in Vives i Batlle et al. (2004). Latest versions of the reports are available from the publications section of the Environment Agency's website (www.environment-agency.gov.uk) but this does not include the spreadsheet tools which can be downloaded from: http://www.coger.org.uk/R&D128index.html).	The methodology and guidance have been, and continues to be used in a regulatory context by the England and Wales Environment Agency to assess the impact of authorised discharges of radioactive substances to Natura 2000 sites under the Conservation (Natural Habitats) Regulations 1994, the UK implementation of the EU Birds and Habitats Directives (Council Directives 79/409/EEC and 92/43/EEC) (see Allott & Copplestone 2008). The method has also been used in assessments of releases to marine ecosystems in Australia (e.g. Twining et al. 2005).	4/4

Approach	Short description	Documentation/availability	Application in assessments*	Evaluated by IAEA EMRAS BWG**
ERICA Tool	Tiered approach considering exposure of biota in freshwater, terrestrial and marine ecosystems developed by an EURATOM 6th Framework consortium. The approach used some elements developed during the earlier EURATOM projects FASSET and EPIC (see below). In Tier 1 input media activity concentrations are compared to environmental media concentration limits. Tiers 2 and 3 include default CR and DCC databases for radionuclides of 31 elements and 38 reference organisms. Further organism and radionuclides can be defined by the user. Tier 3 has probabilistic ability. The tool contains outputs from/links to (depending upon tier) an on-line radiation effects database. The ERICA Tool is now being maintained and updated by a core group of institutes involved in its initial development.	The ERICA Tool is described in Beresford et al. (2007b) and Brown et al. (2008). All documentation for the ERICA Integrated Approach is available from: http://www.ceh.ac.uk/PROTECT/ERICAdeliverables.html. The tool also has a comprehensive on-line help function. The ERICA Tool is freely available from: http://www.project.facilia.se/erica/download.html. The ERICA Integrated Approach is also described within a special issue of *J. Environ. Radioactivity* (Howard & Larsson 2008).	The ERICA Tool, or elements of it, has been/is being used in assessments within a number of countries, including: Finland - Olkiluto repository (Smith & Robinson 2006) Sweden – used by regulator and industry United Kingdom – UK low level waste repository (see Beresford et al. 2008a); in support of Natura 2000 assessments (Allott & Copplestone 2008; Beresford et al. 2007c); generic waste repository assessment (Smith et al. 2008) Norway – assessment of releases of radioactivity in the Norwegian Sea for use in contingency planning (Liland et al. in preparation). The ERICA Tool was also used to conduct the OSPAR assessment of impact on marine biota of anthropogenic sources of radioactive substances[2]. Parameters and radiation effects databases from the ERICA Tool are being heavily utilised by the ICRP in development of their Reference Animal	4/4

[2] Report will subsequently be available from: http://www.ospar.org/eng/html/welcome.html

Approach	Short description	Documentation/availability	Application in assessments*	Evaluated by IAEA EMRAS BWG**
			and Plant concept (see main text).	
RESRAD-BIOTA	A computer code which implements the US Department of Energy's (DOE's) 'graded approach for evaluating radiation doses to freshwater and terrestrial biota'. Its database contains 46 radionuclides, four organism types (terrestrial animals, terrestrial plants, aquatic animals, and riparian animals), and eight default geometries. "New organism wizard" provides step by step instructions on creating new organisms for consideration, which can be linked to organisms of lower trophic levels as food sources, thereby enabling the establishment of simple food web relationships. Text reports and graphic charts are generated and can be exported. Sensitivity analyses on input parameters can also be conducted.	RESRAD-BIOTA is freely available and can be downloaded from the RESRAD web site (http://www.evs.anl.gov/resrad) or the US Department of Energy Biota Dose Assessment Committee Web site (http://homer.ornl.gov/nuclearsafety/nsea/oepa/bdac/resrad.html). Related documents on the methodology (USDoE 2002) and operation of the code (user's guide) are also available from these web sites. A number of refereed papers describing the graded approach can be found in Woodhead (2003). Training courses for RESRAD-BIOTA are held at moderately frequent intervals (see http://web.ead.anl.gov/resrad/training/).	There is a requirement for USDoE sites to include a biota dose assessment in the site's annual environmental monitoring report (USDoE 1993; 2003); many sites have used Levels 1 and 2 of the RESRAD-BIOTA code to conduct these assessments. Reports of some assessments can be found on http://www.lanl.gov/environment/compliance/biota-assessment.shtml and http://homer.ornl.gov/nuclearsafety/nsea/oepa/bdac/. RESRAD-BIOTA is also used by other US Federal and state agencies. Elements of RESRAD-BIOTA have been used to provide parameters for other approaches (e.g. see Vives i Batlle et al. 2007; Beresford et al. 2008b). Parameters have also been used, together with those from other methods, to derive environmental no effects media concentrations for assessment of nuclear facilities (Chouhan et al. submitted) and potential deep waste repositories (Garisto et al. 2008) in Canada.	4/4
SADA	The SADA (Spatial Analysis and Decision Assistance) software package was	A fully functional freeware version of SADA is available from:	See http://www.tiem.utk.edu/~sada/applicati	No

Approach	Short description	Documentation/availability	Application in assessments*	Evaluated by IAEA EMRAS BWG**
	developed for the US Environmental Protection Agency and the US Nuclear Regulatory Commission. It includes integrated modules for visualisation, geospatial analysis, statistical analysis, human health risk assessment, ecological risk assessment, cost/benefit analysis, sampling design, and decision analysis. SADA has a strong emphasis on the spatial distribution of contaminant data. Whilst primarily developed for non-radioactive contaminants, SADA can be applied to radioactive contamination for basic screening tier assessments by inclusion of USDoE (2002) *biota concentration guidelines (BCG's)* (i.e. predicted no-effects media concentrations). In effect this means that SADA can be used for assessments equivalent to Level 1 of the RESRAD-BIOTA package but with the added functionality of being able to consider the data within a spatial context.	http://www.tiem.utk.edu/~sada/index.shtml. User guides, help files and training manuals can be downloaded from: http://www.tiem.utk.edu/~sada/documentation.shtml. Training courses are held for SADA and there is also a user's email forum.	ons.shtml although it is unclear if any of the assessments listed has included application of SADA to consider radiological risk to wildlife.	
EPIC	The EPIC methodology was developed specifically for Arctic ecosystems. Documentation included tabulated CR and DCC values for Arctic marine, freshwater and terrestrial reference organisms and species. A bespoke dosimetry tool was developed to	All EPIC documentation is available from: http://www.ceh.ac.uk/PROTECT/EPICdeliverables.html. A number of refereed papers also describe elements of the EPIC methodology (Beresford et al. 2005a; Brown et al. 2006; Sazykina & Kryshev 2003;2006)	A few specific elements of the EPIC methodology were used in combination with other models for the Finnish Olkiluto repository assessments (Smith & Robinson 2006).	No

Approach	Short description	Documentation/availability	Application in assessments*	Evaluated by IAEA EMRAS BWG**
	derive DCC values (EPIC DOSES-3D) which is overviewed separately below. *NOTE – the EPIC methodology has been superseded by the ERICA Tool which utilised some data from the transfer and effects databases from EPIC in its development.*			
FASSET	Documentation for the FASSET environmental assessment framework included tabulated CR and DCC values for marine, freshwater and terrestrial reference organisms. An on-line database of radiation effects was also compiled (this was further developed, and utilised, during both the ERICA and PROTECT projects). *NOTE – the FASSET framework has been superseded by the ERICA Tool which utilised the reference organism justification, and transfer and effects databases from FASSET in its development. Much of the dosimetry methodology developed for FASSET was also adopted within the ERICA Tool.*	All FASSET documentation is available from: http://www.ceh.ac.uk/PROTECT/FASSETdeliverables.html. Elements of the FASSET framework are also described in Williams (2004).	Elements of the FASSET framework have been used to provide parameters for other approaches (e.g. see Vives i Batlle et al. 2007; Beresford et al. 2008b). Parameters have also been used, together with those from other methods, to derive environmental no effects media concentrations for assessment of nuclear facilities (Chouhan et al. submitted) and potential deep waste repositories (Garisto et al. 2008) in Canada.	2/4
Tools/approaches enabling multiple aspects of exposure assessment to be conducted (not freely available)				
AECL	Atomic Energy Canada Limited (AECL) has typically adopted a multi-tiered approach ranging from very conservative Tier 1 to	The approach is not formally documented although it is described within the IAEA EMRAS report[3] in relation to its application	Has been developed for, and applied at, AECL sites.	3/4

[3] In preparation

Approach	Short description	Documentation/availability	Application in assessments*	Evaluated by IAEA EMRAS BWG**
	more realistic Tier 3 (based on Environment Canada, 1996 and 1997). Site-specific transfer parameters are preferred, with values from the scientific literature being taken when site-specific data are not available. To determine dose, DCC values and methods to estimate them are taken from various published sources.	within BWG comparisons.		
CARREN	Screening calculation tool (Excel file) to assess the ecological risk due to liquid and gaseous releases of radioactive substances into the environment, in relation to French nuclear power plants. Based on the ERICA screening tier method, it offers several predefined scenarios. Unlike the ERICA Tool it enables assessment of acute exposure scenarios as well as chronic exposure. Three ecosystems (freshwater, terrestrial and marine) and associated reference organisms (some of which may slightly different than the defaults in the ERICA Tool) are considered for both chronic and acute release scenarios. Inputs are radionuclide concentrations in water, air and/or sediment/soil guided for a predefined list of 21 radionuclides present in NPP releases. Outputs are risk index per medium (against default or customised benchmark values). Weighted and unweighted DCCs were	The first release of CARREN (December 2006) has been revised recently (September 2008). Currently documentation available in French only: Beaugelin-Seiller & Garnier-Laplace (2006); Beaugelin-Seiller et al. (2008).	Developed to help Electricité de France in assessing environmental risk associated to routine or accidental releases from their nuclear power plants.	No

Approach	Short description	Documentation/availability	Application in assessments*	Evaluated by IAEA EMRAS BWG**
	calculated using the EDEN model which is considered below).			
D-Max	Screening model proposed for assessing exposure of biota in freshwater, terrestrial and marine ecosystems. Calculates maximum possible dose to any organism or tissue in the given ecosystem. No assumptions concerning species/organism, geometry, or behaviour.	The approach, suggested in Smith (2005), is described within the IAEA EMRAS report in relation to its application within BWG comparisons.	n/a	2/4
DosDiMEco	This model uses CRs soil-plant transfer and the calculation of the concentration in invertebrates, fish and plankton. For terrestrial mammal and bird species, concentrations are calculated from the intake rate (using an allometric relation between body mass and intake rate), fractional gastrointestinal radionuclide absorption and retention inside the animal body. DCCs are derived by using a build-up factor corrected point Kernel technique (γ) and the Beth-Bloch equation (α and β).	The model is being developed through interaction in the IAEA EMRAS BWG. No documentation is available although it is described within the IAEA EMRAS report in relation to its application within BWG comparisons.	n/a	3/4
LIETDOS-BIO	LIETDOS-BIO is being developed to address contamination issues associated with nuclear power production in Lithuania. The code is designed to be consistent with MCNPX, a commonly used general purpose Monte-Carlo radiation transport model. An in-built method for describing phantoms allows exposure to be calculated for organisms of	The LIETDOS-BIO approach is still under development. Some details are presented in Nedveckaite et al. (2007) and also in the IAEA EMRAS report (in relation to application within BWG comparisons).	Has been applied in Lithuania to the Ignalina NPP cooling ponds (Nedveckaite et al. 2007).	4/4

Approach	Short description	Documentation/availability	Application in assessments*	Evaluated by IAEA EMRAS BWG**
	any size or form. The uncertainty in model parameter values is determined by a statistical approach. The model uses two CR databases: site-specific (used by preference) and generic (mostly based on FASSET and data from the Russian language literature).			
WSC Dynamic assessment model	Three-compartment biokinetic model based on first order linear kinetics, with interchange rates between marine organisms and their surrounding environment. The model considers ^{99}Tc, ^{127}I, ^{129}I, ^{131}I, ^{134}Cs, ^{137}Cs, ^{238}Pu, ^{239}Pu, ^{241}Pu and ^{241}Am for some of the marine organisms included within the EA R&D128 methodology; DCCs are taken from EA R&D128. Water concentrations can be input in daily, monthly or yearly time steps. Where biokinetic parameters are not available equilibrium CRs are used.	The model is described in Vives i Batlle et al. (in press). A trial version of the model and associated user guidance is available from the developers.	n/a	No
Tools/approaches to estimate environmental media concentration guideline[4]				
BCG calculator	Spreadsheets which provide a semi-automated tool for implementing screening and analysis methods contained within the USDoE (2002) graded approach. The spreadsheet tool provides much, although not all, of the functionality of RESRAD-BIOTA for a more limited set of radionuclides	The BCG calculator spreadsheets are available from: http://homer.ornl.gov/nuclearsafety/nsea/oepa/bdac/biota/calculator.cfm. The spreadsheets contain some guidance and information of default parameter value provenance.	Has been applied in assessments of USDoE sites.	No

[4] Also referred to as 'no-effects concentrations' or 'biota concentration guidelines' see section 3.2.1 for definitions.

Approach	Short description	Documentation/availability	Application in assessments*	Evaluated by IAEA EMRAS BWG**
	(n=23). Although the BCG (biota concentration guidelines) calculator is still available RESRAD-BIOTA has been developed to replace it.	Related documents on the USDoE graded approach (USDoE 2002) are available from: http://homer.ornl.gov/nuclearsafety/nsea/oepa/bdac/biota/		
Nuclear Waste Management Organisation - NECs	Approach described to derive soil, sediment, surface water and groundwater 'no-effect concentrations' (NECs) for screening assessments for selected radionuclides relevant to post closure of deep repository for used nuclear fuel. Developed for feature species in different freshwater and terrestrial ecosystems in Canada. Uses DCC and transfer values from other approaches described here, but also develops a generic transfer approach for mammals and birds.	Report, with tabulated parameters and values, available from: www.nwmo.ca	Developed for use in case study assessments of potential Canadian deep repository (see Garisto et al. 2008)	No
Transfer tools/approaches				
CASTEAUR	Calculation tool for the dynamic assessment of the spatio-temporal distribution of radionuclides in the main abiotic and biotic components of the rivers. The model accounts for hydrography, hydraulic, and sedimentary aspects, ecological functioning (trophic chain) and radioecology. Can be applied to both routine and accidental discharges, with default parameterisation for ^{110m}Ag, ^{241}Am, ^{58}Co, ^{60}Co, ^{134}Cs, ^{137}Cs, ^{54}Mn,	Information and software can be obtained from: casteaur@irsn.fr Details of the CASTEAUR model can be found in: Boyer et al. (2005) Duchesne et al. (2003); Beaugelin-Seiller et al. (2002).		1/4

Approach	Short description	Documentation/availability	Application in assessments*	Evaluated by IAEA EMRAS BWG**
	^{103}Ru and ^{106}Ru.			
ECOMOD	A freshwater transfer model which uses stable element concentrations in water for some radionuclides. DCCs from the literature are used.	Elements of the model are described in: Sazykina (2000); Kryshev (2002a;b); Kryshev, A.I. & Ryabov, I.N. (2000).		3/4
FASTer	FASTer is a multi-compartmental model that can be used to simulate transfer through a simple terrestrial food-chain. The rate of change of the radionuclide inventory in compartments is described by linear differential equations. Parameters for interception and soil compartments etc. are taken from models previously published predominantly for human assessments. Intakes of radionuclides by vertebrates are simulated using (i) allometrically derived ingestion rates, (ii) radionuclide-dependent assimilation efficiencies and (iii) assumptions concerning dietary composition. Biological half-lives are defined using allometric relationships or previously published retention functions. Within one of the IAEA EMRAS BWG intercomparisons a version of the model utilising CRs from the ERICA Tool to determine the activity concentrations of dietary components was applied.	The model is not openly available as a completed software code but its configuration within appropriate simulation software (e.g. ModelMaker, ECOLEGO) is a straight-forward process. The original model description can be found in: Brown et al. (2003) and Avila et al. (2004). Adaptation of the model using ERICA Tool CR values to determine dietary activity concentrations can be found within the IAEA EMRAS report.	An earlier version of the model was used to derive numerous default equilibrium CR values presented in the FASSET documentation and a few of these values are used as default parameters in ERICA.	1/4
LAKECO	LAKECO is a dynamic model of radionuclide behaviour in lakes. It takes into	Details of LAKECO can be found in: Popov & Heling (1996); Heling, (1996; 1997);	n/a	1/4

Approach	Short description	Documentation/availability	Application in assessments*	Evaluated by IAEA EMRAS BWG**
	account the propagation of radionuclides throughout the food web. It aims to be a generally applicable ecological model for lakes ecosystems with a minimum amount of input parameters. Subroutines use environmental parameters as input, so calibration is not needed. For the uptake of radionuclides it uses the target-tissue approach, limiting the amount of input parameters. Primarily developed for use within assessments of human exposure the model has been adapted and applied to a limited number of radionuclides within the IAEA EMRAS BWG.	Zheleznyak et al. (1996); Kryshev et al. (1999); IAEA (2000). Details of adaptation and application to assessment of non-human biota are described within the IAEA EMRAS report. LAKECO is included within the RODOS, decision support system (www.rodos.fzk.de/).		
Dosimetric tools/approaches				
EDEN	Calculation tool based on an intermediate solution between full Monte Carlo calculation and analytical empirical equations, to evaluate the energy dose rate (expressed as a Dose Conversion Coefficient, DCC) delivered to any non-human species exposed to any radionuclide internally or externally. Geometric characteristics are required to define the exposure situation to be modelled and an option is offered to calculate the DCC for a nuclide and its daughters assuming secular equilibrium.	The software is described within Beaugelin-Seiller (2006a:b) and Beaugelin-Seiller et al. (2006). The EDEN software (and user licence) is freely available upon request: eden@irsn.fr.	The EDEN software was used to derive DCC values for the CARREN tool. It was also used for dosimetric calculations in the development of a screening level environmental assessments of combined radiological and chemical risk for radioisotopes of uranium series: (i) chronic uranium contamination of freshwater ecosystems (Beaugelin-Seiller et al. submitted) - subsequently applied to former uranium ore mining sites in central of France; (ii) authorised releases from nuclear power	2/4

Approach	Short description	Documentation/availability	Application in assessments*	Evaluated by IAEA EMRAS BWG**
			plants (Garnier-Laplace et al. submitted).	
EPIC DOSES-3D	Research tool that allows doses from external (β particles, photons) and internal exposure (α, β particles, photons) in biological objects of any (user-defined) size and form to be calculated. Doses can be calculated for any radionuclide, although in the present version of the program an initial data set for 42 radionuclides is used. The software was used to derive dose conversion coefficients in the EPIC project (Golikov & Brown, 2003) and is under further development.	The software is described within Golikov & Brown (2003) – the authors can be contacted for a trial version of the tool.	n/a	3/4

*Examples of application in regulatory assessment or contributions to other assessment methodology are presented where known; n/a denotes where we are aware that an approach has not been used in regulatory assessment; blank entries denote those approaches for which we have no information on application in assessment (they may have been applied to verification/developmental case studies). **Level of participation in the four model-model and model-data comparisons conducted by the IAEA EMRAS BWG is noted.

2.2 The proposed ICRP framework

In their revised Recommendations the ICRP (2007a) recognised that there was a need to provide advice on exposure of non-human species to ionising radiation. The ICRP intends to develop a framework to assess the relationships between exposure and dose, and between dose and effect, and the consequences of such effects, for non-human species, on a common scientific basis. Table 2.1 does not consider the proposed ICRP framework, as only an draft report on the concept and use of Reference Animals and Plants (ICRP 2007b) has been made available for consultation to date. The ICRP committee (Committee 5) responsible for the report is currently revising it to address comments received. The draft ICRP report is summarised and discussed below. Comments submitted in response to the ICRP consultation can be viewed on http://www.icrp.org/remissvar/listcomments.asp, and discussions of the ICRP draft during PROTECT workshops are available in Beresford et al. (2008a) and Andersson et al. (2008b).

The ICRPs aim is to develop an approach that is both compatible with '*other approaches being made to protect the environment from all other human impacts, particularly those arising from similar human activities*' and also the present system for human radiological protection. The intended approach is stated as being developed to provide 'high level' guidance for demonstration of compliance corresponding with existing/emerging national and international legislation and serve as a basis from which national and other bodies could develop, as necessary, more applied and specific numerical approaches to the assessment and management of risks to non-human species. The implication is that the ICRP approach is not meant to be a replacement for other methods, but rather should be seen as an encompassing system which other approaches can use as a basis and point of reference when performing their own bespoke analyses. Other approaches described in this report might be considered as examples of the 'more applied and specific numerical approaches' that the ICRP refer to. Whereas such approaches often employ the use of multi-tiered systems, this is not reflected in the structural form of the ICRP approach.

The ICRP have opted to use a similar approach to Reference Man for the environment, proposing a set of 12 Reference Animals and Plants (RAPs). The list of RAPs is significantly smaller than the corresponding reference organism suites used in the ERICA and the EA R&128 approaches. However, the ICRP approach places more emphasis on life stages than the other methodologies considered, with the draft report presenting DCC values for a number of life-stages for some of the RAPs. The RAPs are suggested as 'points of reference' for drawing comparisons with sets of information on other organisms. It is acknowledged that the RAPs may not be the direct objects of protection *per se* and that it may be necessary to establish a 'secondary set of Reference Organisms for a specific purpose or geographical area'.

Since there are no internationally accepted 'rules' on classification above Family (or 'Super Family') level, the ICRP have suggested that this constitutes the most suitable level of generalisation. A RAP is defined as: '*a hypothetical entity, with the assumed basic biological characteristics of a particular type of animal or plant, as described to the generality of the taxonomic level of Family, with defined anatomical, physiological, and life-history properties, that can be used for the purposes of relating exposure to dose, and dose to effects, for that type of living organism.*' The RAPs are defined in more specific terms than are reference organism in approaches such as ERICA and EA R&D 128 (note other approaches may define objects of protection at the level of species); at the moment it is unclear whether this more specific definition is an advantage or not. It is stated that RAPs are not: (i) meant to serve as 'sentinel' organisms; organisms which the Commission suggest should be particularly protected; (ii) representative of key links in foodchains or ecosystem functioning. This contrast to the reference organism selection of, for instance, the ERICA approach which did consider the requirement to encompass: (i) European protected species; (ii) organisms likely to be comparatively highly exposed; (iii) comparatively radiosensitive organisms; and (iv) different ecological niches.

The ICRP approach briefly touches on the subject of exposure analysis, noting the required applicability to *planned*, *emergency* and *existing* situations. The approach notes that although direct measurements are sometimes available for biological compartments, modelling approaches will often be required (notably in planned and emergency situations). The draft ICRP report only briefly considers environmental transfer noting that required databases would need to be carefully considered and compiled and that this would be the subject of a subsequent report in relation to RAPs. A task group has been formed to consider the derivation of transfer databases to support the RAP approach and initial suggestions are that the ERICA database will form the basis for these values. However, as the draft ICRP report to some extent acknowledges, there are likely to be few data for some of the defined RAPs; this problem has already been encountered in trying to define typical natural radionuclide activity concentrations for RAPs to determine background exposure rates (Beresford et al. 2008d).

The draft ICRP report provided a detailed description on the derivation of unweighted DCC values (sometimes referred to as dose conversion factors (DCFs) within the report) for RAPs; consideration of Relative Biological Effectiveness (RBE) is intended to be the theme of an associated Task Group report. As discussed above, for the approaches described in Table 2.1, the main simplification involves the representation of whole organisms by simple shapes. The guidance considers that uniform isotropic models, or simplified analytical or semi-analytical methods, are often sufficient for aquatic environments, whereas in cases where there are large density differences (i.e. terrestrial ecosystems), radiation transport models (e.g. using Monte Carlo methods) are often required for accurate calculation. Following an intercomparison exercise to consider the fundamental quantity of the absorbed fraction calculated by a suite of commonly used modelling approaches (details of this intercomparison are provided in the draft report) an approach based upon the FASSET-ERICA methodology (see Ulanovksy & Pröhl (2006) and Ulanovksy et al. (2008)) was selected for the reference DCC derivation as '*it encompassed the largest set of geometry and exposure situations and used a flexible dosimetry method to calculate DCC values for a sufficiently wide range of organisms to include the specific dimensions of the Reference Animals and Plants*'. The ERICA Tool includes geometries corresponding to those specified by ICRP for the adult life-stages (and bird egg) of all proposed RAPs. Tabulated versions of DCCs for RAPs are provided in the draft report. Some preliminary considerations, essentially for illustrative purposes, were also given to the relative dosimetry of internal organs, such as the liver and gonads. The theme of 'more realistic' dosimetry, accounting for more realistic shapes and the non-homogeneous distribution of radionuclides, will also be the theme of a further ICRP Task Group.

A large component of the draft ICRP report comprises a review of radiation effects data for non-human species. This is used to suggest *Derived Consideration Levels* (DCLs) for each RAP where the DCLs are a band of absorbed dose rate for each RAP. The DCLs are not intended to be dose limits but rather: '*They are zones of dose rates at which, with respect to the Reference Animals or Plants, or types similar to them, a more considered level of evaluation of the situation would be warranted. It does not imply that higher dose rates would be environmentally damaging, nor that lower dose rates were in some way 'safe' or non-damaging. But they are dose rates that could be used in any management action or decision-making process, in terms of being starting points from which further, auditable, information could be appended in order to justify or optimise any subsequent action that was taken.*'. The derivation and suggested purpose of the ICRP DCLs are considered by the

PROTECT consortium within Andersson et al. (2008a). The draft ICRP report suggests that '*all of the derived* (radiation effects) *information relevant to each type of animal and plant could then be simplified into bands of dose rates relevant to their individual background radiation dose rates'*, and the tables of DCL values present a background dose rate. However, in the draft report, this value is the same for all species (<0.01 mGy d^{-1}) and it is unclear how it was derived in relation to the data reviewed within the text of the draft.

ICRP Committee 4 (C4) are currently in the process of assessing the draft report and PROTECT's input into C4 considerations is presented in Appendix 1. The Appendix presents hypothetical marine and terrestrial assessments, implementing, where possible, the draft ICRP report. Points arising from the assessments, additional to those discussed above were:

(i) the draft ICRP report (in common with RESRAD-BIOTA and the ERICA Tool) does not consider radioisotopes of noble gases, which may constitute a significant component of aerial discharges from nuclear power plants;

(ii) the list of RAPs includes considerably more organisms from terrestrial than aquatic environments (8 of the 12 RAPs are terrestrial organisms, whereas (e.g.) only three are freshwater organisms);

(iii) the draft ICRP report defined the RAPs at the family level but provided limited explanation on how they (and the associated information provided) should be used in assessments and related to species of interest.

(iv) no clear advice is given however on these DCLs can be applied in such a decision making process.

The comments above relate to the December 2007 draft of the ICRP report and may not be relevant to the revision which, although anticipated to be available in the near future, was not available to be considered here. Furthermore, ICRP (2007b) is focused on the concept and use of RAPs and states that a series of further reports, including one on the application of the basic approach to different exposure situations, are planned.

3. Fit for purpose

3.1 Overview of the findings of the IAEA EMRAS BWG

In total, 15 models and approaches were applied to one or more of the exercises conducted by the IAEA EMRAS BWG; these are identified within Table 2.1. Here, we present a brief overview of the findings of these activities, further details can be found in: Vives i Batlle (2007); Beresford et al. (2008b; 2008e; submitted); and a forthcoming IAEA report on the BWG activities.

3.1.2 Intercomparison exercises

The BWG conducted two intercomparison exercises to enable an evaluation of the basic components of the models:

- Dose conversion coefficients (Vives i Batlle et al. 2007) – participants were asked to estimate the unweighted absorbed dose rates for both internal and external exposure assuming an activity concentration of 1 Bq kg^{-1} in the organism or surrounding media, respectively. A selection of freshwater and terrestrial geometries proposed by the ICRP for their Reference Animal and Plants (RAPs) were used for the exercises. Estimates were made for seven radionuclides (^{3}H, ^{14}C, ^{60}Co, ^{90}Sr, ^{137}Cs, ^{238}U and ^{241}Am) chosen to cover a range of energies and radiation types.
- Transfer (Beresford et al. 2008b) - participants were required to estimate the whole-body activity concentration, of eighteen radionuclides, in seven terrestrial organisms (grass/herb, shrub, earthworm, herbivorous mammal, carnivorous mammal, rodent, bird egg) and twelve freshwater organisms (phytoplankton, zooplankton, macrophyte, benthic mollusc, small benthic crustacean, large benthic crustacean, pelagic fish, benthic fish, fish egg, amphibian, duck and mammal) assuming an activity concentration of 1 Bq per unit (kg, l or m^3) of media (soil, water or air, respectively).

Subsequently, two model-data comparisons (or scenario applications) were conducted:

- Perch Lake – located on the AECL Chalk River Laboratories site (Ontario), Perch Lake has received chronic, low-level inputs of a number of radionuclides since the 1950s. Participants were supplied with ^{90}Sr, ^{3}H, ^{60}Co and ^{137}Cs activity concentrations in water and sediments for selected years to allow the comparison of predictions of whole-body activity concentrations in a range of biota, including different fish species, aquatic mammals, plants, aquatic reptiles, amphibians and a range of invertebrate species. Unweighted internal and external absorbed dose rates were also estimated.
- Chernobyl exclusion zone - participants were provided with soil activity concentrations (^{90}Sr, ^{137}Cs, ^{241}Am and Pu-isotopes) and requested to make predictions of whole-body activity concentrations, and internal and external unweighted absorbed dose rates. Results were compared to available data for a range of biota types including: graminaceous vegetation; invertebrates; birds; a wide range of mammal species (from small rodents to deer and carnivorous species) and amphibians. Data from thermoluminescent dosimeters attached to small mammals were also available allowing a comparison with predicted external gamma dose rates.

3.2.2 Results and recommendations

Dosimetry and transfer intercomparisons

The exercise to compare predicted unweighted whole-body absorbed dose rates for a selection of the proposed ICRP RAP geometries demonstrated that all the 11 participating approaches generally estimated comparable internal dose rates even though different assumptions were made. The notable exception was a consequence of different daughter products being included (e.g. one approach included ^{234}U in the estimation of the DCC for ^{238}U). Variation was greater for the estimation of external dose rates, most notably for α- and β-emitters (e.g. from ^{3}H, plutonium and some naturally occurring radionuclides). However, external exposure of biota by such emitters is of little radiological significance due to the low range of α- and β-emitters in matter. External DCCs for ^{90}Sr reported by the ERICA and related FASSET approaches were lower for terrestrial organisms than those of other approaches. This is likely to have been the consequence of the consideration of a shielding skin/fur layer within these approaches (for terrestrial although not aquatic organisms). Whilst two of the approaches participating within this exercise, RESRAD-BIOTA and EA R&D128, have freely available software packages some of the inputs were produced using the approaches underlying methodology and would not be within the abilities of general users of the software.

The comparison of predicted activity concentrations in a range of freshwater and terrestrial biota by eight of the participating models, assuming 1 Bq per unit media, demonstrated considerably more variability than the comparison of unweighted dose estimates. For many radionuclide-reference organism combinations, variability in predictions covered three or more orders of magnitude. Predictions were often most variable for poorly studied organisms, such as fish egg, bird egg, duck, amphibian and aquatic mammals. Some of the more extreme variability could be explained by the use of 'guidance' methodology to provide values by a number of approaches in the absence of data (see section 2.1.2 above). However, in some approaches, (e.g. EA R&D128) the guidance methodology is intended to be conservative and, in most instances, it resulted in comparatively high (and hence conservative) predictions.

Model-data intercomparisons

The two scenario applications allowed model predictions to be compared to measured whole-body activity concentration data for a range of freshwater and terrestrial biota. Whilst some predictions deviated by more than three orders of magnitude from the available data, the majority of the models predicted activity concentrations in most organism types to within an order of magnitude. It was acknowledged that an order of magnitude variation may not be acceptable to regulators/industries who may use the models tested here, however, it was suggested that this level of agreement was pragmatic when considering the inherent variability in the measured data and the values used to parameterise the models.

The scenarios allowed comparison of the predictions of simple concentration ratio based approaches with more complex food-chain models under equilibrium conditions. Overall, the two approaches compared favourably. In the case of Perch Lake, three of the models which take into account water chemistry better predicted the transfer of ^{90}Sr to fish (Figure 3.1). Model parameters provided using laboratory studies (sometimes used within the CASTEAUR and ECOMOD models) often under-predicted biota activity concentrations.

The variability between the participating models in estimated dose rates could largely be explained by that in predicted whole-body activity concentrations. For the Chernobyl scenario, there was, surprisingly, less variability observed in the estimated total dose rates (typically less than an order of magnitude) than may have been anticipated from observed variation in predicted activity concentrations (typically at least three orders of magnitude). This was because some models under-estimated for one radionuclide whilst they over-predicted for another for the same organism, and hence the overall prediction of dose balanced out (N.B. total dose rates were not compared for Perch Lake).

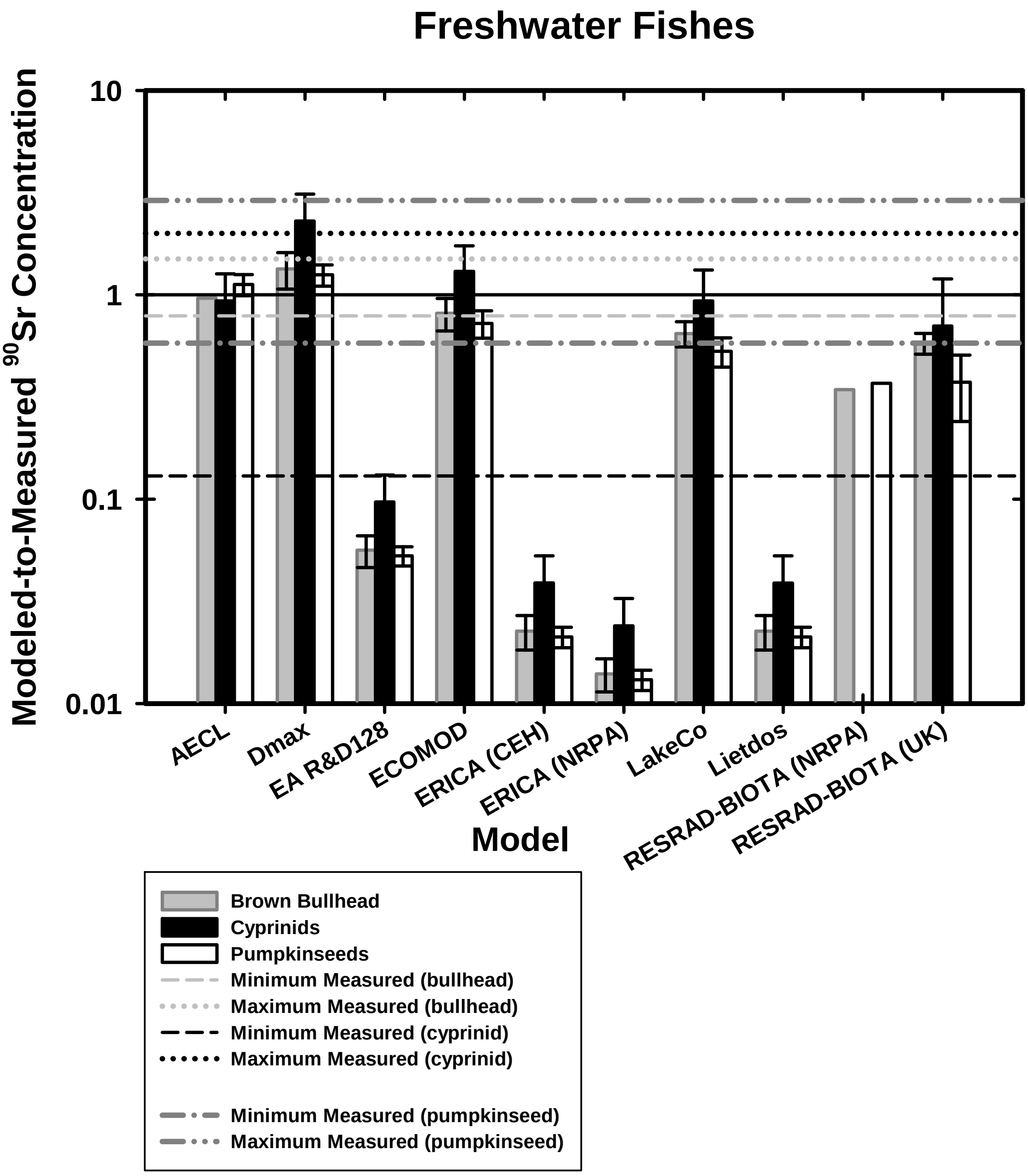

Figure 3.1. Comparison of modelled-to-measured ^{90}Sr concentrations for freshwater fish in Perch Lake. Dashed and dotted horizontal lines represent minimum and maximum measured values in the lake for a given type of fish species; error bars represent the standard error in predicted values for a given fish species by a given model. Note predictions by AECL, ECOMOD and D-Max were estimated taking water Ca concentration into account. Figure is reproduced from Beresford et al. (submitted); see Yankovich (2005) for a description of Perch Lake scenario.

For the Chernobyl scenario, predicted external dose rates generally contributed little to the overall total dose rate. Therefore, differences in assumptions on occupancy contribute little to the overall variation in estimated dose rates. However, assumptions with regard to diet and CR values used to predict the activity concentration in dietary components were responsible for variation observed between those participating models which use food chain approaches rather than simple biota-media CR values.

Recommendations

The BWG, which will continue into the follow-up programme to EMRAS, made a number of recommendations based upon their activities (see Beresford et al. submitted). Relevant to this report these included:

- There is a clear need to better share knowledge on the transfer of radionuclides to biota and to provide authoritative collations of those data which are available. It was suggested that a document for biota which is equivalent to the IAEA handbook on transfer parameters for human food chains (IAEA 1994) should be produced; this suggestion is actively being taken forward by the IAEA.
- The planned ICRP outputs should be evaluated in any future BWG scenario applications and model intercomparisons.
- Future scenarios should focus on situations which regulators/industry are having to consider (e.g. waste repositories, assessments for new power stations, sites contaminated by TeNORM). Such scenarios would better enable the comparison of the available approaches within a regulatory context, and evaluation of the various tiers of assessment (from screening level through to detailed assessment) which the more comprehensive approaches contain. Consideration should also be given to involving more 'informed users' within the BWG rather than a predominance of model developers.

3.2 Screening tier comparisons

As acknowledged in their recommendations, the IAEA EMRAS BWG did not evaluate the available approaches when applied within regulatory assessment scenarios. Within PROTECT, we have begun to address this deficit by considering the application of the three assessment approaches and their associated tools which are freely available for anybody to use. These are: the ERICA integrated approach (Beresford et al. 2007b; Howard & Larsson 2008) and the ERICA Tool (Brown et al. 2008); the USDoE graded approach (USDoE 2002) and the RESRAD-BIOTA software; the EA R&D128 methodology (Copplestone et al. 2001; 2003) and associated spreadsheets. Our assessment has concentrated on the initial screening level application of these approaches which is designed to be simple, require minimal inputs and provide conservative results. The aim is to identify sites of negligible concern and to remove them from further consideration with a high degree of confidence. It is envisaged that the majority of assessed sites would require only a screening tier assessment.

In part, the comparison was prompted by the results of an exercise run at one of the PROTECT workshops, where we provided participants with the ERICA Tool, RESRAD-BIOTA and EA R&D128 software and associated documentation. Participants were also provided with a scenario based loosely on discharges to a river which had been assessed within England and Wales by the Environment Agency (see Beresford et al. (2007a) for details). Partially, the exercise was designed to begin to gather views on the transparency/usability of these three approaches (see section 3.4 below).

The models gave very different results, identifying different rate limiting organisms and radionuclides which can be summarised as follows:

- ERICA Tool – highest dose rate (*circa* E3 μGy h^{-1}) predicted for insect larvae dominated by ^{234}Th;

- EA R&D128 – highest dose rate (*circa* E3 μGy h^{-1}) predicted for amphibian dominated by ^{239}Pu;
- RESRAD-BIOTA – ^{137}Cs was the only nuclide to result in a risk quotient (RQ) in excess of 1 (for riparian animal).

Following the workshop, the reasons for the different results from the three approaches were investigated further. All three models were run inputting ^{234}Th, ^{137}Cs and ^{239}Pu water concentrations only (as these had been the three nuclides resulting in RQs >1 in the three models). For the first run, all model parameters were left at their default values. As the critical organisms in EA R&D128 and ERICA were amphibian and insect larvae respectively, predictions were made in RESRAD-BIOTA for organisms of default geometries 2 (for insect larvae) and 3 (for amphibian). To compare with ERICA results for insect larvae, the small benthic crustacean organism results were reported for EA R&D128.

Table 3.1 compares predicted dose rates from the three models together with a number of the default parameter values; note that DCC values are broadly comparable for the three models and hence are not presented. The most apparent differences between the model predictions are the high predictions of ^{239}Pu dose rates to amphibians by EA R&D128 and high predictions of ^{234}Th dose rates to insect larvae by the ERICA Tool. Looking at the default parameter values listed in Table 3.1, the K_d value for Th used in ERICA and the Pu CR value for amphibians used in EA R&D128 are both considerably higher than those used by the other two models. The amphibian Pu CR value used within EA R&D128 is a default value which, in the lack of any data, was assumed to be the same as the models Pu K_d value.

The models were subsequently rerun using the default K_d values from EA R&D128 and CR values from the ERICA Tool in all three models. The results of this second model run are presented in Table 3.2. Results for the two selected organisms for all three models are broadly consistent when considering that no other default parameters (including radiation weighting factors, occupancy factors, and sediment moisture content all of which differ between the models) were amended.

Table 3.1. Default parameter values as used in the three models and results for the freshwater (river) scenario from Beresford et al. (2007a) using the default parameter values available in each model.

Parameter/output	ERICA Tool	EA R&D128	RESRAD-BIOTA
Radiation weighting factors			
α	10	20	20
Low-β	3	3	1
K_d values (l/kg)			
Cs	$1.37x10^5$	$1x10^3$	$5x10^2$
Pu	$1.39x10^6$	$1x10^5$	$2x10^3$
Th	$1.84x10^7$	$1x10^4$	$6x10^4$
Insect larvae (ERICA) *cf* Small Benthic Crustacean (R&D128) *cf* Geometry 2 (RESRAD-BIOTA)			
Total dose rate (μGy/h)	3200	4.3	28
Cs Total dose rate (μGy/h)	116	1.3	6.8
Pu Total dose rate (μGy/h)	11	2.6	19
Th Total dose rate (μGy/h)	3070	0.3	1.9
CR Cs (Bq/kg:Bq/l)	10400	5230	22000
CR Pu (Bq/kg:Bq/l)	1100	137	1000
CR Th (Bq/kg:Bq/l)	100	100	80
Amphibian (ERICA and R&D128) *cf* Geometry 3 (RESRAD-BIOTA)			
Total dose rate (μGy/h)	5.4	1898	28
Cs Total dose rate (μGy/h)	3.1	4.2	7.5
Pu Total dose rate (μGy/h)	2.2	1892	19.2
Th Total dose rate (μGy/h)	0.03	2.2	0.9
CR Cs (Bq/kg:Bq/l)	9300	11000	22000
CR Pu (Bq/kg:Bq/l)	230	100000	1000
CR Th (Bq/kg:Bq/l)	110	10000	80

Table 3.2. Results for the freshwater (river) scenario from Beresford et al. (2007a) predicted using EA R&D 128 K_d and the ERICA Tool CR values in all three models (amended parameters are indicated in red) in all three models.

Parameter/output	ERICA Tool	EA R&D128	RESRAD-BIOTA
Radiation weighting factors			
α	10	20	20
Low-β	3	3	1
K_d values (l/kg)			
Cs	$1x10^3$	$1x10^3$	$1x10^3$
Pu	$1x10^5$	$1x10^5$	$1x10^5$
Th	$1x10^4$	$1x10^4$	$1x10^4$
Insect larvae (ERICA) *cf* Small Benthic Crustacean (R&D128) *cf* Geometry 2 (RESRAD-BIOTA)			
Total dose rate (µGy/h)	15	24	25
Cs Total dose rate (µGy/h)	3.1	2.5	3.5
Pu Total dose rate (µGy/h)	11	21	21
Th Total dose rate (µGy/h)	1.7	0.3	0.3
CR Cs (Bq/kg:Bq/l)	10400	10400	10400
CR Pu (Bq/kg:Bq/l)	1100	1100	1100
CR Th (Bq/kg:Bq/l)	100	100	100
Amphibian (ERICA and R&D128) *cf* Geometry 3 (RESRAD-BIOTA)			
Total dose rate (µGy/h)	5.4	8	8.0
Cs Total dose rate (µGy/h)	3.1	3.5	3.4
Pu Total dose rate (µGy/h)	2.2	4.4	4.4
Th Total dose rate (µGy/h)	0.03	0.06	0.2
CR Cs (Bq/kg:Bq/l)	9300	9300	9300
CR Pu (Bq/kg:Bq/l)	230	230	230
CR Th (Bq/kg:Bq/l)	110	110	110

3.2.1 Model descriptions

Before comparing and discussing outputs of the three models further, this section provides a short description of each model, highlighting differences and concentrating on the initial screening tier (although higher tiers are briefly discussed). The conservatism included within the approaches is also highlighted.

<u>The ERICA Tool</u>

The ERICA Tool (Brown et al. 2008) implements the tiered assessment elements of the ERICA Integrated Approach (Beresford et al. 2007b; Howard & Larsson 2008). The tool includes default parameters for radioisotopes of 31 elements in terrestrial, freshwater and marine ecosystems with a total of 38 reference organisms being approximately equally divided between the three ecosystems. The assessment element of the ERICA Integrated Approach is organised into three separate tiers, where satisfying certain criteria in Tiers 1 and 2, allows the user to exit the assessment while being confident that the effects on biota are low or negligible. Tiers 2 and 3 provide the user with increasing ability to consider any situation of concern in more detail. Figure 3.2 provides a flow chart demonstrating the ERICA Integrated Approach.

The only user inputs required for Tier 1 assessments are radionuclide activity concentrations in media (although the tool contains some simple transport models to estimate these from release data if they are not available). It is recommended that maximum measured or modelled media activity concentrations are used for Tier 1 assessments. These are compared to pre-calculated *environmental media concentration limits* (EMCLs), defined as the activity concentration in the selected media (soil or air (H, C, S and P only) in terrestrial environments, water or sediment in aquatic environments) that would result in a dose-rate to the most exposed reference organism equal to that of the selected screening dose-rate. The ERICA Tool contains EMCLs for a default generic screening dose rate of 10 µGy h^{-1} for all organisms and ecosystems. It also contains EMCLs for screening dose rates of 40 µGy h^{-1} for terrestrial animals and 400 µGy h^{-1} for terrestrial plants and all organisms in aquatic environments. The user can also input their own generic screening dose rate. A difference to the RESRAD-BIOTA approach (see below) is that for aquatic ecosystems, the EMCL for water includes consideration of external exposure from sediments (in addition to internal exposure and external exposure from water). Similarly, the EMCL for sediment includes external exposure from water and internal exposure (estimated using K_d and CR values).

The outputs of the screening tier are risk quotients (RQ) which are the ratio of input media concentration to the EMCL for the most limiting organism. Only one RQ per radionuclide is reported and the most exposed (or limiting) reference organism for any given assessment may vary between radionuclides. An overall RQ value representing the sum of the RQs for the radionuclides included within a given assessment is also recorded. The ERICA Tool does not enable the user to identify the most exposed organism within the outputs of a Tier 1 assessment. For aquatic ecosystems limiting RQs for different radionuclides may be for different media (i.e. water or sediment). In this case, RQs based on different media types are added together to produce the overall summed RQ value.

To determine the EMCL values:

- internal and external DCC values estimated for simplified geometries to represent each reference organism were used together with default radiation weighting factors of 10 for alpha radiation, 3 for low energy beta and 1 for (high energy) beta and gamma radiation;
- habitat assumptions were selected to maximise likely exposure (e.g. the geometry representative of a rat was assumed to spend 100 % of time underground whilst the geometry representative of a deer was assumed to spend 100 % of time on the ground surface);
- probability distributions associated with the default CR and K_d databases were used to determine 5^{th} percentile EMCL values (which are the values used in the tool).

Conservatism within Tier 1 of the ERICA Tool is therefore in the recommendation for maximum media concentration inputs, habit assumptions and prediction of 95^{th} percentile whole-body, water and sediment concentrations as appropriate. There is no conservatism within the selection of DCC values.

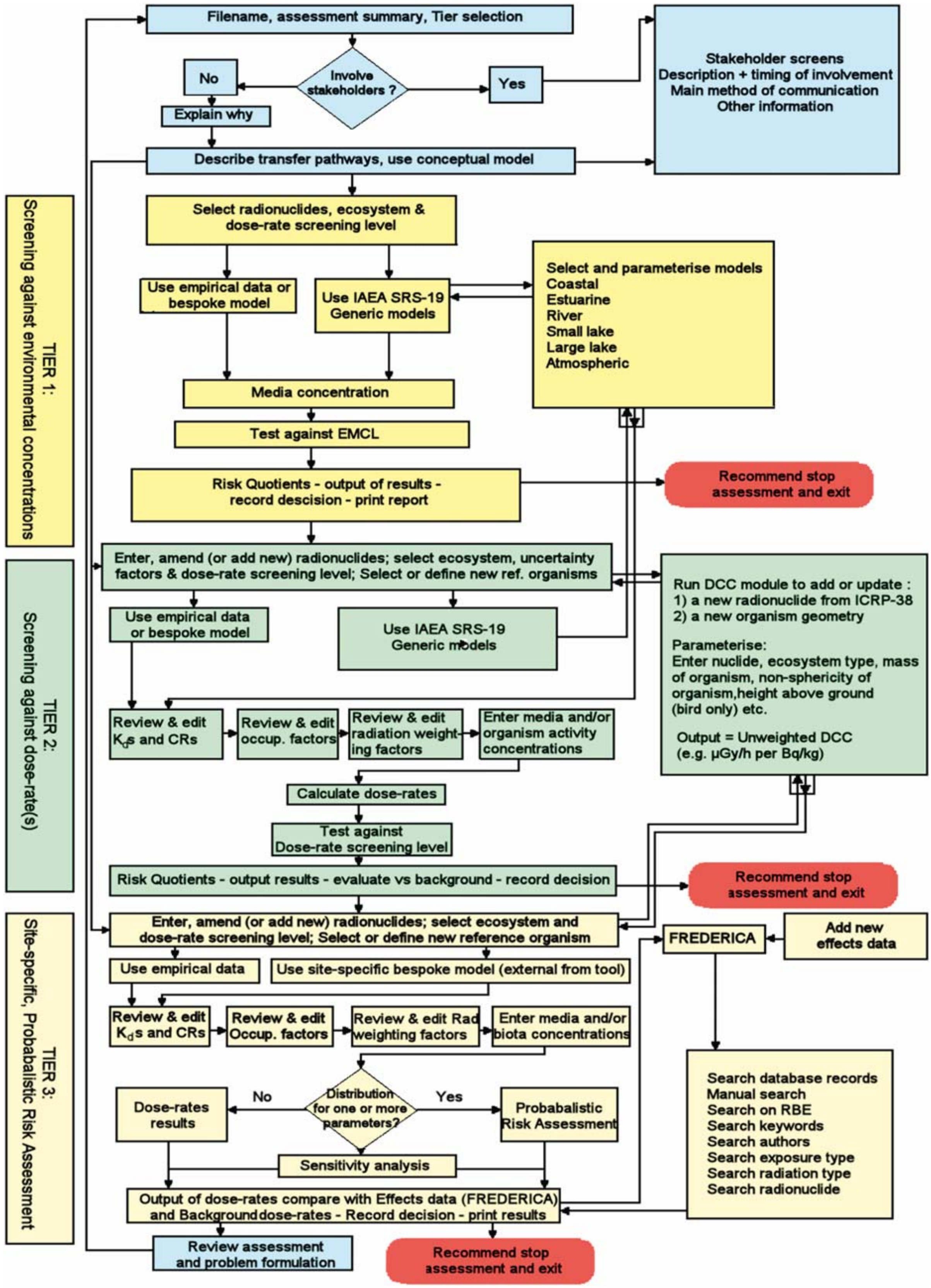

Figure 3.2. Flow chart demonstrating the implementation of the tiered ERICA integrated approach within the ERICA Tool (figure reproduced from Brown et al. (2008)).

The transfer parameters and associated probability distribution functions used within the determination of the EMCL values, and provided as defaults at higher tiers, were the result of comparatively (relative to the other two approaches considered in this section) extensive literature reviews (Beresford et al. 2008c; Hosseini et al. 2008). Where values could not be derived from the literature, a series of options were defined so that a default value could be generated (Tier 1 required a complete set of CR and K_d values), these were:

1. Use an available CR value for an organism of similar taxonomy within that ecosystem for the radionuclide under assessment (preferred option).
2. Use an available CR value for a similar reference organism (preferred option).
3. Use CR values recommended in previous reviews or derive them from previously published reviews (preferred option).
4. Use specific activity models for ^{3}H and ^{14}C (preferred option).
5. Use an available CR value for the given reference organism for an element of similar biogeochemistry.
6. Use an available CR value for biogeochemically similar elements for organisms of similar taxonomy.
7. Use an available CR value for biogeochemically similar elements available for a similar reference organism.
8. Use allometric relationships, or other modelling approaches, to derive appropriate CRs.
9. Assume the highest available CR (least preferred option).
10. Use a CR or K_d for appropriate reference organism from another ecosystem (least preferred option; aquatic ecosystems only).

The application of these options is detailed within Hosseini et al. (2008) and Beresford et al. (2008c).

In Tiers 2 and 3 of the ERICA Tool the user can input measured biota concentrations, replace default CR or K_d values with their own values, create organism and add radionuclides (Figure 3.2; Brown et al. 2008).

RESRAD-BIOTA

The RESRAD-BIOTA code was designed to be consistent with, and provide a tool for, implementing the graded approach for biota dose assessment (USDoE 2002). The graded approach consists of three levels (or tiers) of analysis (Figure 3.3) and considers terrestrial and freshwater ecosystems. Four generic organisms are considered (although higher level assessments allow the user to add additional more specifically defined organisms): terrestrial plant, terrestrial animal, aquatic animal and riparian animal (within the aquatic ecosystem). Forty six radionuclides are included within the tools databases.

For the initial screening level (Level 1) assessments the recommended inputs are maximum media activity concentrations. For aquatic assessments, the user can input either sediment or water concentrations, or both if available; K_d values are used to determine the concentration in water or sediment if only one of the two are available. For terrestrial assessments, the user can input both soil and water activity concentrations.

These are compared with *biota concentration guidelines* (BCG) which are the estimated media concentration for which the corresponding dose rate is equal to the screening dose rate; the output is the ratio of input media activity concentrations to the BCG. The model presents a combined 'ecosystem' ratio (e.g. combining sediment and water ratios) which is estimated from individual media ratios for the different organisms. The BCGs are estimated assuming: infinitely large and small geometries for internal and external dose calculations respectively; 100% of time in soil (terrestrial) or at the sediment-water interface (aquatic); generally conservative parameters to estimate biota activity concentrations; default radiation weighting factors of 20 for alpha radiation and 1 for beta and gamma radiation; screening dose rates of 1 mGy d^{-1} (*circa* 40 μGy h^{-1}) for terrestrial and riparian animals, and 10 mGy d^{-1} (*circa* 400 μGy h^{-1}) for terrestrial plants and aquatic animals. For terrestrial plants and aquatic animals, maximum biota to media concentration ratios, largely identified from published literature reviews, are used in the derivation of BCGs. For terrestrial and riparian animals 95th percentile CR values predicted using an allometric approach are used. Where literature CR values are used, the values are for any appropriate organism (i.e. the values used in the programme for aquatic animal may be for fish, snails, molluscs or crustaceans depending upon the radionuclide) and tend to be the maximum average reported value from the review publications cited (see USDoE (2002) *Module 3*). Best estimate distribution coefficient (K_d) values are used. Four generic organisms are considered in the screening tier: terrestrial plants; terrestrial animals; aquatic animals; riparian animals. The BCGs are estimated assuming the following exposure routes:

- Aquatic animals
  - Sediment - external exposure due to contaminated sediment
  - Water - internal and external exposure due to contaminated water
- Riparian animals
  - Sediment – internal and external exposure due to contaminated sediment
  - Water - internal and external exposure due to contaminated water
- Terrestrial animals
  - Soil - internal and external exposure due to contaminated soil
  - Water - internal and external exposure due to contaminated water
- Terrestrial plants
  - Soil - internal and external exposure due to contaminated soil
  - Water - external exposure due to contaminated water

Whilst the BCGs and output ratios are similar to the ERICA Tool EMCLs and output RQs respectively there are differences in their calculation including exposure pathways considered.

Conservatism within Level 1 of the USDoE graded approach as implemented within RESRAD-BIOTA is therefore in the recommendation for maximum media concentration inputs, habit assumptions, geometry assumptions and use of maximal identified literature CR values[5] or 95th percentile allometrically derived values.

As the user progresses to Levels 2 and 3, fewer assumptions are made but more site- or receptor-specific input data are required. More user input is allowed at Levels 2 and 3 including the ability to edit transfer parameters, use allometric models and develop simple food webs and create user defined organisms (although one of a number of predefined geometries needs to be associated to these rather than the user having the ability to create a geometry). A difference between the USDoE graded and the ERICA Integrated approaches is that RESRAD-BIOTA does no allow the input of measured biota concentrations until Level 3 (see Figure 3.3) whereas this option is available at Tier 2 in the ERICA Tool.

[5]Although as noted above the maximum values tend to be maximum average values from review publications.

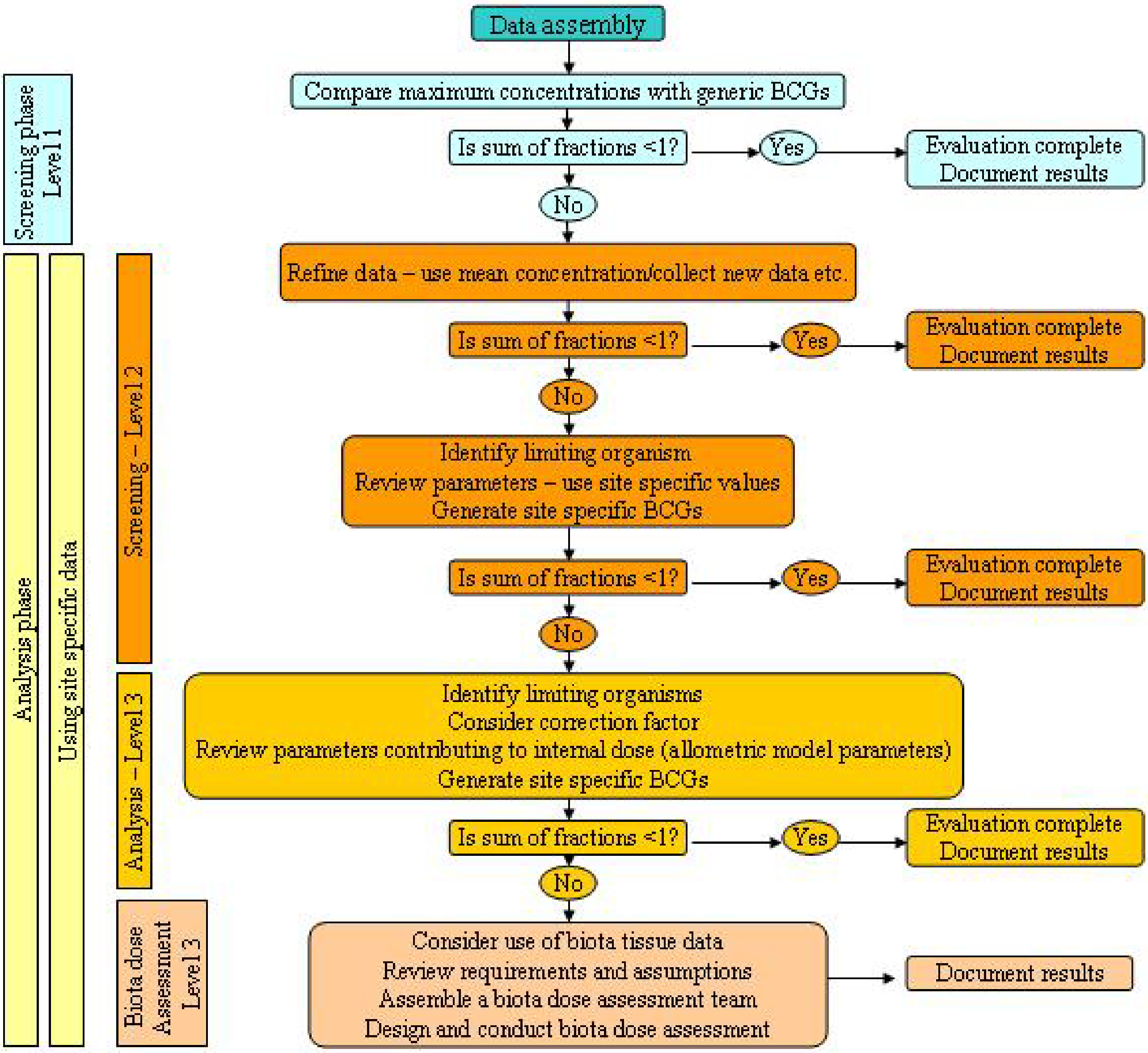

Figure 3.3. Schematic of USDoE graded approach as implemented within RESRAD-BIOTA (adapted from USDoE (2002)).

EA R&D128

This approach was developed to enable the England and Wales Environment Agency (EA) to conduct assessments in compliance with UK interpretation of the EU Birds and Habitats Directives (Copplestone et al. 2001; 2003). Terrestrial, freshwater and coastal (marine) ecosystems are considered. A more limited set of radionuclides (17 in terrestrial and 16 in aquatic ecosystems) are considered compared to the two models already discussed. Whilst this simple spreadsheet model does not have in-built tiers, the method of application to assessments by the EA (Allott & Copplestone 2008) is broadly compatible to the tiered approaches used by others and maximum inputs are used in initial screening assessments. When applied by the EA in screening assessments, results are compared to a screening level dose rate of 5 µGy h^{-1}; 40 µGy h^{-1} is used as an 'upper action level' in more refined assessments.

Default CR and K_d values provided within the spreadsheets were selected on the basis of a comparatively limited literature review. A full set of CR values were needed to allow the required assessments to be completed. Where empirical CR values were not available the developers derived a series of 'expert judgement' rules to provide default values (Copplestone et al. 2003). These were assumed to be conservative. In order of preference these were:

- use an available CR for an organism of similar ecology if available;
- use highest available CR, or for aquatic ecosystems the K_d value if that is greater;
- for terrestrial ecosystems if no data are available assume CR=1.

The approach to select CR values when data are lacking aims to be conservative. When a radionuclide which needs to be assessed is not included within the spreadsheets CR and DCC values for an analogous element as defined in EA (2002) are used. An example of this is to assume ^{137}Cs values for ^{99m}Tc, an approach which is acknowledged to have the potential to result in some very conservative estimates of dose rate (Copplestone et al. 2005).

Default radiation weighting factors of 20 for alpha radiation, 3 for low energy beta and 1 for beta and gamma radiation are used. Default occupancy factors do not assume maximal exposure

3.2.2 Screening tier comparison

All three models were run assuming 1 Bq per unit media (terrestrial soil, freshwater sediment and freshwater water) for the 36 radionuclides common to both RESRAD-BIOTA and the ERICA Tool; many of these radionuclides are considered within EA R&D 128. To enable comparison with the outputs of RESRAD-BIOTA (which uses predefined screening dose rates of 1 mGy d^{-1} for terrestrial and riparian animals, and 10 mGy d^{-1} for all other organisms), the ERICA Tool was run using its optional screening dose rates of 40 µGy h^{-1} for terrestrial animals and 400 µGy h^{-1} for terrestrial plants and all organisms in aquatic environments. Results of R&D 128 were compared to the same screening dose rates as the ERICA Tool. The ERICA Tool version used was that available in January 2008; a test version of RESRAD-BIOTA (version 1.22 Beta (created 12/01/06)) made available by the tool developers (Argonne National Laboratory) was used; the R&D128 spreadsheets used were v1.15, v1.15 and v1.20 for freshwater, coastal and terrestrial ecosystems respectively.

Results, presented as the ratio of estimated dose rate to the screening dose rate (subsequently referred to as risk quotients (RQ)), are presented by ecosystem in Tables 3.3-3.6. The assumption of 1 Bq kg^{-1} sediment could only be conducted for RESRAD-BIOTA and the ERICA Tool (Table 3.4) as the spreadsheets implementing the EA R&D128 approach do not allow radionuclide activity concentrations to be input to sediment. For terrestrial ecosystems, no results are reported for ^{3}H and ^{14}C from RESRAD-BIOTA as this requires soil activity concentrations whereas the other two models both require air concentrations for these two radionuclides (Table 3.5). RESRAD-BIOTA does not consider marine ecosystems so the comparison could only be made for EA R&D128 and the ERICA Tool. Table 3.6 consequently compares results for those radionuclides common to EA R&D128 and the ERICA Tool. Again, the EA R&D128 coastal ecosystem spreadsheets do not enable the input of sediment concentrations.

<u>Results</u>

The results presented in Tables 3.3-36 demonstrate considerable variability between estimated RQ values for some radionuclides, with estimates commonly ranging over more than two orders of magnitude between the models. The most variable results were observed between RQ values predicted by EA R&D128 and the ERICA Tool for marine ecosystems. With the exception of predictions for the marine ecosystem, there was no particular trend between the RQ values output by the three models. For the marine ecosystem, EA R&D128 tended to consistently predict markedly higher RQ values than the ERICA Tool.

There are a number of factors, including the differences in assumptions and method of calculation described above, which contribute to the variability observed in the estimated RQ values between the three models.

The ERICA Tool and EA R&D128 consider a greater range of organisms compared with the four generic organisms considered in RESRAD-BIOTA. Some of these (e.g. phytoplankton) tend to accumulate comparatively high concentrations of some radionuclides and are consequently often identified as the most limiting organisms with comparatively high RQ values as demonstrated in Table 3.3.

There is a difference in how RESRAD-BIOTA and the ERICA Tool consider organisms such as mammals, amphibians and birds which may be exposed in both terrestrial and aquatic environments. The ERICA Tool assesses these organisms against a screening dose rate of 40 $\mu Gy\ h^{-1}$ in terrestrial ecosystems and 400 $\mu Gy\ h^{-1}$ in aquatic ecosystems (the same approach was adopted here to estimate RQ values from the EA R&D128 methodology). Within RESRAD-BIOTA, these organisms are considered as the generic 'riparian animal' for which a screening dose rate of 40 $\mu Gy\ h^{-1}$ is (in our opinion more logically) applied regardless of contamination route. The consequence of this difference, is that for such animals, RESRAD-BIOTA should result in an RQ which is one order of magnitude greater than that estimated by the ERICA Tool.

Default radiation weighting factors for alpha and low energy beta emitters differ between the three models (see above). However, the differences in default radiation weighting factors should add no more than a three-fold variation to any RQ value (i.e. for a pure low energy beta emitter).

A common contributor to variation in estimated RQ values are the different default CR and K_d values used within the models. In preliminary discussion of the results at a PROTECT workshop (Beresford et al. 2008a), it was suggested that some of the observed variability in RQ values estimated for the freshwater ecosystem may have been because RESRAD-BIOTA used K_d values for terrestrial soil for some radionuclides (see USDoE (2002)[6] which identifies those radionuclides for which freshwater K_d values are used within RESRAD BIOTA).

[6]See Module 3 Table 4.3.

Table 3.3. Comparison of estimated risk quotient and associated limiting organism for 36 radionuclides predicted by RESRAD-BIOTA, the ERICA Tool and EA R&D128 assuming 1 Bq l^{-1} in water of freshwater ecosystems. Predictions differing by >2-orders of magnitude are shaded.

Nuclide	RESRAD-BIOTA*	ERICA Tool	EA R&D128	RESRAD-BIOTA*	ERICA Tool	EA R&D128
	RQ			Limiting organism		
H-3	1.02E-07	6.96E-08	2.46E-08	Riparian	Phytoplankton	All organisms
C-14	4.43E-02	1.54E-03	5.20E-04	Riparian	Bird	Duck
Cl-36	1.91E-03	2.26E-04	n/a	Riparian	Vascular plant	n/a
Co-58	9.89E-03	5.30E-01	n/a	Aquatic(w)/ Riparian(s)	Insect larvae	n/a
Co-60	2.57E-02	1.28E+00	7.50E-03	Aquatic(w)/ Riparian(s)	Insect larvae	Bacteria
Se-75	5.73E-04	5.28E-03	n/a	Aquatic(w)/ Riparian(s)	Insect larvae	n/a
Sr-90	9.85E-02	6.84E-03	1.89E-03	Riparian	Insect larvae	Duck
Zr-95	1.53E-02	1.29E-02	n/a	Aquatic(w)/ Riparian(s)	Zooplankton	n/a
Tc-99	4.37E-05	4.75E-04	1.90E-04	Riparian	Vascular plant	Duck
Sb-125	7.74E-05	2.86E-02	n/a	Aquatic(w)/ Riparian(s)	Insect larvae	n/a
I-129	7.12E-04	8.71E-04	7.84E-05	Riparian	Phytoplankton	Duck
I-131	2.02E-03	1.15E-03	2.06E-04	Riparian	Phytoplankton	Duck
Cs-134	1.29E+00	1.16E+00	n/a	Riparian	Insect larvae	n/a
Cs-135	5.06E-02	4.34E-03	n/a	Riparian	Insect larvae	n/a
Cs-137	6.38E-01	4.70E-01	5.03E-03	Riparian	Insect larvae	Duck
Ce-141	4.76E-03	1.75E-01	n/a	Aquatic(w)/ Riparian(s)	Insect larvae	n/a
Ce-144	2.62E-02	1.87E+00	n/a	Aquatic(w)/ Riparian(s)	Insect larvae	n/a
Eu-152	5.51E-03	3.34E-03	n/a	Aquatic(w)/ Riparian(s)	Vascular plant	n/a
Eu-154	6.50E-03	3.36E-03	n/a	Aquatic(w)/ Riparian(s)	Vascular plant	n/a
Pb-210	3.57E-01	3.05E-01	n/a	Aquatic(w)/ Riparian(s)	Phytoplankton	n/a
Po-210	7.42E-02	8.86E+00	1.56E+01	Aquatic(w)/ Riparian(s)	Bivalve mollusc	Benthic mollusc & Benthic crustaceans
Ra-226	6.65E+00	1.71E+00	n/a	Riparian	Vascular plant	n/a
Ra-228	7.98E+00	8.74E-02	n/a	Riparian	Insect larvae	n/a
Th-228	2.08E+00	9.02E+01	n/a	Aquatic(w)/ Riparian(s)	Insect larvae	n/a
Th-230	1.67E-01	7.75E-01	n/a	Aquatic(w)/ Riparian(s)	Phytoplankton	n/a
Th-232	1.34E+00	6.60E-01	n/a	Aquatic(w)/ Riparian(s)	Phytoplankton	n/a
Th-234	3.75E-01	2.57E+01	1.24E-02	Aquatic(w)/ Riparian(s)	Insect larvae	Duck
U-234	1.34E-01	5.69E-01	n/a	Aquatic(w)/ Riparian(s)	Vascular plant	n/a

Nuclide	RESRAD-BIOTA*	ERICA Tool RQ	EA R&D128	RESRAD-BIOTA*	ERICA Tool Limiting organism	EA R&D128
U-235	1.24E-01	5.28E-01	n/a	Aquatic(w)/ Riparian(s)	Vascular plant	n/a
U-238	1.22E-01	4.87E-01	1.68E+00	Aquatic(w)/ Riparian(s)	Vascular plant	Amphibian & Duck
Np-237	3.95E-01	7.87E+00	n/a	Aquatic(w)/ Riparian(s)	Phytoplankton	n/a
Pu-238	1.62E-01	1.12E+00	n/a	Aquatic(w)/ Riparian(s)	Phytoplankton	n/a
Pu-239	1.54E-01	1.05E+00	1.48E+01	Aquatic(w)/ Riparian(s)	Phytoplankton	Amphibian
Am-241	8.79E-02	9.12E+00	6.32E+00	Aquatic(w)/ Riparian(s)	Phytoplankton	Amphibian & Duck
Cm-242	8.17E-01	4.92E+00	n/a	Aquatic(w)/ Riparian(s)	Zooplankton	n/a
Cm-244	4.09E-01	4.63E+00	n/a	Aquatic(w)/ Riparian(s)	Zooplankton	n/a

*The 'ecosystem' ratio is presented for RESRAD-BIOTA (i.e. the sum of ratios for sediment and water); (w) and (s) denote the rate limiting organisms for water and sediment respectively (where only a single organism is identified this was rate limiting for both media).
n/a – radionuclide not considered in EA R&D128.

As noted above, for the marine ecosystem RQ values predicted by EA R&D128 tended to be higher than values predicted by the ERICA Tool (Table 3.6). In many instances, the limiting organisms identified by the EA R&D128 methodology are sea mammals and birds. Intuitively, this may appear surprising as lower organisms may be expected to be more exposed (as identified by the ERICA Tool). However, with the exception of ^{137}Cs for seal and whale, all CRs for sea mammals and birds in the EA R&D128 methodology were derived by the approaches described above because data were lacking. Whole-body activity concentrations of most radionuclides in sea mammals and birds were derived using CR values for phyto- or zoo-plankton, or assuming that CR is equal to the K_d value. This will result in highly conservative estimates of transfer to sea mammals and birds. The default CR values in the ERICA Tool for these organisms are more often based on identified data or use less extreme assumptions (see above) (Hosseini et al. 2008).

Table 3.4. Comparison of estimated risk quotient and associated limiting organism for 36 radionuclides predicted by RESRAD-BIOTA and the ERICA Tool assuming 1 Bq kg^{-1} in sediment of freshwater ecosystems. Predictions differing by >2-orders of magnitude are highlighted.

Nuclide	RESRAD-BIOTA RQ	ERICA Tool RQ	RESRAD-BIOTA* Limiting organism	ERICA Tool Limiting organism
H-3	1.0E-04	5.4E-07	Riparian	Phytoplankton
C-14	4.4E+01	2.0E-03	Riparian	Bird
Cl-36	3.9E-05	1.8E-03	Riparian	Vascular plant
Co-58	9.9E-06	1.9E-06	Aquatic(w)/Riparian(s)	Insect larvae
Co-60	2.6E-05	3.6E-06	Aquatic(w)/Riparian(s)	Insect larvae
Se-75	1.9E-04	2.5E-06	Aquatic(w)/Riparian(s)	Insect larvae
Sr-90	3.3E-03	2.0E-06	Riparian	Insect larvae
Zr-95	1.5E-05	8.6E-05	Aquatic(w)/Riparian(s)	Zooplankton
Tc-99	8.8E-06	6.0E-04	Riparian	Vascular plant
Sb-125	7.7E-05	7.0E-07	Aquatic(w)/Riparian(s)	Insect larvae
I-129	7.1E-05	1.5E-05	Riparian	Phytoplankton
I-131	2.0E-04	1.9E-05	Riparian	Phytoplankton
Cs-134	2.6E-03	4.0E-06	Riparian	Insect larvae
Cs-135	1.0E-04	5.9E-07	Riparian	Insect larvae
Cs-137	1.3E-03	3.0E-06	Riparian	Insect larvae
Ce-141	4.8E-06	1.5E-07	Aquatic(w)/Riparian(s)	Insect larvae
Ce-144	2.6E-05	1.5E-06	Aquatic(w)/Riparian(s)	Insect larvae
Eu-152	1.1E-05	3.8E-05	Aquatic(w)/Riparian(s)	Vascular plant
Eu-154	1.3E-05	3.8E-05	Aquatic(w)/Riparian(s)	Vascular plant
Pb-210	1.8E-05	1.9E-05	Aquatic(w)/Riparian(s)	Phytoplankton
Po-210	2.5E-03	2.6E-06	Aquatic(w)/Riparian(s)	Bivalve mollusc
Ra-226	9.5E-02	5.7E-04	Riparian	Vascular plant
Ra-228	1.1E-01	2.3E-06	Riparian	Insect larvae
Th-228	3.5E-05	1.2E-03	Aquatic(w)/Riparian(s)	Insect larvae
Th-230	2.8E-06	1.7E-04	Aquatic(w)/Riparian(s)	Phytoplankton
Th-232	2.2E-05	1.4E-04	Aquatic(w)/Riparian(s)	Phytoplankton
Th-234	6.3E-06	9.1E-07	Aquatic(w)/Riparian(s)	Insect larvae
U-234	2.7E-03	7.5E-02	Aquatic(w)/Riparian(s)	Vascular plant
U-235	2.5E-03	6.9E-02	Aquatic(w)/Riparian(s)	Vascular plant
U-238	2.4E-03	6.4E-02	Aquatic(w)/Riparian(s)	Vascular plant
Np-237	4.0E-02	4.6E+00	Aquatic(w)/Riparian(s)	Phytoplankton
Pu-238	8.1E-05	4.0E-05	Aquatic(w)/Riparian(s)	Phytoplankton
Pu-239	7.7E-05	3.8E-05	Aquatic(w)/Riparian(s)	Phytoplankton
Am-241	1.8E-05	4.7E-04	Aquatic(w)/Riparian(s)	Phytoplankton
Cm-242	4.1E-03	6.5E-03	Aquatic(w)/Riparian(s)	Zooplankton
Cm-244	2.0E-03	6.2E-03	Aquatic(w)/Riparian(s)	Zooplankton

*The ‘ecosystem’ ratio is presented for RESRAD-BIOTA (i.e. the sum of ratios for sediment and water); (w) and (s) denote the rate limiting organisms for water and sediment respectively (where only a single organism is identified this is rate limiting for both media).
n/a – radionuclide not considered in EA R&D128.

Table 3.5. Comparison of estimated risk quotient and associated limiting organism for 36 radionuclides predicted by RESRAD-BIOTA, the ERICA Tool and EA R&D128 assuming 1 Bq kg^{-1} in soil of terrestrial ecosystems. Predictions differing by >2-orders of magnitude are shaded.

Nuclide	RESRAD-BIOTA (RQ)	ERICA Tool (RQ)	EA R&D128 (RQ)	RESRAD-BIOTA (Limiting organism)	ERICA Tool (Limiting organism)	EA R&D128 (Limiting organism)
H-3*	n/r	9.22E-05	3.93E-05	n/r	Amphibian	Ant
C-14*	n/r	2.88E-03	5.35E-04	n/r	Mammal (Deer)	Herbivorous mammal
Cl-36	9.36E-05	8.19E-05	n/a	Terrestrial animal	Bird	n/a
Co-58	1.50E-05	1.57E-05	n/a	Terrestrial animal	Mammal (Rat)	n/a
Co-60	3.91E-05	3.26E-05	2.64E-05	Terrestrial animal	Mammal (Rat)	Earthworm
Se-75	5.66E-06	6.34E-06	n/a	Terrestrial animal	Soil Invertebrate (worm)	n/a
Sr-90	1.20E-03	6.39E-04	7.97E-05	Terrestrial animal	Reptile	Carnivorous mammal
Zr-95	2.31E-05	9.60E-06	n/a	Terrestrial animal	Detritivorous invertebrate, Soil Invertebrate (worm)	n/a
Tc-99	6.02E-06	1.14E-04	n/a	Terrestrial animal	Bird egg	n/a
Sb-125	7.68E-06	6.43E-06	n/a	Terrestrial animal	Detritivorous invertebrate	n/a
I-129	4.77E-06	5.64E-04	1.40E-06	Terrestrial animal	Bird egg	Earthworm
I-131	3.13E-05	1.36E-03	6.58E-06	Terrestrial animal	Bird egg	Earthworm
Cs-134	2.39E-03	1.44E-04	n/a	Terrestrial animal	Mammal (Deer)	n/a
Cs-135	1.03E-04	1.23E-05	n/a	Terrestrial animal	Reptile	n/a
Cs-137	1.30E-03	7.68E-05	4.97E-05	Terrestrial animal	Mammal (Deer)	Carnivorous mammal
Ce-141	3.42E-06	6.51E-07	n/a	Terrestrial animal	Soil Invertebrate (worm)	n/a
Ce-144	1.88E-05	5.66E-07	n/a	Terrestrial animal	Soil Invertebrate (worm)	n/a
Eu-152	1.77E-05	1.39E-05	n/a	Terrestrial animal	Soil Invertebrate (worm), Detritivorous invertebrate	n/a
Eu-154	2.09E-05	1.54E-05	n/a	Terrestrial animal	Detritivorous invertebrate	n/a
Pb-210	1.90E-05	7.20E-06	n/a	Terrestrial animal	Detritivorous invertebrate	n/a
Po-210	6.24E-05	9.53E-04	n/a	Terrestrial animal	Lichen & bryophytes	n/a
Ra-226	5.35E-04	9.15E-04	9.33E-03	Terrestrial animal	Detritivorous invertebrate	All animals except Rodent & Bird
Ra-228	6.16E-04	1.39E-05	n/a	Terrestrial animal	Soil Invertebrate (worm)	n/a
Th-228	5.00E-05	1.41E-04	n/a	Terrestrial animal	Detritivorous invertebrate	n/a

Nuclide	RESRAD-BIOTA	ERICA Tool RQ	EA R&D128	RESRAD-BIOTA	ERICA Tool Limiting organism	EA R&D128
Th-230	2.71E-06	1.76E-05	n/a	Terrestrial animal	Detritivorous invertebrate	n/a
Th-232	1.79E-05	1.50E-05	n/a	Terrestrial animal	Detritivorous invertebrate	n/a
Th-234	1.25E-05	5.30E-07	3.98E-06	Terrestrial animal	Soil Invertebrate (worm)	Ant
U-234	5.27E-06	1.78E-05	n/a	Terrestrial animal	Soil Invertebrate (worm)	n/a
U-235	9.75E-06	1.80E-05	n/a	Terrestrial animal	Soil Invertebrate (worm)	n/a
U-238	1.71E-05	1.59E-05	1.81E-03	Terrestrial animal	Lichen & bryophytes	All animals except Rodent & Herbivorous mammal
Np-237	7.00E-06	3.82E-04	n/a	Terrestrial animal	Gastropod	n/a
Pu-238	5.13E-06	2.15E-04	n/a	Terrestrial animal	Gastropod	n/a
Pu-239	4.42E-06	2.01E-04	1.04E-03	Terrestrial animal	Gastropod	Caterpillar, Carnivorous mammal, Bird, Bird egg & reptile
Am-241	6.94E-06	3.84E-04	1.11E-03	Terrestrial animal	Flying insects	Caterpillar, Carnivorous mammal, Bird, Bird egg & reptile
Cm-242	1.32E-05	3.50E-04	n/a	Terrestrial animal	Flying insects, Gastropod	n/a
Cm-244	6.66E-06	3.29E-04	n/a	Terrestrial animal	Flying insects, Gastropod, Soil Invertebrate (worm)	n/a

*The required input for both the ERICA Tool and EA R&D128 for ^{3}H and ^{14}C is the activity concentration in air (Bq m^{-3}); the input for RESRAD-BIOTA is soil and hence a result is not reported here.
n/r – not reported see comment above.
n/a – radionuclide not considered in EA R&D128.

Table 3.6. Comparison of estimated risk quotient and associated limiting organism for 16 radionuclides predicted by EA R&D128 and the ERICA Tool assuming 1 Bq l^{-1} in water of marine ecosystems. Predictions differing by >2-orders of magnitude are shaded.

Nuclide	ERICA Tool RQ	EA R&D128 RQ	ERICA Tool Limiting organism	EA R&D128 Limiting organism
H-3	5.40E-07	2.46E-08	Phytoplankton	All
C-14	2.03E-03	1.43E-03	Bird	Seal
P-32	2.15E-02	7.98E-03	Bird	Whale
Co-60	3.62E-06	4.07E-01	Insect larvae	Whale
Sr-90	1.98E-06	1.62E-03	Insect larvae	Whale
Tc-99	6.00E-04	1.17E-03	Vascular plant	Seal
Ru-106	2.52E-06	4.38E-01	Insect larvae	Whale
I-125	7.42E-06	3.25E-04	Phytoplankton	Whale
I-129	1.47E-05	4.29E-04	Phytoplankton	Whale
I-131	1.93E-05	1.75E-03	Phytoplankton	Whale
Cs-137	3.00E-06	1.66E-03	Insect larvae	Seabird
Po-210	2.62E-06	3.06E+03	Bivalve mollusc	Fish egg, Seabird, Seal & Whale
Th-234	9.14E-07	2.58E+00	Insect larvae	Whale
U-238	6.41E-02	2.59E-01	Vascular plant	Seabird, Seal & Whale
Pu-239	3.79E-05	1.48E+01	Phytoplankton	Phytoplankton, Fish egg, Seabird, Seal & Whale
Am-241	4.73E-04	3.16E+02	Phytoplankton	Fish egg, Seabird, Seal & Whale

3.2.3 Case study applications

Above, we have demonstrated that potentially the three most developed approaches which are readily available may, in some instances, produce screening tier assessment results with very different outputs. In this sub-section, we consider the impact of this observation on conservative screening level assessments using data available for a range of sites.

SENES (2007) presents information for a number of sites including data suitable for conducting an initial screening level assessment. To enable a comparison of the three models, the following were selected from those available to give a number of both freshwater and terrestrial assessments, and a range of radionuclides (see SENES 2007 for more detailed site descriptions):

Freshwater assessments

- Marcoule – nuclear complex located on Rhone river in southern France
- Hanford Area 300 – site of fuel fabrication (USA)
- Pickering – nuclear power plant (Canada)
- McArthur River – uranium mine (Saskatchewan, Canada)

Terrestrial assessments

- Hanford Bear Creek – waste disposal area (USA)
- Pickering – nuclear power plant (Canada)
- McArthur River – uranium mine (Saskatchewan, Canada)

A marine assessment was not included as this ecosystem is not included within RESRAD-BIOTA.

Available media concentration data were input into the ERICA Tool[7] (Tier 1), RESRAD-BIOTA (Level 1) and EA R&D128 models. Available maximum media concentrations were used to be consistent with the required inputs for initial screening tier estimates (presented in Tables 3.7 and 3.8). EA R&D128 considers a more limited number of radionuclides than the other two models, for ease of comparison the radionuclides considered within the assessments were restricted to those available within the EA R&D128 spreadsheets. For the Pickering terrestrial assessment, air concentrations were available for ^{14}C, whilst this is the required input for the ERICA Tool and the EA R&D128 spreadsheet the RESRAD-BIOTA model requires soil concentrations. To provide a soil concentration, a specific activity approach was used assuming 0.18 g C m^{-3} air and a soil carbon content of 90 % which represents a highly organic soil and will result in a comparatively high soil ^{14}C activity concentration. Where groundwater concentrations where available for the Pickering terrestrial assessment, these were input into the RESRAD-BIOTA model as well as soil concentrations as both are allowed inputs. For freshwater assessments where only sediment concentrations were available (^{131}I Marcoule and ^{137}Cs Hanford Area 300), the models K_d values were manually used to provide input water values for use in the EA R&D128 spreadsheets. The different half-lives assumed in default DCC's required some assumptions to be made for sites where ^{238}U series radionuclides were present:

- EA R&D128 – ^{238}U DCC contains all daughter radionuclide down to and including ^{234}U, therefore only available ^{238}U were input
- RESRAD-BIOTA – assumes a 100 year half-life cut-off therefore when available both ^{234}U and ^{238}U data were input if available (secular equilibrium was assumed if data for only ^{238}U were available)
- ERICA Tool – assume a 10 d half-life cut-off therefore when available ^{234}Th, ^{234}U and ^{238}U data were all input if available (secular equilibrium was assumed if data were not available for ^{234}Th and/or ^{234}U)

To simplify the comparison, and to be more relevant to the generic screening value derived by PROTECT (Andersson et al. 2008a), a generic screening benchmark of 10 µGy h^{-1} was used to derive RQ values for all three models outputs[8].

Tables 3.9 and 3.10 present the results for freshwater and terrestrial assessments respectively. The predicted limiting organism and estimated RQ are presented for each radionuclide considered for a given site together with the summed RQ value. Estimated RQ values in excess of 1 are highlighted; an RQ of ≥1 resulting from initial conservative screening level assessments identifies that a more detailed assessment is required. In the case of RESRAD-BIOTA, the nuclide specific RQ presented is the highest RQ for any given organism; the summed RQ represents the 'ecosystem' ratio as reported by the programme, this is the sum of the highest radionuclide specific RQ for each media for which there are data, for a given radionuclide these may be for different organisms. The summed RQ may not therefore be equal to the sum of the individual radionuclide RQs presented in the tables.

[7]Note the ERICA Tool version released April 2008 was used for this exercise; versions of RESRAD-BIOTA and EA R&D128 were as listed in section 3.2.2.
[8]The methodologies and benchmark dose rates used in the actual site assessments as described in SENES (2007) varied between sites.

Table 3.7. Input data for freshwater case study applications (adapted from SENES (2007)).

	Activity concentration (Bq l^{-1} or Bq kg^{-1})						
	Marcoule		Hanford 300 Area		Pickering	McArthur River	
Nuclide	**Water**	**Sediment**	**Water**	**Sediment**	**Water**	**Water**	**Sediment**
^{3}H	5.60E+4				2.78E+3		
^{14}C					4.81E-1		
^{60}Co	2.52E-2	1.59E+2			8.51E-2		
^{90}Sr	1.60E-1	6.00E+2	7.50E-3	9.60E-1	2.74E-1		
^{106}Ru	2.60	2.32E+3			8.14E-1		
^{131}I	1.10E-1*	1.10			1.44E-1		
^{137}Cs	8.80E-2	2.08E+3	8.50E-3*	8.50	4.44E-3		
^{210}Po	5.00E-2	3.70E+2				3.70E-2	1.51E+3
^{234}U**	8.00E-2	2.05E+1	2.00	1.00E+2		3.05E-1	2.15E+4
^{234}Th***	8.00E-2	1.00E+2	1.80	9.10E+1		3.05E-1	2.15E+4
^{238}U	8.00E-2	1.00E+2	1.80	9.10E+1		3.05E-1	2.15E+4
^{239}Pu	9.50E-5	5.06E+1					
^{241}Am	5.00E-3	5.00E+1					

*Input for EA R&D128 only, data not supplied in SENES (2007) estimated using EA R&D128 K_d values and available water activity concentration data; **Input for RESRAD-BIOTA and the ERICA Tool only; *** Input for the ERICA Tool only.

Table 3.8. Input data for terrestrial case study applications (adapted from SENES (2007)).

Nuclide	**Hanford Bear Creek**	**Pickering**			**McArthur River**
	Soil (Bq kg^{-1})	**Air (Bq m^{-3})**	**Soil (Bq kg^{-1})**	**Groundwater (Bq m^{-3})**	**Soil (Bq kg^{-1})**
^{3}H		6.59E+2	4.97E+7	7.00E+9	
^{14}C		4.81E-1	2.40E+3*	2.37E+6	
^{60}Co			4.52E+2		
^{90}Sr			1.85		
^{137}Cs	1.80E+2		2.85E+1		
^{234}U**	6.09E+4				6.08
^{234}Th***	9.40E+3				6.08
^{238}U	9.40E+3				6.08
^{239}Pu	7.00				

*Estimated from air concentration for input into RESRAD-BIOTA (see text); **Input for RESRAD-BIOTA and the ERICA Tool only; *** Input for the ERICA Tool only.

As anticipated, based upon the analyses conducted in the previous sub-section, the outputs of the three models varied considerably. In the case of freshwater assessments (Table 3.9), the overall assessment RQ varied between the models by approximately 3-orders of magnitude for all four assessment sites. Whilst all models predicted overall RQs in excess of 1 for three of the sites assessed, for Pickering only the ERICA Tool predicted an RQ in excess of 1 (a value of approximately 11 being estimated). Although the freshwater assessments included a range of radionuclides, the overall RQ decreased in the order ERICA Tool > EA R&D128 > RESRAD-BIOTA. Conversely, the ERICA Tool did not estimate the highest RQ for any of the three terrestrial assessments (Table 3.10). The highest predicted

RQs for McArthur River and Hanford Bear Creek originate from the EA R&D128 approach, whilst RESRAD-BIOTA predicted the highest RQ for Pickering. Only one model predicted an RQ in excess of 1 for both Pickering (RESRAD-BIOTA; RQ=34) and McArthur River (EA R&D128; RQ=1.9) assessments.

By far the greatest difference in predicted RQ values is the much higher prediction by the ERICA Tool compared to both the other models for the McArthur River freshwater assessment as a consequence of the higher RQ values estimated for ^{238}U and ^{234}U by this model. This appear to be the consequence of the K_d value used in the ERICA Tool (50 l kg^{-1}) which is obviously considerably higher than that which can be estimated from the data (*circa* $7x10^{-4}$ l kg^{-1}) in Table 3.7. For aquatic ecosystems in Tier 1 the ERICA Tool allows inputs of both water and sediment concentrations if both are available. The RQ reported for each radionuclide is that based on the most limiting input media activity concentration. As a K_d of 50 l kg^{-1} is used in the ERICA Tool for U-isotopes then, in effect, a water concentration of 430 Bq kg^{-1} is assumed for both isotopes based upon the input sediment activity concentrations (i.e. >3-orders of magnitude higher than the measured water activity concentration). In Tier 2 of the ERICA Tool the actual input water and sediment activity concentrations are used. Inputting the activity concentrations for McArthur River from Table 3.7 into Tier 2 of the ERICA Tool a conservative RQ[9] of 16 is estimated[10].

Uranium-238 series radionuclides are significant contributors to the estimated dose rate at three of the freshwater sites (Table 3.9). However, comparative differences between the models are not consistent between the three assessments. This is, in part, the consequence of how the models consider ^{238}U series radionuclides (e.g. secular equilibrium in the series between ^{238}U and ^{234}U is in effect assumed within EA R&D128) and the availability of data for ^{234}Th and ^{234}U for the ERICA Tool and RESRAD-BIOTA as appropriate. The relative activity concentrations in water and sediment also contribute to the relative variation in predicted RQ values between the models. For some sites, secular equilibrium between the ^{238}U series radionuclides is obviously not a valid assumption (e.g. for Hanford Bear Creek soil ^{238}U activity concentrations are 9400 Bq kg^{-1} compared to 60900 Bq ^{234}U kg^{-1}). Users of approaches assuming secular equilibrium would be advised to investigate any available data and ensure their screening level assessment results in a conservative output. The Pickering terrestrial assessment results (Table 3.10) also demonstrate the influence of different inputs between the three models. The dominant radionuclide in the RESRAD-BIOTA assessment (the only model to predict an RQ>1) is ^{3}H. Whilst both the ERICA Tool and EA R&D128 require ^{3}H activity concentrations in air (which were available), RESRAD-BIOTA requires soil and groundwater activity concentrations (both of which were also available). The RQ of 33 predicted by RESRAD-BIOTA for ^{3}H (Table 3.10) is dominated by the contribution from soil with groundwater contributing approximately 10% to the ^{3}H RQ value. In this instance, the maximum available measured activity concentration in soil ($4.97x10^{7}$ Bq kg^{-1}) was considerably higher than that which may be expected from the maximum air concentrations.

[9] Where the conservative RQ approximates to a 95th percentile estimate (Brown et al. 2008).
[10] Andersson et al. (2008a) presents dose rates using Tier 2 of the ERICA Tool for all of the sites from the SENES (2007) used in this section.

Table 3.9. A comparison of RQ values estimated using model screening levels for freshwater sites. Red text identifies RQ value in excess of 1.

Radionuclide	EA R&D128 Most exposed group	EA R&D128 RQ	RESRAD-BIOTA Most exposed group	RESRAD-BIOTA RQ	ERICA Tool Most exposed group	ERICA Tool RQ
McArthur River						
^{226}Ra	Large benthic crustacean	2.3E+01	Aquatic animal	1.1E-01	Bivalve mollusc	1.4E+01
^{234}U		n/a	Aquatic animal	1.6E+00	Vascular plant	6.7E+04
^{234}Th		n/a		n/a	Insect larvae	3.3E+02
^{238}U	Duck	2.1E+01	Aquatic animal	2.0E+00	Vascular plant	5.7E+04
SUM		4.4E+01		4.6E+00		1.3E+05
Pickering						
^{3}H	Phytoplankton, Macrophyte, Bacteria, Zooplankton	2.73E-03	Riparian animal	1.14E-03	Phytoplankton	8.06E-03
^{14}C	Duck	1.00E-02	Riparian animal	8.52E-02	Bird	3.09E-02
^{60}Co	Bacteria	2.55E-02	Aquatic animal	3.06E-02	Insect larvae	4.55E+00
^{90}Sr	Duck	2.07E-02	Riparian animal	1.08E-01	Insect larvae	7.81E-02
^{106}Ru	Duck	6.24E-01		n/i	Insect larvae	6.35E+00
^{131}I	Duck	1.19E-03	Riparian animal	1.16E-03	Phytoplankton	6.88E-03
^{137}Cs	Duck	8.93E-04	Riparian animal	1.13E-02	Insect larvae	8.70E-02
SUM		6.85E-01		2.38E-01		1.11E+01
Hanford 300						
^{90}Sr	Duck	5.7E-04	Riparian animal	3.1E-03	Insect larvae	2.1E-03
^{137}Cs	Duck	1.7E-03	Riparian animal	4.3E-02	Insect larvae	1.1E-03
^{234}U		n/a	Aquatic animal	1.1E+01	Vascular plant	3.1E+02
^{234}Th		n/a		n/a	Insect larvae	1.9E+03
^{238}U	Duck	1.2E+02	Aquatic animal	8.7E+00	Vascular plant	2.4E+02
SUM		1.2E+02		1.9E+01		2.5E+03
Marcoule						
^{3}H	Bacteria, Phytoplankton, Zooplankton, Macrophyte	5.5E-02	Riparian animal	2.3E-02	Phytoplankton	1.6E-01
^{60}Co	Bacteria	7.6E-03	Aquatic animal	1.9E-02	Insect larvae	1.3E+00
^{90}Sr	Duck	1.2E-02	Riparian animal	1.7E-01	Insect larvae	4.9E-02
^{106}Ru	Duck	2.0E+00		n/i	Insect larvae	2.0E+01
^{137}Cs	Duck	1.8E-02	Riparian animal	3.0E-01	Insect larvae	1.7E+00
^{131}I	Duck	9.1E-04	Riparian animal	8.9E-04	Phytoplankton	8.9E-04
^{210}Po	Large benthic crustacean	3.1E+01	Aquatic animal	1.5E-01	Bivalve mollusc	1.8E+01
^{234}U		n/a	Aquatic animal	4.3E-01	Vascular plant	6.4E+01
^{234}Th		n/a		n/a	Insect larvae	8.6E+01
^{238}U	Duck	5.4E+00	Aquatic animal	3.9E-01	Vascular plant	2.7E+02
^{239}Pu	Amphibian	5.6E-02	Riparian animal	9.5E-04	Phytoplankton	8.0E-02
^{241}Am	Duck	1.3E+00	Aquatic animal	1.2E-02	Phytoplankton	1.9E+00
SUM		4.0E+01		1.5E+00		4.6E+02

n/a – not applicable isotope included within parent radionuclide DCC; n/i – radionuclide not included in RESRAD-BIOTA

Note, whilst the case study applications presented here use available data from actual sites they are conducted for comparative purposes only and should not be interpreted as 'complete' screening tier assessments. Some of the available data for radionuclides not considered within EA R&D128 were not used and input data have been derived solely from the SENES (2007) report without reference to original sources. Furthermore, the results do not necessarily reflect actual potential risk at the case study sites, as the data sets were used for illustrative purposes only, and detailed knowledge of the sites was not applied; the SENES report outlines the outcomes of more refined assessments where initial conservative assessments identified that this was required.

3.2.4 Discussion

The three approaches considered in this section are readily available for regulators/industry to use within assessments and all are being used for this purpose. Application in screening assessments is designed to enable the user to, with minimal effort (i.e. requiring only the input of media concentrations) but, with a high degree of confidence, decide if sites can be considered to present negligible risk and be excluded from further assessment. It is anticipated that such screening level assessments will be the most common use of these models when applied to planned[11] releases. The large variation within RQ values estimated by the approaches does not promote the level of confidence required by the users and requires further investigation. As variation in transfer parameters/approaches used appears to be a major contributor in some instances to this variation, the results strengthen the recommendations made elsewhere (see sub-section 3.2.2) that there is a clear need to better share knowledge on the parameterisation of radionuclide transfer to biota and to provide authoritative collations of those data which are available (as is now being taken forward by the IAEA).

[11] See ICRP (2007a) for definition of 'planned'

Table 3.10. A comparison of RQ values estimated using model screening levels for terrestrial sites. Red text identifies RQ value in excess of 1.

	EA R&D128		RESRAD-BIOTA		ERICA Tool	
Radionuclide	**Limiting organism**	**RQ**	**Limiting organism**	**RQ**	**Limiting organism**	**RQ**
McArthur River						
^{226}Ra	Fungi	1.8E+00	Terrestrial plant	1.1E-01	Lichen & bryophytes	1.3E-01
^{234}U		n/a	Terrestrial animal	1.3E-04	Lichen & bryophytes	3.6E-03
^{234}Th		n/a		n/a	Grasses & Herbs	3.8E-05
^{238}U	Fungi	8.8E-02	Terrestrial plant	4.2E-04	Lichen & bryophytes	4.0E-03
SUM		1.9E+00		1.1E-01		1.4E-01
Pickering						
^{3}H	Fungi	1.4E-01	Terrestrial animal	3.3E+01	Detritivorous invertebrate	2.5E-01
^{14}C	Seed	6.3E-03	Terrestrial animal	6.5E-02	Mammal (Deer)	5.8E-03
^{60}Co	Fungi	5.3E-02	Terrestrial plant	8.0E-02	Mammal (Rat)	6.1E-02
^{90}Sr	Carnivorous mammal	5.9E-04	Terrestrial animal	8.9E-03	Reptile	4.9E-03
^{137}Cs	Carnivorous mammal	5.7E-03	Terrestrial animal	1.5E-01	Mammal (Deer)	9.1E-03
SUM		2.0E-01		3.4E+01		3.3E-01
Hanford Bear Creek						
^{137}Cs	Carnivorous mammal	3.6E-02	Terrestrial animal	9.4E-01	Mammal (Deer)	5.8E-02
^{234}U		n/a	Terrestrial animal	1.3E+00	Lichen & bryophytes	3.7E+01
^{234}Th		n/a		n/a	Grasses & Herbs	5.9E-02
^{238}U	Fungi	1.4E+02	Terrestrial plant	6.5E-01	Lichen & bryophytes	6.2E+00
^{239}Pu	Fungi	5.8E-02	Terrestrial plant	6.0E-04	Lichen & bryophytes	6.4E-03
SUM		1.4E+02		2.9E+00		4.3E+01

n/a – not applicable isotope included within parent radionuclide DCC

3.3 Experience of applications in assessment

Table 2.1 lists various assessments that some of the available approaches have been applied to. In this section we will consider these assessments in more detail and highlight any issues raised by users.

3.3.1 EA R&D128

Within England and Wales, 600 out of approximately 700 sites with authorisations to discharge radioactivity were identified as not requiring more detailed assessment by the application of a screening level assessment using the EA R&D128 approach and applying a generic screening level of 5 µGy h^{-1} (Allott and Copplestone 2008). It could be considered, therefore, that the approach met the objective of the screening tier being used to remove many sites which pose negligible risk from further assessment. Whilst the comparative assessments considered in section 3.2 suggest that EA R&D128

may not always be the most conservative model, in their assessments the EA consider that the total permitted discharges are released to the environment. This is likely to result in conservative assessments.

Allott and Copplestone (2008) state that there is an intention to revise the EA R&D128 assessment methodology to include more realistic data from the ERICA Tool and that the results using these new data should be reviewed. From the above comparisons, it could be suggested that some assessments may change considerably resulting in either higher or lower estimated dose rates depending upon ecosystem and radionuclides considered. However, a greater use of the ERICA parameters would remove the need for reliance upon analogue element assumptions when considering radionuclides not included in EA R&D128. Currently, assessments within the UK could not rely solely on the use of the ERICA Tool as it does not consider noble gas releases to the atmosphere (the EA R&D128 methodology does). Noble gases can constitute a major component of releases, for instance, they constitute at least 80 % of the total atmospheric releases envisaged from one of the nuclear reactor types currently under consideration in England (Copplestone pers. comm.).

It is worth noting that Natura 2000 sites in England and Wales requiring assessment are often not straightforward terrestrial, marine or freshwater ecosystems. A number are estuarine or sand dune ecosystems; Allott & Copplestone (2008) also note the need to consider a terrestrial assessment involving flooding by river water. It is questionable how appropriate the default transfer parameters within any of the approaches databases are for such ecosystems (the default database of the ERICA Tool specifically excluded measurements made on estuarine saltmarshes)[12]. Allott and Copplestone (2008) note that they have demonstrated that it is cautious to use the freshwater assessment methodology for assessing the dose rate to the worst affected organism as a result of flooding of terrestrial sites (although results were not available within the paper).

3.3.2 RESRAD-BIOTA

RESRAD-BIOTA has been used in the USA for biota dose assessment, especially at USDoE sites (USDoE requires that a biota dose assessment is included in the site's annual environmental monitoring report). Many of the sites have used RESRAD-BIOTA Levels 1 and 2 in their biota dose assessment. Most sites would pass in Level 1, but some sites are electing to use Level 2 or a mixture of Levels 2 and 3 to demonstrate compliance with the dose criteria (C. Yu pers comm[13].).

Site assessors are reportedly confused with regard to population dose and individual dose and this has been highlighted as requiring clarification, as have the use of area factors, accounting for home range, and how to average input concentrations (C. Yu pers comm.).

3.3.3 The ERICA Tool

As identified in Table 2.1 the ERICA Tool has been used in a number of assessments.

For more involved assessments (i.e. those requiring multiple or temporal predictions) a criticism of the Tool has been that data entry is cumbersome (note the same criticism would apply to RESRAD-BIOTA and perhaps to a lesser extent EA R&D128). To resolve this problem, some assessors have applied parameters from the ERICA Tool in spreadsheet implementations (see Smith et al. (2008) and discussions of OSPAR assessment in Beresford et al. (2008a)).

[12] Assessments of the application of the ERICA Tool, RESRAD-BIOTA and EA R&D128 to a UK sand dune ecosystem are presented by Wood et al. (2008 a;b).
[13] Argonne National Laboratory, USA

Limitations on the size of organisms for some habitats which can be created by the user were commented upon by Smith & Robinson (2006) who noted that, for instance, large mammals such as a bear could not be modelled during hibernation underground. In France, the EDEN dosimetric tool continues to be used as it is considered more flexible than the dosimetric module of the ERICA Tool allowing more variable media assumptions (e.g. layer thickness and composition) organism compositions and target organism locations (K. Beaugelin-Seiller pers comm.). For example, DCCs from EDEN were used to assess uranium daughter products including gaseous ^{222}Rn which is not included in the ERICA Tool.

A comment received from a representative of a regulatory organisation during consultation by PROTECT was that the lack of ability to consider contaminated water intake by terrestrial mammals within the ERICA Tool was a major omission with regard to assessment required by their organisation. An advantage of the RESRAD-BIOTA package is that water intake is considered (including by the provision of BCGs at Level 1) with the ability to model this at higher levels using allometric relationships.

Other comments received on the ERICA Tool relate to transparency and are discussed below in section 3.4.

Note comments in this subsection may appear to be more (constructively) critical of the ERICA Tool than those related to other approaches. However, this is likely to be the consequence of a greater degree of independent evaluation of the ERICA Tool than at least some of the other approaches considered.

3.4 Transparency to other users

RESRAD-BIOTA/the USDoE graded approach, the ERICA Tool and EA R&D128 have associated documentation (see Table 2.1) describing derivation and application of the approaches. In one of the IAEA EMRAS BWG exercises discussed above, the RESRAD-BIOTA model was applied by two groups of users with little previous experience of the software. In some cases, the two applications produced results (predicted radionuclide activity concentrations in biota) which varied by up to four orders of magnitude. However, in both instances the model was applied outside of its intended purpose. One user applied the allometric options available in the RESRAD-BIOTA package to predict activity concentrations in organisms such as fish and invertebrates, whilst the other applied the default CR values which are provided for screening purposes only. Whilst the help function within the package is basic and consideration could be given to restricting the allometric functionality, greater attention to the various reports supporting the graded approach and RESRAD-BIOTA would have identified that the models/parameter values were being used for purposes they had not been designed.

Similarly, we are aware of some assessors adopting default CR values from the EA R&D128 methodology (for use in other models) which have been selected using the ‘expert judgement’ rules described above (section 3.2.1) without acknowledging the potentially highly conservative assumptions used in their derivation. However, all default values within the EA R&D128 methodology derived by expert judgement rules are clearly identified within Copplestone et al. (2003).

There has been some comment that the derivation of the ERICA Tool default CR and DCC values needs to be more clearly presented. These comments were made prior to the publication of a series of papers presenting the ERICA approach in more detail (Howard & Larsson 2008).

The lack of information on changes in updated versions of the ERICA Tool has also been criticised, including at PROTECT workshops. The April 2008 release of the ERICA Tool addressed this to some degree with changes being listed in 'release notes' although these give only very basic information.

The developers of RESRAD-BIOTA run relatively frequent training courses for users (see http://web.ead.anl.gov/resrad/training/). Although its radiological application is limited, training courses are also available for the SADA model which in addition has an email discussion/information forum. The potential of such training opportunities should be considered for the ERICA Tool; this could perhaps be included within the activities of any future Network of Excellence (NoE) for radioecology within Europe if a NoE is taken forward within the Seventh Framework Programme (Gariel et al. 2008).

4. Discussion

Approaches to determine the exposure and risk of wildlife to ionising radiation are available and are currently being used in a regulatory context in a number of EC member states (Table 2.1). These are increasingly being used by groups who were not involved in their development (e.g. the ERICA Tool now has more than 150 registered user) and developers are often being asked for additional information, advice and clarification. There is likely to be a significant future requirement for such tools as a consequence of revised ICRP Recommendations, and EC and International Safety Standards currently being prepared. The existence of currently available assessment tools considered here will reduce the cost to any further industry users/regulators who may need to demonstrate protection of the environment in response to international guidelines and resultant national legislation. However, currently none of the available approaches is comprehensive and, as a consequence, elements of different approaches are often being combined for use in some assessments.

In terms of predictive ability, the IAEA EMRAS BWG adopted the view that predictions (of biota radionuclide activity concentrations and dose rate) within an order of magnitude of available data in model-data comparisons were 'acceptable'. This was criticised within PROTECT consultations (Beresford et al. 2007a) on the basis that regulators could not make decisions based upon model predictions which may be under or over predicting by an order of magnitude. Whilst this is an understandable comment from the viewpoint of a regulator (or industry) it is unrealistic to expect the available tools to be able to achieve this degree of accuracy given the inherent variability in the available transfer parameters. If this accuracy is required, then more ecosystem specific models (e.g. models for estuarine systems (see section 3.3.1)), site specific parameters or less simplistic models are needed. Evaluations by PROTECT support the conclusions of IAEA EMRAS BWG, and others, that the transfer components of the assessment tools add most to the overall uncertainty in predictions; when transfer parameters were standardised in the models similar results were obtained (see Table 3.2).

Of the three most developed approaches freely available to any user, EA R&D128 could be described as the most basic and the developers state an intention to adopt parameters from the ERICA Tool (Allott & Copplestone 2008). However, it is the only one of the three approaches to consider radioisotopes of noble gases which can constitute an important component of airborne releases from nuclear power plants. The RESRAD-BIOTA package is designed as a screening tool with, in effect, a requirement for site specific data at anything above initial screening levels (N.B. an initial application of Level 2 may be to input more realistic mean media activity concentrations (Figure 3.3)). However, the tool does contain allometric models enabling the user to define transfer to terrestrial/riparian mammal and bird species of interest (including the creation of simple foodchains). The ERICA Tool has the most developed CR based transfer databases for a wide range of reference organisms giving it, arguably, a better basis to conduct prospective (when site specific data will not be available) assessments. It also considers the largest number of radionuclides having the ability to estimate DCC values for most radionuclides included within ICRP (1983). The ERICA Tool may also provide the most appropriate platform to implement the ICRP framework when that becomes available (the ERICA Tool already includes all of the adult life stages of the ICRP proposed RAPs and the ICRP have adopted the same dosimetric methodology as used in the ERICA Tool). However, it lacks the functionality of RESRAD-BIOTA provided by its allometric models and consequent ability to consider contaminated water intake by terrestrial animals. If organisms are to be assessed at the level of species (e.g. as in the Canadian 'valued ecosystem component' approach) then robust generic approaches to deriving transfer need to be further developed (e.g. allometric models for animals or phylogenetic approaches for plants). Both RESRAD-BIOTA and the ERICA Tool continue to be maintained and developed; in the case of the ERICA Tool this is currently being conducted by a number of the original developing organisations without additional external funding. Given the more comprehensive nature of the ERICA Tool, we recommend its use for chronic exposure assessment within EC member states. However, it may be necessary to use it in conjunction with other models including the allometric modelling functionality of RESRAD-BIOTA. It is also important that development of the ERICA Tool continues to be maintained if it is to be recommended for use.

There may be requirements to conduct temporal and/or spatial assessments, capabilities which the three models considered in most detail in this report do not have. Some dynamic models have been developed, for instance, Vives i Batlle et al. (in-press) for the marine ecosystem. For terrestrial ecosystems Avila et al. (2004) combined elements of models established for human assessment with parameters from the RESRAD-BIOTA and FASSET approaches to propose a dynamic transfer model for a limited range of wildlife. It is likely that additional dynamic models developed for human food chain assessment, especially those considering aquatic ecosystems, could be readily adapted for application in environmental assessments. For spatial assessments, the SADA model enables screening tier assessments to be conducted spatially (utilising parameters from RESRAD-BIOTA) and parameters from both the FASSET framework (Beresford et al. 2005b) and ERICA Tool (Beresford et al. 2008f) have been implemented in geographical information systems. Similarly, if packages such as RESRAD-BIOTA and the ERICA Tool do not have the required flexibility in the dosimetric assessment components there are other tools (e.g. EDEN) which are available and may have the required flexibility, although these may not have been as independently assessed to date as the more generic tools.

Perhaps the most important criteria for the assessment tools, such as RESRAD-BIOTA or the ERICA Tool, is that they can be used with confidence in screening tier assessments. However, the comparison of screening tier predictions presented in section 3.2 does not promote the level of confidence required with large differences in output between the three approaches evaluated. If these models are to be (increasingly) used for regulatory assessment the reasons for such large variation in basic screening tier outputs needs to be more fully understood and any deficiencies addressed. This emphasises the importance of continuing the work of groups such as the IAEA EMRAS BWG and the further funding for this still developing area of radiological protection.

All the major international organisations (i.e. ICRP, EC, IAEA and UNSCEAR) have draft documents in progress on this area. As these become available the requirements for assessment tools and their development may further evolve.

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Appendix 1: Input by PROTECT to ICRP Committee 4 – Application of Draft 4a of the ICRP report on Environmental Protection: the Concept and Use of Reference Animals and Plants

As submitted to ICRP Committee 4 (November 2008)[14]

Copplestone D. (EA), Brown J.E. (NRPA) and Beresford N.A. (CEH)

1. Introduction

ICRP Committee 4 (C4) approached the IAEA EMRAS Biota Working Group (BWG) and the PROTECT consortium in November 2007 with a view to collaborating in the appraisal of the forthcoming report (*Environmental Protection: the Concept and Use of Reference Animals and Plants*) by ICRP Committee 5 (C5) which would contribute to the ICRPs intended framework for assessing the impact of ionising radiation on non-human species. As the PROTECT project had an objective to assess the practicability of existing and developing approaches to radiological environmental assessment including any outputs of the ICRP it was agreed that the PROTECT consortium would try to assist ICRP C4. It was decided to take this forward further at a PROTECT open workshop, which would be attended by a number of members of the BWG, organised for January 2008 at which stage the ICRP C5 draft report would be available.

During the PROTECT January workshop (see Beresford et al. 2008), to begin a discussion of the use of available numeric values within assessments, two hypothetical release scenarios were considered with results being compared for humans and biota. The representative of ICRP C4 attending the workshop requested that the PROTECT consortium use the two scenarios as a basis of an initial assessment of the draft ICRP C5 report. The outcomes of this assessment are described in this document.

1.1 Overview of the draft ICRP C5 report

The draft C5 report was focused on the concept and use of RAPs and states that a series of further reports, including one on the application of the basic approach to different exposure situations, are planned. The evaluation below relates to the December 2007 draft of the ICRP report and may not be relevant to the revision which is anticipated to be available in the near future.

Reference animals and plants The Commission have opted to use Reference Animals and Plants (RAPs), which are essentially a limited group of biota for relating exposure to dose and dose to effect for environmental situations. The draft report suggested that the RAPs can be considered as points of reference for drawing comparisons with sets of information on other organisms although they may not necessarily be the direct objects of protection, *per se*. Furthermore, they are intended to allow more site-specific information (e.g. secondary sets of data) to be compared and examined. Since there are no internationally accepted 'rules' on classification above Family (or 'Super Family') level, the ICRP

[14] This version replaces the draft submitted September 2008 – which contained some errors with respect to the terrestrial assessment results

have suggested that this constitute the most suitable level of generalisation. The RAP is therefore defined as "*a hypothetical entity, with the assumed basic biological characteristics of a particular type of animal or plant, as described to the generality of the taxonomic level of Family, with defined anatomical, physiological, and life-history properties, that can be used for the purposes of relating exposure to dose, and dose to effects, for that type of living organism*."

Dose Conversion Coefficients The draft ICRP report provided a detailed description on the derivation of unweighted DCC values (sometimes referred to as dose conversion factors (DCFs) within the report) for RAPs; consideration of Relative Biological Effectiveness is intended to be the theme of an associated Task Group report. The main simplification involves the representation of whole organisms by simple shapes. Following an intercomparison exercise to consider the fundamental quantity of the absorbed fraction calculated by a suite of commonly used modelling approaches (details of this intercomparison are provided in the draft report) an approach based upon the FASSET-ERICA methodology (see Ulanovksy & Pröhl (2006) and Ulanovksy et al. (2008)) was selected for the reference DCC derivation as: '*it encompassed the largest set of geometry and exposure situations and used a flexible dosimetry method to calculate DCC values for a sufficiently wide range of organisms to include the specific dimensions of the Reference Animals and Plants'*. Tabulated versions of DCCs for RAPs are provided in the draft report. Some preliminary considerations, essentially for illustrative purposes, were also given to the relative dosimetry of internal organs, such as the liver and gonads.

Derived Consideration Levels A large component of the draft ICRP report comprises a review of radiation effects data for non-human species. This is used to suggest *Derived Consideration Levels* (DCLs) for each RAP where the DCLs are a band of absorbed dose rate for each RAP. The DCLs are not intended to be dose limits but rather: '*They are zones of dose rates at which, with respect to the Reference Animals or Plants, or types similar to them, a more considered level of evaluation of the situation would be warranted. It does not imply that higher dose rates would be environmentally damaging, nor that lower dose rates were in some way 'safe' or non-damaging. But they are dose rates that could be used in any management action or decision-making process, in terms of being starting points from which further, auditable, information could be appended in order to justify or optimise any subsequent action that was taken.*' The draft ICRP report suggests that: '*all of the derived* (radiation effects) *information relevant to each type of animal and plant could then be simplified into bands of dose rates relevant to their individual background radiation dose rates'* Tables of DCL values present a background dose rate, however, this value is the same for all species (<0.01 mGy d^{-1}) and it is unclear how it was derived compared to the data reviewed within the text of the ICRP draft report.

The draft ICRP report briefly touches on the subject of exposure analysis, noting the required applicability to *Planned*, *Emergency* and *Existing* situations. The report notes that although direct measurements are sometimes available for biological compartments, modelling approaches will often be required (notably in planned and emergency situations). The draft ICRP report dwelt little on environmental transfer noting that required databases would need to be carefully considered and compiled and that this would be the subject of a subsequent report in relation to RAPs (and we are aware that this is now being conducted by an ICRP C5 Task Group).

1.2 Objectives of this report

All we are able to evaluate here is the content of the draft ICRP report considering RAPs as further reports are planned, including one on the application of the basic approach to different exposure situations. A criticism of the draft ICRP report is that it was not clear how the ICRP recommended that the concepts they proposed would actually be used. We are therefore limited to attempting to implement what is available in the draft in the manner to which we best understand it should be used.

The following sections present the results of hypothetical marine and terrestrial assessments, implementing, where possible, the draft ICRP report. Results of the non-human assessment are compared with a simple evaluation of human dose rates for these scenarios, in-part to consider the previous ICRP recommendation (1991): '*The Commission believes that the standard of environmental control needed to protect man to the degree currently thought desirable will ensure that other species are not put at risk. Occasionally, individual members of non-human species might be harmed, but not to the extent of endangering whole species or creating imbalance between species*'.

The ERICA Tool includes geometries corresponding to those specified by ICRP for the adult life-stages (and bird egg) of all proposed RAPs. As the ICRP draft report presents unweighted DCC values estimated using the ERICA methodology the DCC values proposed by the ICRP should be the same or at least very similar to those in the ERICA Tool.

Any comment on the robustness of the derivation of DCLs is beyond the scope of the following assessment. The DCLs have been simply applied to interpret the dose-rates calculated. The ICRP DCLs are considered further evaluated by the PROTECT consortium within Andersson et al. (in-preparation).

The implication of the draft ICRP report[15] is that the suggested approach is not meant to be a replacement for other methods but rather should be seen as a system which other approaches can use as a point of reference when performing their own bespoke analyses. With this in mind, it was considered appropriate to select one of the available numerical approaches to run in parallel with (and where appropriate as a supplement to) the ICRP guidance. Because of their familiarity with the method, the ERICA integrated approach (Larsson 2008) was selected for this purpose by the authors; as noted above the ERICA Tool also has the advantage that it already includes many of the ICRP geometries. This avoids the problem of becoming hindered at any stage of the assessment where the incomplete nature of the ICRP guidance renders progression difficult.

We have three objectives:

1) Evaluate whether the Concept and Use of Reference Animals and Plants as described in Draft 4a contains sufficient information to allow experienced assessors to conduct dose calculations to the ICRP specified RAPs.
2) Compare the dose calculations for the ICRP RAPs with those conducted using the ERICA methodology.
3) Contrast the dose calculations for non human species with those for humans based on scenarios which will result in exposure to activity concentrations derived at the same location (e.g. crops grown at the same distance to that used for locating a Natura 2000[16] site for the human and non-human species assessments respectively).

[15] Hereafter referred to as the RAPs report
[16] A Natura 2000 site is a protected ecological area within the European Union containing threatened habitats and/or species.

Assessments were conducted for hypothetical planned marine and planned terrestrial scenarios. The two assessments were each conducted by a different individual (both employed by national regulators) who were familiar with approaches to assessing the exposure of non-human biota to ionising radiation. As the assessments were conducted by different individuals comments may be repeated.

2. Scenario 1 – marine, planned

The scenario considers an environmental impact assessment for a marine area contaminated by an operating nuclear facilities. This falls within the scope of the intended application of the ICRP guidance in terms of what the information is likely to be used for, and under what circumstances, as described under paragraph (14)[17] of the draft ICRP RAPs report.

The following assessment is loosely based on actual data from a contaminated coastal marine environment arising from a period of peak discharges from a regulated nuclear complex for the sake of providing some degree of realism. The results should not be considered as an authoritative assessment of impacts on biota (or man) for any actual existing site as all other aspects of the scenario are hypothetical.

2.1 Scenario description

A marine protected area (MPA) has been defined with a boundary that crosses at a distance of 5 km from the nearest discharge outlet for low level liquid effluent. The main commercial fishery (fish and crustaceans) is located approximately 100 km from the discharge point (Figure 1). The ecology of the area is typical of boreal marine ecosystems.

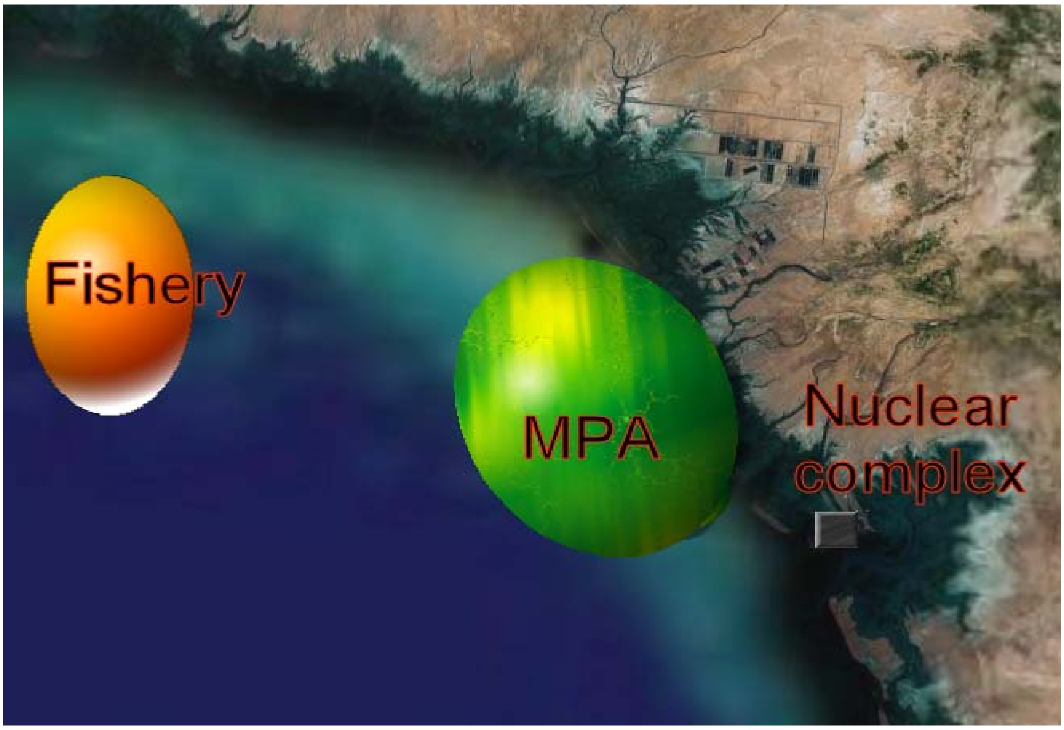

Figure 1. Overview map of scenario.

[17] All paragraph numbers refer to the December 2007 draft of the RAPs report.

Low level liquid effluents arising from a number of sources have been discharged directly to a shallow Sea area.

The following fabricated data (Tables 1 and 2) have been generated for the assessment based on the type of information that is typical of monitoring reports. The data are based partly on actual (historical) information for environmental samples contaminated by discharges arising from a regulated site.

Table 1. Water and sediment activity concentrations for the two sampling areas (shown in Figure 1).

Location	**Radionuclide**	**Empirical water conc. (Bq l^{-1})**	**Empirical sediment conc. (Bq kg^{-1} dry weight)**
MPA	^{137}Cs	10	7100
	^{239}Pu	1.00E-02	1500
	^{241}Am	1.00E-02	1200
Fishery	^{137}Cs	2.5	7700
	^{239}Pu	5.00E-03	4200
	^{241}Am	5.00E-04	2800

Table 2. Activity concentrations in generic biota over all of the assessment area.

Biota	**Radionuclide**	**Empirical activity concentration (Bq kg^{-1} fresh weight)**	
		Minimum	**Maximum**
Macroalgae	Cs-137	30	1600
	Pu-239	56	113
Crustacean	Cs-137	11	600
	Pu-239	0.5	8
Molluscs	Cs-137	14	470
	Pu-239	0.2	150
	Am-241	0.04	100
Fish	Cs-137	2.6	2000
	Pu-239	0.002	0.08
	Am-241	0.002	0.08
Seabird	Cs-137	6.7	n/a
	Pu-239	n/a	n/a

The hypothetical remit for the assessment is to consider the impact of existing levels of contamination upon a broad suite of common organism types within this boreal marine ecosystem and to establish whether the risk of harm (to populations) is significant or negligible. A secondary objective was to run a human radiological assessment to consider which type of assessment constitutes the limiting criteria (i.e. the criteria that is likely to drive management decisions).

2.2 Environmental radiological assessment

2.2.1 Selection of RAPs

With regard to the marine environment, three organisms appear to be relevant for consideration in the following assessment[18]. These are : the ***reference flatfish***, the ***reference crab*** and the ***reference brown seaweed***. Short descriptions are provided on the taxonomy and assumed characteristics of each of these biota types in paragraphs (42) & (43) for flatfish, (46) & (47) for crab and (54) & (55) for brown seaweed. However, no information is provided with respect to how this information should be used explicitly (if at all) in an assessment.

In paragraphs (56)-(60) the guidance provided in the RAPs report considers that although in some cases it may be useful or necessary to know something about the risks to individuals as a result of exposure to radiation, in other cases consideration may largely be directed towards the population. However, it is not clear how the information provided in Table 3 of the RAPs report, concerning population characteristics, can be used to achieve this requirement. The ICRP acknowledge this point notable in paragraph (358) which states that: "*Future efforts to develop measures to protect the animate environment from the incremental radiation exposures arising from human activities will therefore need to consider both the individual and the population to ensure that the intended objective is achieved*." This current lack of guidance on this matter of extrapolation from individuals to populations has limited the current scenario to a consideration of impacts on individual organisms.

Monitoring reports typically provide information on activity concentrations in media (sea water and sediment) and species or generic categories of flora and fauna (see for example the UK RIFE report series, NRPA (2007)). However, such data are usually collected for estimation of human dose rates and as such are for tissues used in the human foodchain. Most approaches for estimating dose rates to non-human biota (including the draft ICRP report and the ERICA Tool) estimate wholebody dose rates. For this particular scenario and with reference to Table 2, it is evident that reference flatfish might be appropriately represented by the category fish, reference crab by crustaceans and brown seaweed by macroalgae. In working through a "real" scenario, the process of collating information specifically for RAPs by extracting from larger more generic monitoring data-sets would seem to be a sensible and practicable way to organise information although guidance to this end is not provided explicitly in the report. Furthermore, it is plausible that a broader, or different, set of organisms might need to be considered in any given assessment. The ICRP provided the following guidance on this matter as described in paragraphs (367) and (368) of the draft:

(367) *It also has to be recognised that, in many cases, much more specific data on local animals and plants may already be available with respect to specific sites; or that data are often required for organisms that are more relevant in other respects, such as their ecological importance at a local level, but the data sets will always be limited because of the sheer impracticality of ever deriving some of the required information – such as that relating to radiation effects. Such organisms might therefore be regarded as secondary reference animals and plants, provided that they could be shown to relate in some way (for example by using the same sort of dosimetry models) to one or more of the ICRP set of Reference Animals and Plants. There are therefore a number of issues relating to our ability to*

[18] There is some ambiguity over whether reference salmonid might also constitute a marine organism (i.e. marine pelagic fish). The strict interpretation of paragraph (41) suggests that the salmonid is applicable to freshwater only.

extrapolate from limited data bases and frameworks in order to deliver environmental protection in a wider and practical sense.
(368) *There are thus three aspects of extrapolation and interpolation to other animal and plant types that need to be considered. One is that of differences in biology, in that the animals or plant are considerably different from those represented by the Reference Animals and Plants (by definition generalised to the taxonomic level of Family); the second is that of differences in dosimetry; and the third is that relating to differences in radiation effects.*

For our purposes, we have assumed that the generic data sets adequately represent the RAPs, but that we will also consider a broader set of marine reference organisms as defined in the ERICA integrated approach, these being: Wading bird, Benthic fish, Benthic mollusc, Crustacean, Macroalgae, Mammal, Pelagic fish, Phytoplankton, Polychaete worm, Reptile, Sea anemones/ true corals, Vascular plant and Zooplankton (see Brown et al., 2008). Within this scenario assessment, these are considered to be a 'secondary set of reference organisms' as referred to by the ICRP.

2.2.2 Extrapolation and interpolation from RAPs to secondary reference organisms

Relating, or extrapolating, the information from datasets for RAPs to those for secondary reference organisms (considered in Chapter 7 of the draft report) is an issue which needs some consideration.

Differences in biology

The ICRP note that it is important to be aware that biological objects of interest may be different to RAPs and that differences in biology could make large differences to estimates of exposure to certain radionuclides via different pathways. The draft RAPs report provides some biological information on each RAP in Appendix A of the report. The information provided covers taxonomy, geographical spread, habitat, life span and aspects of reproduction. However, it is difficult to see how this information can be used directly in the present scenario. For this reason no attempt has been made to apply methods for data interpolation or extrapolation with regards to this point.

Differences in dosimetry

Extrapolation issues with regard to dosimetry relate primarily to the implications of changing various parameters, i.e. mass and shape, on absorbed fractions and the implications of altering target to source configurations. Although the report provides useful contextual information in relating site specific organism dosimetric information to the RAP values, the application in performing these types of calculations in practice is not straight forward. Presumably, following the definition of a site specific geometry and relying on the draft report, this would involve listing the characteristics energies and yields for a given radionuclide, finding the absorbed fractions for the given energy and mass for an equivalent sphere, deriving corrections for non-spherical shapes based on chord lengths and then deriving the radionuclide specific dose conversion using these data and established equations. The information to perform these calculations would need to be extracted from the various figures provided in Section 7.3 of the RAP report creating the possibility that errors could be introduced. However, computerised dosimetric interpolation tools are available that allow these calculations to be made in a relatively straight-forward manner using methodologies consistent with the ICRP approach. The ERICA Tool has these capabilities (although there are some limits to size/position of organism) and the ICRP framework uses the same methodology as the ERICA Tool to determine DCCs (Brown et al., 2008). Vives i Batlle et al (2007) recently demonstrated that there was little effect on the estimated dose rate of using nearest default geometries rather that bespoke geometries for a range of radionuclides and organisms.

For the scenario, default DCCs from the ERICA Tool have been used directly to provide the DCCs for the additional suite of generic organisms considered above.

Differences in radiation effects

The ICRP discusses some issues relating to effects data extrapolation including the extrapolation of high acute dose rates (low LET γ- and X-rays) to lower doses accumulated at lower dose-rates, noting that very few data exist on environmentally relevant dose-rates over the life-span of organisms. The discussion also considers the problems inherent in extrapolating from one organism type to another, from individuals to populations and communities and from laboratory to field. Variation in radiosensitivity between and within taxonomic groups and life-stages is also acknowledged.

The ICRP acknowledge that it is not currently possible to provide recommendations as to how to perform extrapolations that have general applicability in relation to radiation effects stating (in the draft): '*Nevertheless, it is necessary to start somewhere, and thus developing an understanding of the effects of radiation on a limited number of animals and plants, at the individual level, and exploring the consequences of such effects at their population levels, and amongst different populations, will clearly build into a broader understanding against which these wider issues can be assessed.*'

However, based upon information presented in the draft report it has not been possible in this scenario assessment to apply any quantitative methods to account for these issues.

2.2.3 Deriving activity concentrations in marine biota (including RAPs) – transfer

The ICRP notes (paragraph 65) that in many case measurement data for environmental media and biota may be directly available but that in other cases where such information may be limited transfer models will be required. The ICRP also state that reference databases concerning exposure of biota in the environment would be extremely useful and will form the basis of a subsequent report.

For the present assessment we are therefore reliant on alternative methods to derive activity concentrations in the RAPs and their habitat in some cases. Relevant data (Table 2) are available for fish (reference flatfish) and for some radionuclides for macroalgae (reference brown seaweed) and crustaceans (reference crab). The maximum values from Table 2 have been used in the assessment. Where data on activity concentrations in biota are missing, concentration ratios[19] have been applied to the activity concentrations in water (Table 3) using the comprehensive datasets collated for the ERICA Integrated Approach and presented in Hosseini *et al.* (2008). With regards to RAPs in the present assessment CRs were only required for ^{241}Am in the case of reference crab and reference brown seaweed as data were available for all other radionuclide-RAP combinations.

With regards this assessment, DCC values in Appendix C of the draft report are presented for: crab egg mass, crab larvae and (adult) crab, flatfish egg and (adult) flatfish, and brown seaweed. Normally, monitoring data would not include measurements of different life stages reflecting that the available

[19] Defined as $CR = \dfrac{\text{Activity concentration in biota whole body (Bq kg}^{-1}\text{ fresh weight)}}{\text{Activity concentration of filtered water (Bq l}^{-1}\text{)}}$

data are generally for the adult forms of marine biota that are used for human consumption. In order to derive activity concentrations for these various life stages, in the absence of direct empirical information, some guidance on the way in which these values might be derived would be required. In view of the lack of such information, the life stages were not been considered for further analysis in this scenario assessment.

Table 3. CRs Bq kg^{-1} f.w. per Bq l^{-1} used as default in the ERICA Tool (Brown et al., 2008) as applied in this assessment (the ICRP RAPs are indicated in bold).

Organism	Am	Cs	Pu
Bird	150	460	150
Benthic mollusc	58*	86*	3500*
Benthic fish (reference flatfish)	**8100***	**66***	**1100***
Crustacean (reference crab)	**1300**	**41***	**160***
Macroalgae (reference brown seaweed)	**830**	**120***	**4100***
Mammal	280	210	280
Pelagic Fish	58	86	3500
Phytoplankton	210000	130	120000
Polychaete worm	8100	180	1500
Reptile	150	460	150
Sea anenome/Coral	86	380	2700
Sea anenome/Coral	86	380	2700
Vascular plant	830	22	4100
Zooplankton	4000	110	7800

* CR values not used in the assessment – measurement data available

2.2.4 Deriving dose-rates to marine biota (including RAPs)

The ICRP approach provides a detailed description on the derivation of Dose Conversion Coefficients (DCCs) for RAPs. The basic unit employed is the absorbed dose (Gy) acknowledging the fact that different types of radiation are known to produce different degrees of effect in the same biological tissue, for the same absorbed doses, for many types of organisms. The consideration of Relative Biological Effectiveness will be a theme for a Task Group report under the auspices of ICRP Committee 5. In order to accommodate the future requirement to account for RBE, the DCCs are split into components of alpha radiation, low (< 10 keV) beta radiation and beta-gamma radiation. Because no guidance is provided in the report with respect to the application of radiation weighting factors, these have been assumed to be unity in all cases, i.e. unweighted absorbed dose rates have been derived.

Tabulated versions of all DCCs for RAPs are provided in the guidance document as Appendix C (in units of µGy d^{-1} per Bq kg^{-1}). The extraction and application of this information from the ICRP report for application in this scenario was relatively straight-forward.

The location of the organism within its habitat has implications for its exposure. In most cases, simplifications need to be made. The ICRP provide guidance with regards the derivation of DCCs for interfaces between media in paragraph (104): '*The DCFs* (DCC) *for external exposure are given depending on the assumed habitat of the animal or plant. Aquatic organisms are treated as submerged in infinite water medium. For those living on interface (air-water or water-sediment) dose coefficients can be easily derived from geometrical considerations by halving the listed DCF* (DCC).'

As all three RAPs considered in this marine assessment are present at the water-sediment interface, external dose-rates are calculated using the following formula as the DCC for external exposure are the same for water and sediment (Equation 1) :

$$\dot{D}^{j}_{ext} = \sum_{i} DCC^{j}_{ext,i} * \left[0.5 * C_{water,i}. + 0.5 * C_{sed,i}\right] \qquad (1)$$

where:

C_{water} is the average concentration of the radionuclide *i* in water (Bq l^{-1}, dissolved phase)

C_{sed} is the average concentration of the radionuclide *i* in sediment (Bq kg^{-1}, fresh weight (f.w.))

$DCC^{j}_{ext,i}$ is the dose conversion coefficient for external exposure defined as the ratio between the average concentration of the radionuclide *i* in environment (water or sediment) and the dose rate to the organism *j* (µGy d^{-1} per Bq kg^{-1})

The equation above corresponds to the exposure derivation methodology as applied in the ERICA approach. The guidance given within the draft ICRP RAPs report does not explicitly state that this calculation should be applied and in fact the values provided in Appendix C of the report imply that external dose rates might be derived using water concentration values only with no calculation of the contribution from sediment.

The results from the exposure calculations are shown below (Figure 2).

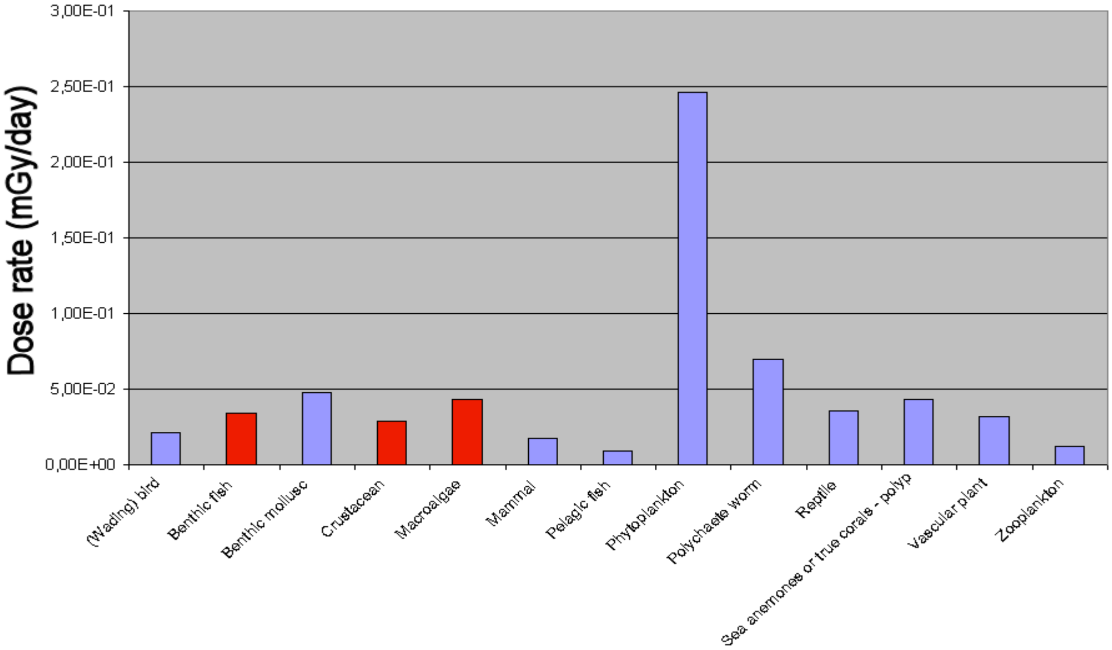

Figure 2. Unweighted, absorbed dose-rates for the different marine biota considered in the marine scenario. The ICRP RAPs values (referred to as benthic fish, crustacean and macroalgae) are shown in red.

This exercise has shown that the ICRP methodology, supplemented by information on transfer from other numerical approaches, can be applied to typical monitoring data sets in order to derive unweighted absorbed dose-rates to RAPs in a reasonably straight forward manner. Figure 2 illustrates that the RAPs are not necessarily the most exposed biota groups. Other organisms, because of relatively high transfer factors for considered radionuclides or their location within the marine environment, may receive higher dose rates. For this scenario, marine phytoplankton are exposed to dose-rates that are more than 5 times greater than any of the RAPs.

The ICRP guidance (paragraph (105)) implies that the user may want to consider integrated dose-rates, i.e. dose-rates accumulated over the life span of the considered RAP: '*Finally it should be noted that the DCF values relate to dose rate. In order to estimate the dose, the dose rate has to be integrated over specific periods of time. In some cases the period of time is limited to the life span, or the time period of that stage of the life cycle. Thus, for example, the dose to a duck egg can only be integrated over a period of 30 days, for it then is no longer an egg – irrespective of the levels, or decay characteristics of the radionuclides. Similarly, the frog egg and tadpole will only be totally immersed in water for a few months. At the other end of the scale, however, it is assumed that a pine tree will live for a very long time, and care needs to be taken with regard to integration of doses over such time periods. The relevant values for the biological periods of integration for the Reference animals and Plants are also given in Table 5.*'

However, it is somewhat unclear as to what criteria accumulated doses would be compared against as the Derived Consideration Levels discussed in the next section relate to dose-rates. For this reason, integrated dose-rates have not been calculated further in this assessment whilst acknowledging the fact that appropriate information is provided in the draft report to allow such values to be derived for RAPs if required.

As noted above the ICRP and ERICA approaches both estimate wholebody dose rates. However most data for activity concentrations presented in Table 2 relate to tissues entering the human foodchain. In this scenario for Pu-239 if values presented in Table 2 were converted to whole body activity concentrations (using information presented in Hosseini et al. (2008)) the total unweighted dose rates would increase by only approximately 1 %.

2.2.5 Interpreting the results – use of Derived Consideration Levels (DCLs)

The DCL bands are 1-10 mGy d^{-1} for brown seaweed and flatfish and 10-100 mGy d^{-1} for crab. These are clearly far in excess of the calculated dose rates for these RAPs in the scenario.

In the event that calculated dose rates fall within the DCL band it seems that the ICRP guidance would be to "pause and consider" other information (e.g. exposure situation ,extent of contamination etc. see paragraph (354)) as appropriate. For this scenario, in the absence of any other considerations and in view of the calculated dose rates falling far below the DCLs, the assessor might simply conclude that environmental risk is negligible. However, a difficulty still remains in extrapolating these observations to the secondary reference organisms included in this scenario especially as some are more exposed (although below the lower DCL band).

The draft ICRP report does not make an recommendation with regard to radiation weighting factors. If the ERICA Tool default value for alpha radiation of 10 is applied the subsequent weighted dose rates are 1.21×10^{-1}, 4.29×10^{-2} and 4.29×10^{-2} mGy d^{-1} for macroalgae, crustaceans and fish respectively. These values are still below the DCL bands but, in the case of macroalgae at least, the margin between the assessment dose-rate and the benchmark is now small enough that a more detailed consideration of uncertainty in estimates might be warranted.

2.3 Human radiological assessment

In line with ICRP recommendations (IAEA, 2007), a "Representative Person" has been identified with typical habits of a small number of individuals representative of those most highly exposed (as oppose to the extreme habits of a single member of the population). In this scenario it has been assumed that site-specific habit surveys have been conducted for the area of interest and that the critical pathway has been identified as arising from the consumption of seafood only as oppose to external exposure from contaminated inter-tidal sediments or a combination of pathways. Consumption rate data have been interpreted to identify groups of high-rate consumers. These data (loosely based on actual data reported in RIFE-5) are presented in Table 4.

Table 4. Consumption rate of seafood for a Representative Person (high rate consumer)

Seafood	kg/y
Plaice and cod	90
Shrimps (crustaceans)	30

The approach taken above whereby human high rate consumers are considered is consistent with the standard methodology applied in human dose assessment. For consistency with the non-human biota assessment, where typical doses have been derived, it is arguably more appropriate to consider average consumption rates. Such information are available in the literature (see, e.g. SACN, 2004) and applying such data would have the effect of reducing the human doses to approximately 10 % of the value derived below for ‘high rate consumers’.

The (maximum) activity concentration data in Table 2, for fish and crustaceans have been used directly. In the case of ^{241}Am, the standard transfer dataset used in routine human radiological assessments from IAEA Technical Report Series 422 (IAEA, 2004)[20] , as opposed to CRs used in the non-human assessment from Table 3, has been applied to derive activity concentrations using seawater concentrations (Table 1).

The committed effective dose, E_{int} for an annual intake of radionuclides has been derived using the following equation :

$$E_{\text{int}} = \sum_i e(\tau)_i \times I_i \qquad (1)$$

Where : $e(\tau)$ = Ingestion dose conversion coefficient (Sv Bq^{-1}) for radionuclide “i”
I_i = Annual Intake of radionuclide “i”, (Bq y^{-1})

Dose conversion coefficients are provided in Table 5

The annual intake of radionuclide can in turn be derived from the following equation :

$$I_i = \sum^{p} C_{ip} \times V_{ip} \times K_{ip} \qquad (2)$$

Where : C_{ip} = activity concentration of radionuclide “i” in foodstuff “p”, Bq/kg
V_{ip} = Annual consumption rate of foodstuff “p”, kg/y
K_{ip} = factor accounting for loss of activity of nuclide “i” during cooking or storage of foodstuff “p”, unitless

K_{ip} was assumed to be 1 (i.e. no loss) for the purposes of this assessment.

Table 5 Ingestion Dose conversion coefficient $e(\tau)$, Sv Bq^{-1}, (committed to 70 years) for adults from ICRP-72 (ICRP, 1996).

Radionuclide	Sv per Bq (Adult)
Cs-137	1.30E-08
Pu-239	2.50E-07
Am-241	2.00E-07

Using the methodology outlined above, a committed effective doses of **2.6 mSv** per annum to a “Representative Person” is calculated.

[20]Whilst the IAEA’s Technical Report Series was been developed for human radiological assessment and hence CR values estimate activity concentration in edible tissues the ERICA CR values estimate whole body activity concentrations.

The dose constraint of 1 mSv y^{-1} as in the Recommendations of the ICRP (ICRP, 2007) is the benchmark in this scenario to identify when human radiological protection criteria trigger a management response (cf. DCLs which would trigger a response from the perspective of environmental protection criteria).

In this scenario, the activity concentration data used to derive dose-rates to flatfish and crab have also been used to derive annual committed effective doses to humans. For this scenario, the use of identical input data for both the human radiological assessment and the environmental impact assessment using ICRP guidance as it currently stands, results in the limiting criteria (i.e. the criteria driving management decisions) being defined by the human assessment.

However, in a realistic situation it is unlikely that the input data would be identical. To illustrate this point in a simple way, if additional information was provided to indicate that the minimum values in Table 2 are for the fishery and the maximum values the MPA then an assessor might be more inclined to use the lower values in the human dose assessment. Were the assessor to do this, an annual committed effective doses to humans of 35 µSv per annum would be calculated (29 times below the reference level) and the environmental assessment would then become the limiting criteria (the dose-rate for macroalgae being a factor of 23 below the DCL); it is likely that the environmental assessment would be even more limiting as this comparision still assumes the same media activity concentrations at both sites. Finally, a moot point arises from the consideration that secondary reference organisms may be exposed to considerably higher doses than RAPs, as exemplified by phytoplankton in the above example. From the guidance as it currently stands it is quite difficult to understand how the information (primarily with regards to difference in biology and radiation effects) for RAPs can be extrapolated to a broader set of organisms that might be included in any given environmental assessment. Put in more direct terms, the demonstration that RAPs are being exposed to dose-rates below ICRP criteria is no guarantee that that the risk of harm to other flora and fauna is negligible.

If we treat the statement :

"*The Commission believes that the standard of environmental control needed to protect man to the degree currently thought desirable will ensure that other species are not put at risk. Occasionally, individual members of non-human species might be harmed, but not to the extent of endangering whole species or creating imbalance between species*."

from the previous ICRP recommendations (ICRP, 1991) as a hypothesis, establishing its validity is far from simple. The statement appears to be valid for the example discussed above. However, it takes little imagination to construct a marine scenario wherein flora and fauna might be at some risk of harm (however this is defined) whereas exposures to humans are negligible (e.g. as illustrated above if the human assessment is based upon the fishery and the non-human upon the MPA)[21]. Furthermore, the principle of the ICRP statement is incompatible with some present-day requirements for environmental protection.

[21] At one of the PROTECT workshops such a (hypothetical) scenario was assessed (see Beresford et al. (2008), the attending independent experts and PROTECT consortium members concluded that '*The ICRP-60 statement could not be supported or repudiated* ….'

3. Terrestrial, Planned Scenario

The assessments conducted below are based on the atmospheric discharges from the planned construction and operation of a new nuclear power plant. We have assumed that the new plant will be a next generation pressurised water reactor design, which has a predecessor design operating at Sizewell in the UK. Assessments of doses to humans from the Sizewell plant (as reported in the RIFE reports. e.g. RIFE -12 (2007)) have been used to check that the estimated doses to humans in this study are reasonable.

For this prospective planned situation, the emission data to atmosphere has been taken from the data submitted as part of a submission to the generic design assessment that is underway in the UK (Westinghouse, 2008). The atmospheric input activity concentrations are given in Table 6. The more significant (in terms of activity) radionuclides have been selected for inclusion in the assessment as highlighted in Table 6.

The discharge is assumed to occur from a single 20m effective height stack on site and the site of exposure to non-human species is assumed to be 500m from the stack. The human assessment assumes that the food is produced at 500m from the stack but in addition there is an external exposure from the gaseous plume which is assumed to, conservatively, take place at 100m. **This may result in the human exposure assessment being somewhat more cautious than the biota assessment**.

The ERICA Tool has been used in this assessment for the reasons presented above for the marine scenario.

3.1 Non-human species assessment

The scenario has been run using for the following:

a) the ERICA reference organisms (Amphibian, Bird, Bird egg, Detritivorous Invertebrate, Flying Insects, Gastropod, Grasses & Herbs, Lichen & Bryophytes, Mammal Deer, Mammal Rat, Reptile, Shrub, Soil Invertebrate (worm) and Tree) – considered by the ICRP to be a set of secondary reference organisms as described in paragraph (12) of the RAPs report.

b) the ICRP terrestrial RAPs (Deer, Rat, Bee, Earthworm, Pine Tree (trunk and layer), Wild Grass (as spike and meristem), Duck and Frog.

Whilst paragraphs (56-60) of the RAPs report discuss whether an assessment should focus on individuals or populations there is no clear guidance provided on these two types of assessment should be conducted. The information given on the RAPs provides for an assessment to be undertaken at the level of the individual but not the population. Consequently for the purposes of this scenario, the assessment has been conducted at the level of the individual.

3.1.1 ERICA reference organisms

The input activity concentrations as atmospheric releases in Bq/s were used with the SRS-19 (IAEA, 2001) terrestrial (air) model that is built into the ERICA assessment tool (dated April 2008) to determine the air activity concentration at the site of interest (the input parameters for the SRS-19 terrestrial (air) model are given in Table 7. The default parameters for dose conversion coefficients, occupancy, concentration ratio and radiation weighting factors were used from Tier 2 of the ERICA Tool for all the nuclides except Kr-85 and Ar-41 (see below). The input parameters are given in Tables 8-11. The predicted activity concentration and dose rates to the ERICA reference organisms are given in Tables 13 and 14 respectively.

The exception to this was the noble gases, modelled as Kr-85 and Ar-41 , as these are not currently considered within the ERICA Tool. To determine the air concentration of these nuclides 500m from the 20m high stack, the England and Wales Environment Agency Initial Radiological Assessment methodology has been used. The atmospheric dispersion component of this is based on the R91 model (NRPB, 1979). The approach used in the Initial Radiological Assessment Tool is designed to be conservative and the meteorological conditions are characterised by a uniform windrose and a defined distribution of atmospheric stability conditions. The atmospheric stability conditions assumed are based on average UK meteorological conditions. Atmospheric stability categories were chosen emphasising those in which dispersion is more limited at the distances of interest, leading to cautious estimates of air concentrations. Full details of this approach are given in Lambers and Thorne (2006a,b).

The predicted annual discharge of Ar-41 and the other noble gases (modelled as Kr-85) and given in Table 6 were multiplied by the appropriate air concentration rate per unit release rate data given in Lambers and Thorne (2006b). These were then scaled to account for the 20m stack height assumed within this scenario. The resulting 0.055 and 17 Bq m^{-3} for Ar-41 and Kr-85 respectively were then input into the Environment Agency Terrestrial Assessment Spreadsheet v 1.20 to determine the dose rate to the reference organisms. Table 15 shows the predicted dose rates to the reference organisms in R&D 128 from Ar-41 and Kr-85. These were then turned into risk quotients (RQs) by dividing the predicted dose rates with the 10 μGy h^{-1} screening value as suggested by PROTECT (Andersson et al. 2008) and available as a default within the ERICA Tool. The resulting RQ values were added to the RQs determined by the ERICA Tool for the other radionuclides included in this scenario to provide a total RQ value.

Within the ERICA tool if the conservative RQ is above 1 for any organism then the probability of the assessment exceeding the screening value at Tier 2 is above that selected (as defined by the uncertainty factor). However, if the expected value RQ is below 1 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 relevant stakeholders) agreeing that the risk is minimal. Under these circumstances the ERICA Tool recommends that assessment and results are reviewed. Finally if both the conservative and expected RQ values are below 1 then you can be reasonably confident that the biota are unlikely to be impacted by ionising radiation.

For the purposes of this scenario only the expected RQ values are reported because of the addition of the Kr-85 and Ar-41 doses using the R&D128 model (which we are only able to determine as ‘best estimates’). Where the RQs are below 1, it can be concluded for the purpose of this scenario that the biota are unlikely to be impacted however a complete evaluation of the ICRP framework for radiological protection of the environment should consider both the expected and conservative RQ values at a Tier 2 type assessment but this also requires the implementation of the Kr-85 and Ar-41 calculations within the ERICA Tool.

Finally, Table 16 shows the calculated RQs for the ERICA reference organisms, including where there are common reference organisms between the two approaches, the contribution from Ar-41 and Kr-85. The RQ values for each reference organism are all below 1 and therefore we can be confident that of no or negligible impact on the exposed biota. For those ERICA reference organisms which do not have a similar geometry in the R&D128 tool, the dose from Ar-41 and Kr-85 is likely to fall in the range of 1E-6 to 1E-4 as these ERICA reference organisms are of a size which falls in the range of those reference organisms for which it is possible to estimate the Ar-41 and Kr-85 doses.

Using the ERICA Tool, there is an assumption that the reference organism list is representative of the species that are present at the site of interest, at 500m from the discharge point, assumed here to be a terrestrial Natura 2000, which may contain protected species that are listed in Table 12. One of the criteria used in selecting the ERICA reference organism list was that it should encapsulate all European protect species (Brown et al. 2008).

3.1.2 ICRP RAPs

The ICRP RAPs report does not contain any information on the concentration ratios to use within the ICRP RAP framework and therefore we have adopted the default CRs from the ERICA Tool. There are also no data provided on the DCCs for Ar-41 and Kr-85 for the ICRP RAPs so the dose rate calculations do not include a contribution from Ar-41 and Kr-85 at this stage. It is relatively easy to extract the information on DCCs (for volume source option) for the other radionuclides and the ICRP DCCs were used in the calculations for those ICRP RAPs reported in the following tables. As the same methodologies (and assumptions) are used it would be expected that the dose rates predicted using the ERICA Tool and ICRP DCC values would be virtually identical. As can be seen from Table 20 in most cases the dose rates estimated by the two methods are within 20 % of each other. The only exception is that some estimates for Pine tree (trunk) are using the ICRP DCC values approximately 50 % of those estimated using the ERICA Tool. Dose rates due to H-3 are consistently (approximately 20%) higher when using the ICRP DCC values compare to the ERICA Tool estimates. There is a need to check that the DCC values for the reference organisms and RAPs that would have been expected to have similar (due to being the same size and in theory in the same conditions (occupancy, position, source exposure)) but this has not been completed to date. In Appendix A of the draft ICRP RAPs report detailed information on the RAPs and their taxonomic position, reproduction and other information related to their life history is provided. However it is not clear how this information is to be used within an assessment.

Table 17(a-h) contain the input data and predicted internal activity concentration and dose rates for the ICRP RAPs; the ICRP values for occupancies, DCCs were used in these calculations whilst the default RBE values and transfer parameters were taken from the ERICA Tool. These can be compared to the tables of Derived Consideration Levels (DCL) fairly easily in the text but there is little information to aid decision making, for example, if you are above the DCL do you need to take action etc..

3.2 Human assessment

The human assessment has been conducted using the Environment Agency Initial Radiological Assessment Methodology (Lambers and Thorne, 2006a,b). The exposed population group is assumed to be locally resident (around 100m from the discharge point) and consuming food produced at 500m from the discharge point (equivalent distance to that assumed for the non-human species). The relevant pathways for the exposed population group are:

- internal irradiation from the inhalation of radionuclides in the effluent plume;
- external radiation from radionuclides in the effluent plume;
- external radiation from radionuclides deposited to the ground;
- internal irradiation from consumption of terrestrial food containing radionuclides deposited to the ground (the methodology excludes radionuclides with half-lives of less than 3 hours).

The human assessment differs from the biota assessment by the inclusion of the inhalation and external radiation from the effluent plume. Whilst this will make the human exposure assessment more conservative than the biota assessment, the contribution of these pathways to the total dose received is only 6.5% and 2% from inhalation and external exposure respectively compared with food ingestion which contributes 91.5% of the total dose.

The initial radiological assessment methodology has been coded into a series of spreadsheets for discharges to air, sewers, marine and freshwater ecosystems. The following calculations have been performed with the air spreadsheet using the same atmospheric scaling parameters for a 20m stack height as used in the non-human assessment above and assuming the locations (100m and 500m) for the exposed population/foodstuff source. The discharge data is input as Bq y^{-1} and the values are taken from Table 6. Full details of the methodology are provided in Lambers and Thorne (2006a, b).

The assessment results indicate a dose from the atmospheric discharges in the order of 10 µSv h^{-1} with approximately 65% of the dose coming from I-131 and I-135, 25% from C-14, and 10% from tritium. Table 18 shows the calculated dose rates. The dose rates from measured data around the Sizewell plant in the UK are in the order of 50 µSv h^{-1} for a critical group consuming fish and shellfish and 90 µSv h^{-1} for a critical group consuming terrestrial foodstuffs, external and inhalation exposure near to the site in 2006. This is much higher than that predicted on the basis of the scenario used here for a new power station and is related to the fact that the Sizewell discharges are 5-times higher for tritium, 3-orders of magnitude higher for Cs-137 and about twice that of the other radionuclides (excluding Ar-41 and Kr-85) than the predicted discharges reported in Table 6 and used in this scenario. Whilst the activity concentrations of Ar-41 and Kr-85 are high compared with the other radionuclides category in the RIFE report for the Sizewell discharges, the predicted dose rates from these radionuclides contributes <1% combined of the total predicted dose rate of 10 µSv h^{-1}. Table 19 contains the discharge information for Sizewell in 2006.

Comparing the dose predictions to the 1mSv y^{-1} public dose limit, then a risk quotient (derived by dividing the predicted dose by the dose limit) for the exposed human population group in this scenario would be 0.01, well below the value of 1 which would be exceeding the limit. This can be compared with the risk quotients derived for the non-human species of 1.0E-3 for the mammals. Thus, in this scenario, the human exposure is more limiting and would be the controlling parameter in determining discharge limits.

It should be noted that the use of differing dispersion models may have resulted in different soil activity concentration inputs to the human and biota assessments presented here.

4 Issues identified with the ICRP RAPs report

The draft C5 report was focused on the concept and use of RAPs and states that a series of further reports, including one on the application of the basic approach to different exposure situations, are planned. The evaluation conducted here relates to the December 2007 draft of the ICRP report and may not be relevant to the revision which is anticipated to be available in the near future. On the basis of the two scenarios considered the following comments can be made with regard to the ICRP RAP report:

1) The ICRP RAPs report defines the RAPs at the family level but provides limited explanation as to how these are representative of real world situations. There was also some confusion about whether, for example, the duck was to represent both the aquatic and terrestrial environments. For example, section 2.6.3 is entitled an aquatic bird – the reference duck but Table 2 lists the duck as both freshwater and terrestrial.
2) The RAPs are described in paragraphs (31) & (32) for the reference deer, (34) & (35) for the reference rat, (44) & (45) for the reference bee, (48) & (49) for the reference earthworm, (50) & (51) for the reference pine tree, (52) & (53) for the reference wild grass, (36) & (37) for the reference duck, (38) & (39) for the reference frog. However, there is no explicit advice on how the information provided should be used in an assessment.
3) Paragraphs 56-60 of the RAPs report discuss whether an assessment should focus on individuals or populations stating that "*In some cases it may be useful or necessary to know something about the risks to individuals as a result of exposure to radiation. In other cases, however, consideration may largely be directed towards the population.*" However the report does not specify which approach should be taken with regard to the reference animal and plants as described in the RAPs report although it does state in paragraph (60) that population characteristics such as those given in Table 8 should be borne in mind (along with the geographic area) but nowhere in the assessment approach that is outlined within the RAPs report is this explored further.
4) No concentration ratios are available for the ICRP RAPs, although the authors are aware that there is a Committee 5 task group working on this aspect.
5) No consideration of radionuclides such as those from the noble gases group which are not taken up into the body of the organism but rather provide an external shine dose as the plume passes. No appropriate information or DCCs are available for these radionuclides in the RAPs report.
6) What do you compare the outputs from the ICRP RAP calculations to? The Derived Consideration Levels show an indicative band of radiation effects but the report fails to explain how these can be applied saying in paragraph (353) "*They are zones of dose rates at which, with respect to the Reference Animals or Plants, or types similar to them, a more considered level of evaluation of the situation would be warranted. It does not imply that higher dose rates would be environmentally damaging, nor that lower dose rates were in some way 'safe' or non-damaging. But they are dose rates that could be used in any management action or decision-making process, in terms of being starting points from which further, auditable, information could be appended in order to justify or optimise any subsequent action that was taken.*" No clear advice is given however on these DCLs can be applied in such a decision making process.

7) Where the terrestrial scenario allowed comparison dose rates estimated using the ERICA Tool were, as would be expected, similar (within 20 %) for the same geometries as those using the ICRP DCCs. Some estimates for Pine tree (trunk) were an exception with larger variation between the ICRP DCC and ERICA Tool estimates. The comparison should be widened to additional RAPs and radionuclides.
8) For terrestrial plants the draft ICRP report presents DCC values for different geometries (e.g. wild grass meristem and spike). How the different results these generate should be interpreted is unclear.
9) The list of RAPs is biased towards the terrestrial environment (8 RAPs versus 3 for the marine environment) - the rationale behind this is unclear.

Whilst we have tried to evaluate the December 2007 draft of the ICRP RAPs report it should be noted that this report describes only part of the proposed framework for radiological protection of the environment. Evaluating only part of framework is difficult as we have had to make assumptions, in particular regarding the transfer parameters, to enable us to undertake appropriate calculations. Whilst this evaluation provides an initial indication of how the December 2007 draft RAPs report may be used, it is expected that once the framework has been completely described some of the difficulties in interpretation will be addressed.

Given this we consider it too early to do a meaningful and complete evaluation on the ICRP recommendations for a framework for environmental protection. We therefore recommend that ICRP should undertake a further review of the framework once it is complete and suggest that ICRP take the opportunity of having their outputs evaluated using international fora such as those provided by the IAEA through their Biota Working Group. In the interim we have provided this report as an input into an expected wider evaluation process.

Table 6. Predicted atmospheric discharges from a new design of pressurised water reactor

	Expected discharge based on GALE code, Revision 1	*Expected discharge based on GALE code, Revision 1*	*Input into assessment (all values >1 E0 taken forward*
Radionuclides	Bq/y	Bq/s	Bq/s
Kr-85m	1.3E+12	4.2E+04	
Kr-85	1.5E+14	4.8E+06	
Kr-87	5.6E+11	1.8E+04	
Kr-88	1.7E+12	5.4E+04	
Xe-131m	6.7E+13	2.1E+06	
Xe-133m	3.2E+12	1.0E+05	
Xe-133	1.7E+14	5.4E+06	
Xe-135m	2.6E+11	8.2E+03	
Xe-135	1.2E+13	3.9E+05	
Xe-138	2.2E+11	7.0E+03	
Above Noble Gases total (modelled as Kr-85)	4.1E+14	1.3E+07	1.3E+07
Ar-41	1.3E+12	4.0E+04	4.0E+04
Ba-140	1.6E+07	4.9E-01	
Co-60	3.2E+08	1.0E+01	1.0E+01
C-14	2.7E+11	8.6E+03	8.6E+03
Ce-141	1.6E+06	4.9E-02	
Co-57	3.0E+05	9.6E-03	
Co-58	8.5E+08	2.7E+01	2.7E+01
Cr-51	2.3E+07	7.2E-01	
Cs-134	8.5E+07	2.7E+00	2.7E+00
Cs-136	3.1E+06	1.0E-01	
Cs-137	1.3E+08	4.2E+00	4.2E+00
Fe-59	2.9E+06	9.3E-02	
H-3	1.3E+13	4.1E+05	4.1E+05
I-131	4.4E+09	1.4E+02	1.4E+02
I-133	1.5E+10	4.7E+02	4.7E+02
Mn-54	1.6E+07	5.0E-01	
Nb-95	9.3E+07	2.9E+00	2.9E+00
Ru-103	3.0E+06	9.4E-02	
Ru-106	2.9E+06	9.1E-02	
Sb-125	2.3E+06	7.2E-02	
Sr-89	1.1E+08	3.5E+00	3.5E+00
Sr-90	4.4E+07	1.4E+00	1.4E+00
Zr-95	3.7E+07	1.2E+00	1.2E+00

Table 7. Input values for the SRS-19 Terrestrial (air) model

Parameter	*Value*
Release height	20 m
Distance to receptor	500m
Wind speed	2 m/s
Fraction of time	0.25
Dry deposition coefficient	500 m/d
Wet deposition coefficient	500 m/d
Surface soil density	260 kg/m^3
Duration of discharge	1 year
Buildings nearby	No

Table 8. Input values for concentration factors [Bq kg^{-1} (f.w.) per Bq kg^{-1} soil (d.w.) or Bq m^{-3} air for H, C, S & P] for ERICA reference organisms

Organism	*C*	*Co*	*Cs*	*H*	*I*	*Nb*	*Sr*	*Zr*
Amphibian	1.34E+03	2.95E-01	5.37E-01	1.50E+02	4.00E-01	1.90E-01	8.25E-01	1.19E-05
Bird	1.34E+03	2.95E-01	7.50E-01	1.50E+02	4.00E-01	1.90E-01	5.49E-01	1.19E-05
Bird egg	8.90E+02	2.95E-01	3.00E-02	1.50E+02	1.60E+02	5.71E-01	1.37E+00	1.19E-05
Detritivorous invertebrate	4.30E+02	3.52E-03	1.34E-01	1.50E+02	3.01E-01	5.05E-04	4.07E-01	5.05E-04
Flying insects	4.30E+02	6.08E-03	5.51E-02	1.50E+02	3.01E-01	5.05E-04	6.32E-02	5.05E-04
Gastropod	4.30E+02	6.08E-03	4.27E-02	1.50E+02	1.80E-01	5.05E-04	9.24E-02	5.05E-04
Grasses & Herbs	8.90E+02	1.35E-02	6.93E-01	1.50E+02	1.40E-01	4.25E-02	2.07E-01	5.30E-04
Lichen & bryophytes	8.90E+02	2.16E-01	5.60E+00	1.50E+02	3.60E-01	1.62E-02	8.68E+00	1.71E-02
Mammal (Deer)	1.34E+03	2.95E-01	2.87E+00	1.50E+02	4.00E-01	1.90E-01	1.74E+00	1.19E-05
Mammal (Rat)	1.34E+03	2.95E-01	2.87E+00	1.50E+02	4.00E-01	1.90E-01	1.74E+00	1.19E-05
Reptile	1.34E+03	2.95E-01	3.59E+00	1.50E+02	4.00E-01	1.90E-01	1.18E+01	1.19E-05
Shrub	8.90E+02	7.50E-01	3.97E+00	1.50E+02	1.40E-01	3.40E-02	4.96E-02	9.43E-05
Soil Invertebrate (worm)	4.30E+02	6.08E-03	8.94E-02	1.50E+02	1.56E-01	5.05E-04	8.97E-03	5.05E-04
Tree	1.30E+03	1.83E-02	1.63E-01	1.50E+02	1.40E-01	3.40E-02	4.89E-01	2.09E-04

Table 9. Input values for ERICA reference organisms: occupancy factors [unitless]

Organism	*On soil*	*In soil*	*In air*
Amphibian	1.00E+00	0.00E+00	0.00E+00
Bird	1.00E+00	0.00E+00	0.00E+00
Bird egg	1.00E+00	0.00E+00	0.00E+00
Detritivorous invertebrate	0.00E+00	1.00E+00	0.00E+00
Flying insects	1.00E+00	0.00E+00	0.00E+00
Gastropod	1.00E+00	0.00E+00	0.00E+00
Grasses & Herbs	1.00E+00	0.00E+00	0.00E+00
Lichen & bryophytes	1.00E+00	0.00E+00	0.00E+00
Mammal (Deer)	1.00E+00	0.00E+00	0.00E+00
Mammal (Rat)	0.00E+00	1.00E+00	0.00E+00
Reptile	1.00E+00	0.00E+00	0.00E+00
Shrub	1.00E+00	0.00E+00	0.00E+00
Soil Invertebrate (worm)	0.00E+00	1.00E+00	0.00E+00
Tree	1.00E+00	0.00E+00	0.00E+00

Table 10. Input values for ERICA reference organisms: dose conversion coefficients (μGy h^{-1} per Bq kg^{-1} or Bq m^{-3})

(i) Co-60

	External radiation in air			*External radiation in soil*			*External radiation on soil*			*Internal radiation*		
Organism	Alpha	Beta gamma	Low beta	Alpha	Beta gamma	Low beta	Alpha	Beta gamma	Low beta	Alpha	Beta gamma	Low beta
Amphibian	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.30E-03	0.00E+00	0.00E+00	4.90E-04	0.00E+00	0.00E+00	1.10E-04	0.00E+00
Bird	0.00E+00	4.30E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.90E-04	0.00E+00	0.00E+00	2.40E-04	0.00E+00
Bird egg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.90E-04	0.00E+00	0.00E+00	1.20E-04	0.00E+00
Detritivorous invertebrate	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.30E-03	0.00E+00	0.00E+00	5.00E-04	0.00E+00	0.00E+00	5.90E-05	0.00E+00
Flying insects	0.00E+00	5.00E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.00E-04	0.00E+00	0.00E+00	6.40E-05	0.00E+00
Gastropod	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.30E-03	0.00E+00	0.00E+00	5.00E-04	0.00E+00	0.00E+00	7.10E-05	0.00E+00
Grasses & Herbs	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.80E-04	0.00E+00	0.00E+00	7.40E-05	0.00E+00
Lichen & bryophytes	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.00E-08	0.00E+00	0.00E+00	5.50E-05	0.00E+00
Mammal (Deer)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.60E-04	0.00E+00	0.00E+00	8.50E-04	0.00E+00
Mammal (Rat)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.20E-03	0.00E+00	0.00E+00	4.80E-04	0.00E+00	0.00E+00	1.70E-04	0.00E+00
Reptile	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.20E-03	0.00E+00	0.00E+00	4.70E-04	0.00E+00	0.00E+00	1.50E-04	0.00E+00
Shrub	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.50E-04	0.00E+00	0.00E+00	7.40E-05	0.00E+00
Soil Invertebrate	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.30E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.70E-05	0.00E+00
Tree	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.90E-04	0.00E+00	0.00E+00	7.30E-04	0.00E+00

(ii) C-14

	External radiation in air			*External radiation in soil*			*External radiation on soil*			*Internal radiation*		
Organism	Alpha	Beta gamma	Low beta	Alpha	Beta gamma	Low beta	Alpha	Beta gamma	Low beta	Alpha	Beta gamma	Low beta
Amphibian	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.77E-05	2.80E-07
Bird	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.87E-05	2.90E-07
Bird egg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.77E-05	2.80E-07
Detritivorous invertebrate	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.77E-05	2.80E-07
Flying insects	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.77E-05	2.80E-07
Gastropod	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.77E-05	2.80E-07
Grasses & Herbs	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.77E-05	2.80E-07
Lichen & bryophytes	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.77E-05	2.80E-07
Mammal (Deer)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.87E-05	2.90E-07
Mammal (Rat)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.87E-05	2.90E-07
Reptile	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.87E-05	2.90E-07
Shrub	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.77E-05	2.80E-07
Soil Invertebrate	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.77E-05	2.80E-07
Tree	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.87E-05	2.90E-07

(iii) Co-58

	External radiation in air			*External radiation in soil*			*External radiation on soil*			*Internal radiation*		
Organism	Alpha	Beta gamma	Low beta	Alpha	Beta gamma	Low beta	Alpha	Beta gamma	Low beta	Alpha	Beta gamma	Low beta
Amphibian	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.10E-04	0.00E+00	0.00E+00	2.00E-04	0.00E+00	0.00E+00	4.18E-05	2.20E-06
Bird	0.00E+00	1.70E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-04	0.00E+00	0.00E+00	9.70E-05	1.98E-06
Bird egg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-04	0.00E+00	0.00E+00	4.70E-05	1.96E-06
Detritivorous invertebrate	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.20E-04	0.00E+00	0.00E+00	2.00E-04	0.00E+00	0.00E+00	1.98E-05	2.20E-06
Flying insects	0.00E+00	2.00E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-04	0.00E+00	0.00E+00	2.28E-05	2.25E-06
Gastropod	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.20E-04	0.00E+00	0.00E+00	2.00E-04	0.00E+00	0.00E+00	2.58E-05	2.24E-06
Grasses & Herbs	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.90E-04	0.00E+00	0.00E+00	2.70E-05	2.03E-06
Lichen & bryophytes	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.10E-08	0.00E+00	0.00E+00	1.78E-05	2.20E-06
Mammal (Deer)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.80E-05	0.00E+00	0.00E+00	3.56E-04	3.60E-06
Mammal (Rat)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.90E-04	0.00E+00	0.00E+00	1.90E-04	0.00E+00	0.00E+00	6.79E-05	2.10E-06
Reptile	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.70E-04	0.00E+00	0.00E+00	1.90E-04	0.00E+00	0.00E+00	6.11E-05	1.89E-06
Shrub	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.80E-04	0.00E+00	0.00E+00	2.70E-05	2.03E-06
Soil Invertebrate	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.20E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.79E-05	2.10E-06
Tree	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.60E-04	0.00E+00	0.00E+00	3.17E-04	3.20E-06

(iv) Cs-134

	External radiation in air			*External radiation in soil*			*External radiation on soil*			*Internal radiation*		
Organism	Alpha	Beta gamma	Low beta	Alpha	Beta gamma	Low beta	Alpha	Beta gamma	Low beta	Alpha	Beta gamma	Low beta
Amphibian	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.20E-04	0.00E+00	0.00E+00	3.20E-04	0.00E+00	0.00E+00	1.30E-04	0.00E+00
Bird	0.00E+00	2.80E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.10E-04	0.00E+00	0.00E+00	2.20E-04	0.00E+00
Bird egg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.10E-04	0.00E+00	0.00E+00	1.40E-04	0.00E+00
Detritivorous invertebrate	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.40E-04	0.00E+00	0.00E+00	3.20E-04	0.00E+00	0.00E+00	8.80E-05	0.00E+00
Flying insects	0.00E+00	3.20E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.20E-04	0.00E+00	0.00E+00	9.70E-05	0.00E+00
Gastropod	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.30E-04	0.00E+00	0.00E+00	3.20E-04	0.00E+00	0.00E+00	1.00E-04	0.00E+00
Grasses & Herbs	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.10E-04	0.00E+00	0.00E+00	1.00E-04	0.00E+00
Lichen & bryophytes	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.70E-08	0.00E+00	0.00E+00	8.20E-05	0.00E+00
Mammal (Deer)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.60E-04	0.00E+00	0.00E+00	6.30E-04	0.00E+00
Mammal (Rat)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.80E-04	0.00E+00	0.00E+00	3.10E-04	0.00E+00	0.00E+00	1.70E-04	0.00E+00
Reptile	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.50E-04	0.00E+00	0.00E+00	3.00E-04	0.00E+00	0.00E+00	1.60E-04	0.00E+00
Shrub	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.90E-04	0.00E+00	0.00E+00	1.00E-04	0.00E+00
Soil Invertebrate	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.30E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.10E-04	0.00E+00
Tree	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.50E-04	0.00E+00	0.00E+00	5.80E-04	0.00E+00

(v) Cs-137

	External radiation in air			*External radiation in soil*			*External radiation on soil*			*Internal radiation*		
Organism	Alpha	Beta gamma	Low beta	Alpha	Beta gamma	Low beta	Alpha	Beta gamma	Low beta	Alpha	Beta gamma	Low beta
Amphibian	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.00E-04	0.00E+00	0.00E+00	1.10E-04	0.00E+00	0.00E+00	1.50E-04	0.00E+00
Bird	0.00E+00	1.00E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.10E-04	0.00E+00	0.00E+00	1.90E-04	0.00E+00
Bird egg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.10E-04	0.00E+00	0.00E+00	1.60E-04	0.00E+00
Detritivorous invertebrate	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.10E-04	0.00E+00	0.00E+00	1.20E-04	0.00E+00	0.00E+00	1.20E-04	0.00E+00
Flying insects	0.00E+00	1.20E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.20E-04	0.00E+00	0.00E+00	1.40E-04	0.00E+00
Gastropod	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.00E-04	0.00E+00	0.00E+00	1.20E-04	0.00E+00	0.00E+00	1.40E-04	0.00E+00
Grasses & Herbs	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.10E-04	0.00E+00	0.00E+00	1.40E-04	0.00E+00
Lichen & bryophytes	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.10E-09	0.00E+00	0.00E+00	1.10E-04	0.00E+00
Mammal (Deer)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.60E-05	0.00E+00	0.00E+00	3.40E-04	0.00E+00
Mammal (Rat)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.80E-04	0.00E+00	0.00E+00	1.10E-04	0.00E+00	0.00E+00	1.70E-04	0.00E+00
Reptile	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.70E-04	0.00E+00	0.00E+00	1.10E-04	0.00E+00	0.00E+00	1.70E-04	0.00E+00
Shrub	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.10E-04	0.00E+00	0.00E+00	1.40E-04	0.00E+00
Soil Invertebrate	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.00E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.40E-04	0.00E+00
Tree	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.00E-05	0.00E+00	0.00E+00	3.20E-04	0.00E+00

(vi) H-3

	External radiation in air			*External radiation in soil*			*External radiation on soil*			*Internal radiation*		
Organism	Alpha	Beta gamma	Low beta	Alpha	Beta gamma	Low beta	Alpha	Beta gamma	Low beta	Alpha	Beta gamma	Low beta
Amphibian	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.25E-07	2.48E-06
Bird	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.25E-07	2.48E-06
Bird egg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.25E-07	2.48E-06
Detritivorous invertebrate	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.25E-07	2.48E-06
Flying insects	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.09E-06	2.21E-06
Gastropod	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.25E-07	2.48E-06
Grasses & Herbs	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.25E-07	2.48E-06
Lichen & bryophytes	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.25E-07	2.48E-06
Mammal (Deer)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.25E-07	2.48E-06
Mammal (Rat)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.25E-07	2.48E-06
Reptile	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.25E-07	2.48E-06
Shrub	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.25E-07	2.48E-06
Soil Invertebrate	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.25E-07	2.48E-06
Tree	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.25E-07	2.48E-06

(vii) I-131

Organism	*External radiation in air* Alpha	Beta gamma	Low beta	*External radiation in soil* Alpha	Beta gamma	Low beta	*External radiation on soil* Alpha	Beta gamma	Low beta	*Internal radiation* Alpha	Beta gamma	Low beta
Amphibian	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.90E-04	0.00E+00	0.00E+00	7.70E-05	0.00E+00	0.00E+00	1.20E-04	0.00E+00
Bird	0.00E+00	6.60E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.70E-05	0.00E+00	0.00E+00	1.40E-04	0.00E+00
Bird egg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.70E-05	0.00E+00	0.00E+00	1.20E-04	0.00E+00
Detritivorous invertebrate	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.90E-04	0.00E+00	0.00E+00	7.80E-05	0.00E+00	0.00E+00	1.00E-04	0.00E+00
Flying insects	0.00E+00	7.80E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.80E-05	0.00E+00	0.00E+00	1.00E-04	0.00E+00
Gastropod	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.90E-04	0.00E+00	0.00E+00	7.80E-05	0.00E+00	0.00E+00	1.10E-04	0.00E+00
Grasses & Herbs	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.70E-05	0.00E+00	0.00E+00	1.10E-04	0.00E+00
Lichen & bryophytes	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.60E-09	0.00E+00	0.00E+00	9.50E-05	0.00E+00
Mammal (Deer)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.70E-05	0.00E+00	0.00E+00	2.50E-04	0.00E+00
Mammal (Rat)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.80E-04	0.00E+00	0.00E+00	7.50E-05	0.00E+00	0.00E+00	1.30E-04	0.00E+00
Reptile	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.70E-04	0.00E+00	0.00E+00	7.30E-05	0.00E+00	0.00E+00	1.30E-04	0.00E+00
Shrub	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.20E-05	0.00E+00	0.00E+00	1.10E-04	0.00E+00
Soil Invertebrate	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.90E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.10E-04	0.00E+00
Tree	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.10E-05	0.00E+00	0.00E+00	2.50E-04	0.00E+00

(viii) I-133

Organism	*External radiation in air* Alpha	Beta gamma	Low beta	*External radiation in soil* Alpha	Beta gamma	Low beta	*External radiation on soil* Alpha	Beta gamma	Low beta	*Internal radiation* Alpha	Beta gamma	Low beta
Amphibian	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.20E-04	0.00E+00	0.00E+00	1.20E-04	0.00E+00	0.00E+00	2.40E-04	0.00E+00
Bird	0.00E+00	1.10E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.20E-04	0.00E+00	0.00E+00	2.80E-04	0.00E+00
Bird egg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.20E-04	0.00E+00	0.00E+00	2.50E-04	0.00E+00
Detritivorous invertebrate	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.20E-04	0.00E+00	0.00E+00	1.20E-04	0.00E+00	0.00E+00	1.80E-04	0.00E+00
Flying insects	0.00E+00	1.20E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.20E-04	0.00E+00	0.00E+00	2.00E-04	0.00E+00
Gastropod	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.20E-04	0.00E+00	0.00E+00	1.20E-04	0.00E+00	0.00E+00	2.10E-04	0.00E+00
Grasses & Herbs	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.20E-04	0.00E+00	0.00E+00	2.20E-04	0.00E+00
Lichen & bryophytes	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.40E-09	0.00E+00	0.00E+00	1.60E-04	0.00E+00
Mammal (Deer)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.10E-05	0.00E+00	0.00E+00	4.50E-04	0.00E+00
Mammal (Rat)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.00E-04	0.00E+00	0.00E+00	1.20E-04	0.00E+00	0.00E+00	2.60E-04	0.00E+00
Reptile	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.90E-04	0.00E+00	0.00E+00	1.20E-04	0.00E+00	0.00E+00	2.60E-04	0.00E+00
Shrub	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.20E-04	0.00E+00	0.00E+00	2.20E-04	0.00E+00
Soil Invertebrate	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.20E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.20E-04	0.00E+00
Tree	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.80E-05	0.00E+00	0.00E+00	4.30E-04	0.00E+00

(ix) Nb-95

	External radiation in air			*External radiation in soil*			*External radiation on soil*			*Internal radiation*		
Organism	Alpha	Beta gamma	Low beta	Alpha	Beta gamma	Low beta	Alpha	Beta gamma	Low beta	Alpha	Beta gamma	Low beta
Amphibian	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.10E-04	0.00E+00	0.00E+00	1.60E-04	0.00E+00	0.00E+00	4.36E-05	4.40E-07
Bird	0.00E+00	1.40E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.50E-04	0.00E+00	0.00E+00	8.61E-05	8.70E-07
Bird egg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.50E-04	0.00E+00	0.00E+00	4.75E-05	4.80E-07
Detritivorous invertebrate	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.10E-04	0.00E+00	0.00E+00	1.60E-04	0.00E+00	0.00E+00	2.74E-05	5.60E-07
Flying insects	0.00E+00	1.60E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.60E-04	0.00E+00	0.00E+00	2.97E-05	3.00E-07
Gastropod	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.10E-04	0.00E+00	0.00E+00	1.60E-04	0.00E+00	0.00E+00	3.14E-05	6.40E-07
Grasses & Herbs	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.50E-04	0.00E+00	0.00E+00	3.23E-05	6.60E-07
Lichen & bryophytes	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.60E-09	0.00E+00	0.00E+00	2.65E-05	5.40E-07
Mammal (Deer)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.70E-05	0.00E+00	0.00E+00	2.90E-04	0.00E+00
Mammal (Rat)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.90E-04	0.00E+00	0.00E+00	1.50E-04	0.00E+00	0.00E+00	6.34E-05	6.40E-07
Reptile	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.70E-04	0.00E+00	0.00E+00	1.50E-04	0.00E+00	0.00E+00	5.84E-05	5.90E-07
Shrub	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.40E-04	0.00E+00	0.00E+00	3.23E-05	6.60E-07
Soil Invertebrate	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.10E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.23E-05	6.60E-07
Tree												

(x) Sr-89

	External radiation in air			*External radiation in soil*			*External radiation on soil*			*Internal radiation*		
Organism	Alpha	Beta gamma	Low beta	Alpha	Beta gamma	Low beta	Alpha	Beta gamma	Low beta	Alpha	Beta gamma	Low beta
Amphibian	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.40E-08	0.00E+00	0.00E+00	1.70E-08	0.00E+00	0.00E+00	3.10E-04	0.00E+00
Bird	0.00E+00	1.50E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.70E-08	0.00E+00	0.00E+00	3.30E-04	0.00E+00
Bird egg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.70E-08	0.00E+00	0.00E+00	3.20E-04	0.00E+00
Detritivorous invertebrate	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.50E-08	0.00E+00	0.00E+00	1.70E-08	0.00E+00	0.00E+00	2.10E-04	0.00E+00
Flying insects	0.00E+00	1.70E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.70E-08	0.00E+00	0.00E+00	2.50E-04	0.00E+00
Gastropod	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.50E-08	0.00E+00	0.00E+00	1.70E-08	0.00E+00	0.00E+00	2.80E-04	0.00E+00
Grasses & Herbs	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.70E-08	0.00E+00	0.00E+00	2.80E-04	0.00E+00
Lichen & bryophytes	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.80E-13	0.00E+00	0.00E+00	1.80E-04	0.00E+00
Mammal (Deer)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.50E-09	0.00E+00	0.00E+00	3.30E-04	0.00E+00
Mammal (Rat)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.20E-08	0.00E+00	0.00E+00	1.70E-08	0.00E+00	0.00E+00	3.30E-04	0.00E+00
Reptile	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.10E-08	0.00E+00	0.00E+00	1.60E-08	0.00E+00	0.00E+00	3.20E-04	0.00E+00
Shrub	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.60E-08	0.00E+00	0.00E+00	2.80E-04	0.00E+00
Soil Invertebrate	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.50E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.90E-04	0.00E+00
Tree	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.30E-08	0.00E+00	0.00E+00	3.40E-04	0.00E+00

(xi) Sr-90

	External radiation in air			*External radiation in soil*			*External radiation on soil*			*Internal radiation*		
Organism	Alpha	Beta gamma	Low beta	Alpha	Beta gamma	Low beta	Alpha	Beta gamma	Low beta	Alpha	Beta gamma	Low beta
Amphibian	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.50E-10	0.00E+00	0.00E+00	1.60E-11	0.00E+00	0.00E+00	5.90E-04	0.00E+00
Bird	0.00E+00	6.40E-12	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.60E-11	0.00E+00	0.00E+00	6.30E-04	0.00E+00
Bird egg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.60E-11	0.00E+00	0.00E+00	6.00E-04	0.00E+00
Detritivorous invertebrate	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.60E-10	0.00E+00	0.00E+00	1.60E-11	0.00E+00	0.00E+00	3.50E-04	0.00E+00
Flying insects	0.00E+00	1.60E-11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.60E-11	0.00E+00	0.00E+00	4.20E-04	0.00E+00
Gastropod	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.50E-10	0.00E+00	0.00E+00	1.60E-11	0.00E+00	0.00E+00	4.90E-04	0.00E+00
Grasses & Herbs	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.30E-10	0.00E+00	0.00E+00	5.10E-04	0.00E+00
Lichen & bryophytes	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.70E-16	0.00E+00	0.00E+00	2.90E-04	0.00E+00
Mammal (Deer)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.60E-12	0.00E+00	0.00E+00	6.50E-04	0.00E+00
Mammal (Rat)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.20E-10	0.00E+00	0.00E+00	1.60E-11	0.00E+00	0.00E+00	6.20E-04	0.00E+00
Reptile	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.10E-10	0.00E+00	0.00E+00	1.50E-11	0.00E+00	0.00E+00	6.00E-04	0.00E+00
Shrub	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.10E-11	0.00E+00	0.00E+00	5.10E-04	0.00E+00
Soil Invertebrate	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.50E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.20E-04	0.00E+00
Tree	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.90E-12	0.00E+00	0.00E+00	6.50E-04	0.00E+00

(xii) Zr-95

	External radiation in air			*External radiation in soil*			*External radiation on soil*			*Internal radiation*		
Organism	Alpha	Beta gamma	Low beta	Alpha	Beta gamma	Low beta	Alpha	Beta gamma	Low beta	Alpha	Beta gamma	Low beta
Amphibian	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.90E-04	0.00E+00	0.00E+00	1.50E-04	0.00E+00	0.00E+00	8.50E-05	0.00E+00
Bird	0.00E+00	1.30E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.50E-04	0.00E+00	0.00E+00	1.30E-04	0.00E+00
Bird egg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.50E-04	0.00E+00	0.00E+00	8.90E-05	0.00E+00
Detritivorous invertebrate	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.00E-04	0.00E+00	0.00E+00	1.50E-04	0.00E+00	0.00E+00	6.70E-05	0.00E+00
Flying insects	0.00E+00	1.50E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.50E-04	0.00E+00	0.00E+00	7.00E-05	0.00E+00
Gastropod	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.00E-04	0.00E+00	0.00E+00	1.50E-04	0.00E+00	0.00E+00	7.30E-05	0.00E+00
Grasses & Herbs	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.50E-04	0.00E+00	0.00E+00	7.30E-05	0.00E+00
Lichen & bryophytes	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.20E-09	0.00E+00	0.00E+00	6.30E-05	0.00E+00
Mammal (Deer)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.40E-05	0.00E+00	0.00E+00	3.20E-04	0.00E+00
Mammal (Rat)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.70E-04	0.00E+00	0.00E+00	1.50E-04	0.00E+00	0.00E+00	1.10E-04	0.00E+00
Reptile	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.60E-04	0.00E+00	0.00E+00	1.40E-04	0.00E+00	0.00E+00	1.00E-04	0.00E+00
Shrub	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.40E-04	0.00E+00	0.00E+00	7.30E-05	0.00E+00
Soil Invertebrate	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.00E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.50E-05	0.00E+00
Tree	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.20E-04	0.00E+00	0.00E+00	3.00E-04	0.00E+00

Table 11. Input values for radiation weighting factors (unitless)

Radiation type	*Value*
Internal alpha	1.00E+01
Internal beta gamma	1.00E+00
Internal low beta	3.00E+00

Table 12. Species of amphibian, bird, invertebrate, mammal and plants that may be present and of interest in a terrestrial Natura 2000 and thus considered within the context of this scenario.

Amphibian, invertebrate, mammal and plant species	*Bird species*
Bechsteins bat	Bewicks swan
Desmoulins whorl snail	Black-tailed godwit
Dormouse	Brent goose
Early gentian	Chough
Fen orchid	Curlew
Great crested newt	Dartford warbler
Greater horseshoe bat	Dunlin
Lesser horseshoe bat	Gadwall
Natterjack toad	Golden plover
Otter	Grey plover
Petal wort	Hen harrier
Shore dock	Honey buzzard
Smooth snake	Kittewake
Stag beetle	Knot
	Lapwing
	Lesser black-backed gull
	Marsh harrier
	Mediterranean gull
	Nightjar
	Oystercatcher
	Peregrine falcon
	Pink footed goose
	Pintail
	Redshank
	Ringed plover
	Ruff
	Sanderling
	Short-eared owl
	Shoveler
	Snipe
	Stone curlew
	Teal
	Whooper Swan
	Wigeon
	Woodlark

Table 13. Predicted activity concentration in ERICA reference organisms (Bq kg^{-1} f.w.)

Organism	*C-14*	*Co-58*	*Co-60*	*Cs-134*	*Cs-137*	*H-3*	*I-131*	*1-133*	*Nb-95*	*Sr-89*	*Sr-90*	*Zr-95*
Amphibian	1.31E+02	3.47E-02	4.43E-02	1.92E-02	3.47E-02	7.00E+02	2.79E-02	1.03E-02	1.22E-03	9.07E-03	1.78E-02	5.68E-08
Bird	1.31E+02	3.47E-02	4.43E-02	2.69E-02	4.86E-02	7.00E+02	2.79E-02	1.03E-02	1.22E-03	6.04E-03	1.18E-02	5.68E-08
Bird egg	8.72E+01	3.47E-02	4.43E-02	1.07E-03	1.94E-03	7.00E+02	1.12E+01	4.10E+00	3.66E-03	1.51E-02	2.96E-02	5.68E-08
Detritivorous invertebrate	4.21E+01	4.14E-04	5.27E-04	4.80E-03	8.68E-03	7.00E+02	2.10E-02	7.72E-03	3.23E-06	4.47E-03	8.77E-03	2.40E-06
Flying insects	4.21E+01	7.14E-04	9.10E-04	1.97E-03	3.57E-03	7.00E+02	2.10E-02	7.72E-03	3.23E-06	6.95E-04	1.36E-03	2.40E-06
Gastropod	4.21E+01	7.14E-04	9.10E-04	1.53E-03	2.76E-03	7.00E+02	1.26E-02	4.61E-03	3.23E-06	1.02E-03	1.99E-03	2.40E-06
Grasses & Herbs	8.72E+01	1.59E-03	2.02E-03	2.48E-02	4.49E-02	7.00E+02	9.77E-03	3.59E-03	2.72E-04	2.27E-03	4.46E-03	2.52E-06
Lichen & bryophytes	8.72E+01	2.54E-02	3.24E-02	2.01E-01	3.63E-01	7.00E+02	2.51E-02	9.23E-03	1.04E-04	9.54E-02	1.87E-01	8.14E-05
Mammal (Deer)	1.31E+02	3.47E-02	4.43E-02	1.03E-01	1.86E-01	7.00E+02	2.79E-02	1.03E-02	1.22E-03	1.91E-02	3.75E-02	5.68E-08
Mammal (Rat)	1.31E+02	3.47E-02	4.43E-02	1.03E-01	1.86E-01	7.00E+02	2.79E-02	1.03E-02	1.22E-03	1.91E-02	3.75E-02	5.68E-08
Reptile	1.31E+02	3.47E-02	4.43E-02	1.29E-01	2.32E-01	7.00E+02	2.79E-02	1.03E-02	1.22E-03	1.29E-01	2.54E-01	5.68E-08
Shrub	8.72E+01	8.81E-02	1.12E-01	1.42E-01	2.57E-01	7.00E+02	9.77E-03	3.59E-03	2.18E-04	5.45E-04	1.07E-03	4.49E-07
Soil Invertebrate	4.21E+01	7.14E-04	9.10E-04	3.20E-03	5.78E-03	7.00E+02	1.09E-02	4.00E-03	3.23E-06	9.85E-05	1.93E-04	2.40E-06
Tree	1.27E+02	2.15E-03	2.74E-03	5.84E-03	1.06E-02	7.00E+02	9.77E-03	3.59E-03	2.18E-04	5.37E-03	1.05E-02	9.95E-07

Table 14. Weighted dose rates (μGy h^{-1}) predicted for ERICA reference organisms

(i) internal dose rate

Organism	*C-14*	*Co-58*	*Co-60*	*Cs-134*	*Cs-137*	*H-3*	*I-131*	*1-133*	*Nb-95*	*Sr-89*	*Sr-90*	*Zr-95*
Amphibian	3.75E-03	1.68E-06	4.87E-06	2.50E-06	5.21E-06	5.78E-03	3.35E-06	2.46E-06	5.47E-08	2.81E-06	1.05E-05	4.82E-12
Bird	3.88E-03	3.57E-06	1.06E-05	5.91E-06	9.22E-06	5.78E-03	3.91E-06	2.87E-06	1.08E-07	1.99E-06	7.46E-06	7.38E-12
Bird egg	2.49E-03	1.84E-06	5.31E-06	1.50E-07	3.11E-07	5.78E-03	1.34E-03	1.03E-03	1.79E-07	4.83E-06	1.78E-05	5.05E-12
Detritivorous invertebrate	1.20E-03	1.09E-08	3.11E-08	4.22E-07	1.04E-06	5.78E-03	2.10E-06	1.39E-06	9.42E-11	9.39E-07	3.07E-06	1.61E-10
Flying insects	1.20E-03	2.11E-08	5.83E-08	1.91E-07	4.99E-07	5.41E-03	2.10E-06	1.54E-06	9.89E-11	1.74E-07	5.72E-07	1.68E-10
Gastropod	1.20E-03	2.32E-08	6.46E-08	1.53E-07	3.87E-07	5.78E-03	1.38E-06	9.68E-07	1.08E-10	2.84E-07	9.76E-07	1.75E-10
Grasses & Herbs	2.49E-03	5.24E-08	1.50E-07	2.48E-06	6.28E-06	5.78E-03	1.07E-06	7.89E-07	9.34E-09	6.36E-07	2.27E-06	1.84E-10
Lichen & bryophytes	2.49E-03	6.19E-07	1.78E-06	1.65E-05	3.99E-05	5.78E-03	2.39E-06	1.48E-06	2.91E-09	1.72E-05	5.43E-05	5.13E-09
Mammal (Deer)	3.88E-03	1.27E-05	3.76E-05	6.48E-05	6.32E-05	5.78E-03	6.98E-06	4.61E-06	3.54E-07	6.31E-06	2.44E-05	1.82E-11
Mammal (Rat)	3.88E-03	2.58E-06	7.52E-06	1.75E-05	3.16E-05	5.78E-03	3.63E-06	2.67E-06	7.96E-08	6.31E-06	2.33E-05	6.24E-12
Reptile	3.88E-03	2.32E-06	6.64E-06	2.06E-05	3.95E-05	5.78E-03	3.63E-06	2.67E-06	7.34E-08	4.14E-05	1.52E-04	5.68E-12
Shrub	2.49E-03	2.91E-06	8.32E-06	1.42E-05	3.60E-05	5.78E-03	1.07E-06	7.89E-07	7.47E-09	1.53E-07	5.45E-07	3.28E-11
Soil Invertebrate	1.20E-03	2.44E-08	7.01E-08	3.52E-07	8.10E-07	5.78E-03	1.20E-06	8.81E-07	1.11E-10	2.86E-08	1.01E-07	1.80E-10
Tree												

(ii) external dose rate

Organism	*C-14*	*Co-58*	*Co-60*	*Cs-134*	*Cs-137*	*H-3*	*I-131*	*1-133*	*Nb-95*	*Sr-89*	*Sr-90*	*Zr-95*
Amphibian	0.00E+00	2.35E-05	7.34E-05	1.15E-05	7.12E-06	0.00E+00	5.37E-06	3.08E-06	1.02E-06	1.87E-10	3.45E-13	7.14E-07
Bird	0.00E+00	2.35E-05	7.34E-05	1.11E-05	7.12E-06	0.00E+00	5.37E-06	3.08E-06	9.61E-07	1.87E-10	3.45E-13	7.14E-07
Bird egg	0.00E+00	2.35E-05	7.34E-05	1.11E-05	7.12E-06	0.00E+00	5.37E-06	3.08E-06	9.61E-07	1.87E-10	3.45E-13	7.14E-07
Detritivorous invertebrate	0.00E+00	6.11E-05	1.95E-04	3.01E-05	2.01E-05	0.00E+00	1.33E-05	8.20E-06	2.63E-06	4.95E-10	3.45E-12	1.90E-06
Flying insects	0.00E+00	2.35E-05	7.49E-05	1.15E-05	7.76E-06	0.00E+00	5.44E-06	3.08E-06	1.02E-06	1.87E-10	3.45E-13	7.14E-07
Gastropod	0.00E+00	2.35E-05	7.49E-05	1.15E-05	7.76E-06	0.00E+00	5.44E-06	3.08E-06	1.02E-06	1.87E-10	3.45E-13	7.14E-07
Grasses & Herbs	0.00E+00	2.23E-05	7.19E-05	1.11E-05	7.12E-06	0.00E+00	5.37E-06	3.08E-06	9.61E-07	1.87E-10	2.80E-12	7.14E-07
Lichen & bryophytes	0.00E+00	1.29E-09	4.49E-09	6.09E-10	3.95E-10	0.00E+00	2.51E-10	1.64E-10	5.51E-11	1.08E-14	7.98E-18	3.90E-11
Mammal (Deer)	0.00E+00	1.15E-05	3.89E-05	5.73E-06	3.62E-06	0.00E+00	2.58E-06	1.56E-06	4.93E-07	9.34E-11	9.92E-14	3.52E-07
Mammal (Rat)	0.00E+00	5.76E-05	1.80E-04	2.79E-05	1.81E-05	0.00E+00	1.26E-05	7.69E-06	2.50E-06	4.62E-10	2.59E-12	1.76E-06
Reptile	0.00E+00	2.23E-05	7.04E-05	1.07E-05	7.12E-06	0.00E+00	5.10E-06	3.08E-06	9.61E-07	1.76E-10	3.23E-13	6.66E-07
Shrub	0.00E+00	2.11E-05	6.74E-05	1.04E-05	7.12E-06	0.00E+00	5.03E-06	3.08E-06	8.97E-07	1.76E-10	1.10E-12	6.66E-07
Soil Invertebrate	0.00E+00	6.11E-05	1.95E-04	2.97E-05	1.94E-05	0.00E+00	1.33E-05	8.20E-06	2.63E-06	4.95E-10	3.23E-12	1.90E-06
Tree	0.00E+00	1.88E-05	5.84E-05	8.95E-06	5.82E-06	0.00E+00	4.26E-06	2.51E-06	7.68E-07	1.43E-10	1.27E-13	5.71E-07

(iii) total dose rate

Organism	*C-14*	*Co-58*	*Co-60*	*Cs-134*	*Cs-137*	*H-3*	*I-131*	*1-133*	*Nb-95*	*Sr-89*	*Sr-90*	*Zr-95*
Amphibian	3.75E-03	2.52E-05	7.83E-05	1.40E-05	1.23E-05	5.78E-03	8.72E-06	5.54E-06	1.08E-06	2.81E-06	1.05E-05	7.14E-07
Bird	3.88E-03	2.71E-05	8.40E-05	1.70E-05	1.63E-05	5.78E-03	9.28E-06	5.95E-06	1.07E-06	1.99E-06	7.46E-06	7.14E-07
Bird egg	2.49E-03	2.53E-05	7.87E-05	1.12E-05	7.43E-06	5.78E-03	1.35E-03	1.03E-03	1.14E-06	4.83E-06	1.78E-05	7.14E-07
Detritivorous invertebrate	1.20E-03	6.11E-05	1.95E-04	3.05E-05	2.11E-05	5.78E-03	1.54E-05	9.59E-06	2.63E-06	9.39E-07	3.07E-06	1.90E-06
Flying insects	1.20E-03	2.35E-05	7.50E-05	1.16E-05	8.26E-06	5.41E-03	7.55E-06	4.62E-06	1.02E-06	1.74E-07	5.72E-07	7.14E-07
Gastropod	1.20E-03	2.35E-05	7.50E-05	1.16E-05	8.15E-06	5.78E-03	6.83E-06	4.04E-06	1.02E-06	2.85E-07	9.76E-07	7.14E-07
Grasses & Herbs	2.49E-03	2.24E-05	7.21E-05	1.36E-05	1.34E-05	5.78E-03	6.45E-06	3.87E-06	9.70E-07	6.37E-07	2.27E-06	7.14E-07
Lichen & bryophytes	2.49E-03	6.20E-07	1.78E-06	1.65E-05	3.99E-05	5.78E-03	2.39E-06	1.48E-06	2.97E-09	1.72E-05	5.43E-05	5.17E-09
Mammal (Deer)	3.88E-03	2.43E-05	7.66E-05	7.05E-05	6.69E-05	5.78E-03	9.56E-06	6.18E-06	8.47E-07	6.31E-06	2.44E-05	3.52E-07
Mammal (Rat)	3.88E-03	6.01E-05	1.87E-04	4.54E-05	4.97E-05	5.78E-03	1.62E-05	1.04E-05	2.58E-06	6.31E-06	2.33E-05	1.76E-06
Reptile	3.88E-03	2.46E-05	7.70E-05	3.13E-05	4.66E-05	5.78E-03	8.72E-06	5.74E-06	1.03E-06	4.14E-05	1.52E-04	6.66E-07
Shrub	2.49E-03	2.41E-05	7.57E-05	2.46E-05	4.31E-05	5.78E-03	6.10E-06	3.87E-06	9.04E-07	1.53E-07	5.45E-07	6.66E-07
Soil Invertebrate	1.20E-03	6.11E-05	1.95E-04	3.01E-05	2.02E-05	5.78E-03	1.45E-05	9.08E-06	2.63E-06	2.91E-08	1.01E-07	1.90E-06
Tree	3.77E-03	1.95E-05	6.04E-05	1.23E-05	9.20E-06	5.78E-03	6.70E-06	4.05E-06	8.25E-07	1.83E-06	6.85E-06	5.72E-07

Table 15. Dose rates (µGy h^{-1}) predicted for the R&D128 reference organisms for Ar-41 and Kr-85

		Lichen	***Tree***	***Shrub***	***Herb***				
^{41}Ar		1.9E-05	2.0E-05	2.0E-05	2.0E-05				
^{85}Kr		1.5E-04	3.3E-04	3.3E-04	3.3E-04				
	Bee	***Woodlouse***	***Earthworm***	***Herbivorous Mammal***		***Rodent***	***Bird***	***Bird egg***	***Reptile***
^{41}Ar	3.3E-05	1.9E-05	4.3E-09	7.4E-06		6.8E-06	2.3E-05	1.7E-05	9.4E-06
^{85}Kr	1.1E-04	1.7E-04	2.4E-08	6.3E-06		1.5E-05	1.9E-05	3.5E-05	1.1E-05

Table 16. **Risk** Quotients determined for each reference organism using a 10 µGyh^{-1} screening level. Where there are comparable reference organisms between ERICA and R&D128, the RQs contain a contribution from Ar-41 and Kr-85

Reference Organism	*Dose Rate ERICA RO*	*Dose Rate Ar-41+Kr-85*	*Combined total dose rate*	*Total RQ*
	µGy h-1	µGy h-1	µGy h-1	
Amphibian	9.7E-03		9.7E-03	9.7E-04
Bird*	9.8E-03	4.2E-05	9.8E-03	9.8E-04
Bird egg*	1.1E-02	5.2E-05	1.1E-02	1.1E-03
Detritivorous invertebrate*	7.3E-03	1.9E-04	7.5E-03	7.5E-04
Flying insects*	6.7E-03	1.4E-04	6.8E-03	6.8E-04
Gastropod	7.1E-03		7.1E-03	7.1E-04
Grasses & Herbs*	8.4E-03	3.5E-04	8.8E-03	8.8E-04
Lichen & bryophytes	8.4E-03	1.7E-04	8.6E-03	8.6E-04
Mammal (Deer)*	9.9E-03	1.4E-05	9.9E-03	9.9E-04
Mammal (Rat)*	1.0E-02	2.2E-05	1.0E-02	1.0E-03
Reptile*	1.0E-02	2.0E-05	1.0E-02	1.0E-03
Shrub*	8.5E-03	3.5E-04	8.9E-03	8.9E-04
Soil Invertebrate*	7.3E-03	2.8E-08	7.3E-03	7.3E-04
Tree*	9.7E-03	3.5E-04	1.0E-02	1.0E-03

*combined with R&D128 reference organism data for Kr-85 and Ar-41

Table 17. Input values, estimated weighted dose rates using the ICRP DCC data for each ICRP RAP

(a) Deer

Radionuclide	[a]Bq/m^3 in air or [b]Bg/kg dw in soil	CR Deer	Internal Bq/kg	Deer Volume Internal DCC	External DCC	Internal dose	External dose	µGy/d Total dose	µGy/h Total dose
H-3[a]	4.7E+00	1.5E+02	7.0E+02	7.9E-05		1.7E-01	0.0E+00	1.7E-01	6.9E-03
C-14[a]	9.8E-02	1.3E+03	1.3E+02	6.8E-04		8.9E-02	0.0E+00	8.9E-02	3.7E-03
Co-58[b]	1.2E-01	3.0E-01	3.5E-02	1.1E-02	2.4E-03	3.8E-04	2.8E-04	6.6E-04	2.8E-05
Co-60[b]	1.5E-01	3.0E-01	4.4E-02	2.0E-02	6.3E-03	8.9E-04	9.5E-04	1.8E-03	7.6E-05
Sr-89[b]	1.1E-02	1.7E+00	1.9E-02	8.0E-03	2.0E-07	1.5E-04	2.2E-09	1.5E-04	6.4E-06
Sr-90[b]	2.2E-02	1.7E+00	3.8E-02	1.6E-02	1.1E-10	6.0E-04	2.4E-12	6.0E-04	2.5E-05
Zr-95[b]	4.8E-03	1.2E-05	5.7E-08	7.8E-03	1.8E-03	4.4E-10	8.6E-06	8.6E-06	3.6E-07
Nb-95[b]	6.4E-03	1.9E-01	1.2E-03	6.9E-03	1.8E-03	8.4E-06	1.2E-05	2.0E-05	8.3E-07
I-131[b]	7.0E-02	4.0E-01	2.8E-02	6.0E-03	8.9E-04	1.7E-04	6.2E-05	2.3E-04	9.6E-06
I-133[b]	2.6E-02	4.0E-01	1.0E-02	1.1E-02	1.5E-03	1.1E-04	3.8E-05	1.5E-04	6.3E-06
Cs-134[b]	3.6E-02	2.9E+00	1.0E-01	1.5E-02	3.8E-03	1.5E-03	1.4E-04	1.7E-03	7.0E-05
Cs-137[b]	6.5E-02	2.9E+00	1.9E-01	8.2E-03	1.4E-03	1.5E-03	9.1E-05	1.6E-03	6.7E-05

(b) Rat

Radionuclide	[a]Bq/m^3 in air or [b]Bg/kg dw in soil	CR Rat	Internal Bq/kg	Rat in soil Internal DCC	External DCC	Internal dose	External dose	µGy/d Total dose	µGy/h Total dose
H-3[a]	4.7E+00	1.5E+02	7.0E+02	7.9E-05		1.7E-01	0.0E+00	1.7E-01	6.9E-03
C-14[a]	9.8E-02	1.3E+03	1.3E+02	6.8E-04		8.9E-02	0.0E+00	8.9E-02	3.7E-03
Co-58[b]	1.2E-01	3.0E-01	3.5E-02	4.0E-03	1.2E-02	1.4E-04	1.4E-03	1.5E-03	6.4E-05
Co-60[b]	1.5E-01	3.0E-01	4.4E-02	4.0E-03	2.9E-02	1.8E-04	4.4E-03	4.5E-03	1.9E-04
Sr-89[b]	1.1E-02	1.7E+00	1.9E-02	7.8E-03	1.0E-06	1.5E-04	1.1E-08	1.5E-04	6.2E-06
Sr-90[b]	2.2E-02	1.7E+00	3.8E-02	1.5E-02	3.0E-09	5.6E-04	6.5E-11	5.6E-04	2.3E-05
Zr-95[b]	4.8E-03	1.2E-05	5.7E-08	2.5E-03	9.0E-03	1.4E-10	4.3E-05	4.3E-05	1.8E-06
Nb-95[b]	6.4E-03	1.9E-01	1.2E-03	1.5E-03	9.3E-03	1.8E-06	6.0E-05	6.1E-05	2.6E-06
I-131[b]	7.0E-02	4.0E-01	2.8E-02	3.1E-03	4.3E-03	8.7E-05	3.0E-04	3.9E-04	1.6E-05
I-133[b]	2.6E-02	4.0E-01	1.0E-02	6.3E-03	7.2E-03	6.5E-05	1.8E-04	2.5E-04	1.0E-05
Cs-134[b]	3.6E-02	2.9E+00	1.0E-01	4.1E-03	1.9E-02	4.2E-04	6.8E-04	1.1E-03	4.6E-05
Cs-137[b]	6.5E-02	2.9E+00	1.9E-01	4.1E-03	6.8E-03	7.6E-04	4.4E-04	1.2E-03	5.0E-05

(c) Bee

Radionuclide	[a]Bq/m³ in air or [b]Bg/kg dw in soil	CR Bee	Internal Bq/kg	Bee volume Internal DCC	External DCC	Internal dose	External dose	µGy/d Total dose	µGy/h Total dose
H-3[a]	4.7E+00	1.5E+02	7.0E+02	7.9E-05		1.7E-01	0.0E+00	1.7E-01	6.9E-03
C-14[a]	9.8E-02	4.3E+02	4.2E+01	6.8E-04		2.9E-02	0.0E+00	2.9E-02	1.2E-03
Co-58[b]	1.2E-01	6.1E-03	7.1E-04	2.9E-03	4.8E-03	2.1E-06	5.6E-04	5.6E-04	2.3E-05
Co-60[b]	1.5E-01	6.1E-03	9.1E-04	1.6E-03	1.2E-02	1.5E-06	1.8E-03	1.8E-03	7.5E-05
Sr-89[b]	1.1E-02	6.3E-02	7.0E-04	6.1E-03	4.1E-07	4.2E-06	4.5E-09	4.2E-06	1.8E-07
Sr-90[b]	2.2E-02	6.3E-02	1.4E-03	1.0E-02	3.9E-10	1.4E-05	8.4E-12	1.4E-05	5.7E-07
Zr-95[b]	4.8E-03	5.1E-04	2.4E-06	1.7E-03	3.6E-03	4.1E-09	1.7E-05	1.7E-05	7.1E-07
Nb-95[b]	6.4E-03	5.1E-04	3.2E-06	7.2E-04	3.8E-03	2.3E-09	2.4E-05	2.4E-05	1.0E-06
I-131[b]	7.0E-02	3.0E-01	2.1E-02	2.6E-03	1.9E-03	5.5E-05	1.3E-04	1.9E-04	7.8E-06
I-133[b]	2.6E-02	3.0E-01	7.7E-03	4.8E-03	3.0E-03	3.7E-05	7.7E-05	1.1E-04	4.7E-06
Cs-134[b]	3.6E-02	5.5E-02	2.0E-03	2.3E-03	7.6E-03	4.5E-06	2.7E-04	2.8E-04	1.2E-05
Cs-137[b]	6.5E-02	5.5E-02	3.6E-03	3.2E-03	2.8E-03	1.1E-05	1.8E-04	1.9E-04	8.0E-06

(d) Earthworm

Radionuclide	[a]Bq/m³ in air or [b]Bg/kg dw in soil	CR Earthworm	Internal Bq/kg	Earthworm in soil Internal DCC	External DCC	Internal dose	External dose	µGy/d Total dose	µGy/h Total dose
H-3[a]	4.7E+00	1.5E+02	7.0E+02	7.9E-05		1.7E-01	0.0E+00	1.7E-01	6.9E-03
C-14[a]	9.8E-02	4.3E+02	4.2E+01	6.8E-04		2.9E-02	0.0E+00	2.9E-02	1.2E-03
Co-58[b]	1.2E-01	6.1E-03	7.1E-04	3.0E-03	1.2E-02	2.1E-06	1.4E-03	1.4E-03	5.9E-05
Co-60[b]	1.5E-01	6.1E-03	9.1E-04	1.8E-03	3.1E-02	1.6E-06	4.7E-03	4.7E-03	1.9E-04
Sr-89[b]	1.1E-02	9.0E-03	9.9E-05	6.9E-03	1.1E-06	6.8E-07	1.2E-08	6.9E-07	2.9E-08
Sr-90[b]	2.2E-02	9.0E-03	1.9E-04	1.3E-02	3.7E-09	2.5E-06	8.0E-11	2.5E-06	1.0E-07
Zr-95[b]	4.8E-03	5.1E-04	2.4E-06	1.8E-03	9.5E-03	4.3E-09	4.5E-05	4.5E-05	1.9E-06
Nb-95[b]	6.4E-03	5.1E-04	3.2E-06	8.0E-04	9.9E-03	2.6E-09	6.3E-05	6.3E-05	2.6E-06
I-131[b]	7.0E-02	1.6E-01	1.1E-02	2.7E-03	4.6E-03	2.9E-05	3.2E-04	3.5E-04	1.5E-05
I-133[b]	2.6E-02	1.6E-01	4.0E-03	5.2E-03	7.7E-03	2.1E-05	2.0E-04	2.2E-04	9.1E-06
Cs-134[b]	3.6E-02	8.9E-02	3.2E-03	2.6E-03	2.0E-02	8.3E-06	7.2E-04	7.2E-04	3.0E-05
Cs-137[b]	6.5E-02	8.9E-02	5.8E-03	3.4E-03	7.3E-03	2.0E-05	4.7E-04	4.9E-04	2.0E-05

(e) Pine Tree

Radionuclide	[a]Bq/m^3 in air or [b]Bg/kg dw in soil	CR Tree	Internal Bq/kg	Pine trunk volume Internal DCC	External DCC	Internal dose	External dose	µGy/d Total dose	µGy/h Total dose
H-3[a]	4.7E+00	1.5E+02	7.0E+02	7.9E-05		1.7E-01	0.0E+00	1.7E-01	6.9E-03
C-14[a]	9.8E-02	1.3E+03	1.3E+02	6.8E-04		8.7E-02	0.0E+00	8.7E-02	3.6E-03
Co-58[b]	1.2E-01	1.8E-02	2.1E-03	1.0E-02	1.6E-03	2.1E-05	1.9E-04	2.1E-04	8.7E-06
Co-60[b]	1.5E-01	1.8E-02	2.7E-03	1.8E-02	4.3E-03	4.9E-05	6.5E-04	6.9E-04	2.9E-05
Sr-89[b]	1.1E-02	4.9E-01	5.4E-03	8.0E-03	1.4E-07	4.3E-05	1.5E-09	4.3E-05	1.8E-06
Sr-90[b]	2.2E-02	4.9E-01	1.1E-02	1.6E-02	5.6E-11	1.7E-04	1.2E-12	1.7E-04	7.0E-06
Zr-95[b]	4.8E-03	2.1E-04	9.9E-07	7.2E-03	1.2E-03	7.2E-09	5.7E-06	5.7E-06	2.4E-07
Nb-95[b]	6.4E-03	3.4E-02	2.2E-04	6.3E-03	1.2E-03	1.4E-06	7.7E-06	9.1E-06	3.8E-07
I-131[b]	7.0E-02	1.4E-01	9.8E-03	5.9E-03	5.8E-04	5.8E-05	4.0E-05	9.8E-05	4.1E-06
I-133[b]	2.6E-02	1.4E-01	3.6E-03	1.0E-02	9.7E-04	3.6E-05	2.5E-05	6.1E-05	2.5E-06
Cs-134[b]	3.6E-02	1.6E-01	5.8E-03	1.4E-02	2.5E-03	8.2E-05	9.0E-05	1.7E-04	7.1E-06
Cs-137[b]	6.5E-02	1.6E-01	1.1E-02	7.8E-03	8.9E-04	8.2E-05	5.8E-05	1.4E-04	5.8E-06

Radionuclide	[a]Bq/m^3 in air or [b]Bg/kg dw in soil	Tree	Internal Bq/kg	pine layer volume Internal DCC	External DCC	Internal dose	External dose	µGy/d Total dose	µGy/h Total dose
H-3[a]	4.7E+00	1.5E+02	7.0E+02			0.0E+00	0.0E+00	0.0E+00	0.0E+00
C-14[a]	9.8E-02	1.3E+03	1.3E+02			0.0E+00	0.0E+00	0.0E+00	0.0E+00
Co-58[b]	1.2E-01	1.8E-02	2.1E-03		3.7E-03	0.0E+00	4.3E-04	4.3E-04	1.8E-05
Co-60[b]	1.5E-01	1.8E-02	2.7E-03		9.3E-03	0.0E+00	1.4E-03	1.4E-03	5.8E-05
Sr-89[b]	1.1E-02	4.9E-01	5.4E-03		3.2E-07	0.0E+00	3.5E-09	3.5E-09	1.5E-10
Sr-90[b]	2.2E-02	4.9E-01	1.1E-02		1.4E-10	0.0E+00	3.0E-12	3.0E-12	1.3E-13
Zr-95[b]	4.8E-03	2.1E-04	9.9E-07		2.8E-03	0.0E+00	1.3E-05	1.3E-05	5.6E-07
Nb-95[b]	6.4E-03	3.4E-02	2.2E-04		2.9E-03	0.0E+00	1.9E-05	1.9E-05	7.7E-07
I-131[b]	7.0E-02	1.4E-01	9.8E-03		1.5E-03	0.0E+00	1.0E-04	1.0E-04	4.4E-06
I-133[b]	2.6E-02	1.4E-01	3.6E-03		2.3E-03	0.0E+00	5.9E-05	5.9E-05	2.5E-06
Cs-134[b]	3.6E-02	1.6E-01	5.8E-03		6.0E-03	0.0E+00	2.1E-04	2.1E-04	9.0E-06
Cs-137[b]	6.5E-02	1.6E-01	1.1E-02		2.2E-03	0.0E+00	1.4E-04	1.4E-04	5.9E-06

(f) Wild Grass

Radionuclide	[a]Bq/m^3 in air or [b]Bg/kg dw in soil	CR Grass	Internal Bq/kg	Grass meristem volume Internal DCC	External DCC	Internal dose	External dose	µGy/d Total dose	µGy/h Total dose
H-3[a]	4.7E+00	1.5E+02	7.0E+02			0.0E+00	0.0E+00	0.0E+00	0.0E+00
C-14[a]	9.8E-02	8.9E+02	8.7E+01			0.0E+00	0.0E+00	0.0E+00	0.0E+00
Co-58[b]	1.2E-01	1.4E-02	1.6E-03		4.6E-03	0.0E+00	5.4E-04	5.4E-04	2.2E-05
Co-60[b]	1.5E-01	1.4E-02	2.0E-03		1.1E-02	0.0E+00	1.7E-03	1.7E-03	6.9E-05
Sr-89[b]	1.1E-02	2.1E-01	2.3E-03		4.0E-07	0.0E+00	4.4E-09	4.4E-09	1.8E-10
Sr-90[b]	2.2E-02	2.1E-01	4.5E-03		3.0E-09	0.0E+00	6.5E-11	6.5E-11	2.7E-12
Zr-95[b]	4.8E-03	5.3E-04	2.5E-06		3.5E-03	0.0E+00	1.7E-05	1.7E-05	6.9E-07
Nb-95[b]	6.4E-03	4.3E-02	2.7E-04		3.7E-03	0.0E+00	2.4E-05	2.4E-05	9.9E-07
I-131[b]	7.0E-02	1.4E-01	9.8E-03		1.8E-03	0.0E+00	1.3E-04	1.3E-04	5.2E-06
I-133[b]	2.6E-02	1.4E-01	3.6E-03		2.9E-03	0.0E+00	7.4E-05	7.4E-05	3.1E-06
Cs-134[b]	3.6E-02	6.9E-01	2.5E-02		7.4E-03	0.0E+00	2.6E-04	2.6E-04	1.1E-05
Cs-137[b]	6.5E-02	6.9E-01	4.5E-02		2.7E-03	0.0E+00	1.7E-04	1.7E-04	7.3E-06

Radionuclide	[a]Bq/m^3 in air or [b]Bg/kg dw in soil	CR Grass	Internal Bq/kg	Grass spike volume Internal DCC	External DCC	Internal dose	External dose	µGy/d Total dose	µGy/h Total dose
H-3[a]	4.7E+00	1.5E+02	7.0E+02	7.9E-05		1.7E-01	0.0E+00	1.7E-01	6.9E-03
C-14[a]	9.8E-02	8.9E+02	8.7E+01	6.8E-04		5.9E-02	0.0E+00	5.9E-02	2.5E-03
Co-58[b]	1.2E-01	1.4E-02	1.6E-03	3.0E-03	4.8E-03	4.7E-06	5.6E-04	5.7E-04	2.4E-05
Co-60[b]	1.5E-01	1.4E-02	2.0E-03	1.8E-03	1.2E-02	3.6E-06	1.8E-03	1.8E-03	7.5E-05
Sr-89[b]	1.1E-02	2.1E-01	2.3E-03	6.8E-03	4.1E-07	1.5E-05	4.5E-09	1.5E-05	6.5E-07
Sr-90[b]	2.2E-02	2.1E-01	4.5E-03	1.2E-02	3.9E-10	5.4E-05	8.4E-12	5.4E-05	2.2E-06
Zr-95[b]	4.8E-03	5.3E-04	2.5E-06	1.8E-03	3.6E-03	4.5E-09	1.7E-05	1.7E-05	7.1E-07
Nb-95[b]	6.4E-03	4.3E-02	2.7E-04	7.8E-04	3.7E-03	2.1E-07	2.4E-05	2.4E-05	1.0E-06
I-131[b]	7.0E-02	1.4E-01	9.8E-03	2.6E-03	1.9E-03	2.5E-05	1.3E-04	1.6E-04	6.6E-06
I-133[b]	2.6E-02	1.4E-01	3.6E-03	5.2E-03	3.0E-03	1.9E-05	7.7E-05	9.5E-05	4.0E-06
Cs-134[b]	3.6E-02	6.9E-01	2.5E-02	2.5E-03	7.6E-03	6.2E-05	2.7E-04	3.3E-04	1.4E-05
Cs-137[b]	6.5E-02	6.9E-01	4.5E-02	3.4E-03	2.8E-03	1.5E-04	1.8E-04	3.3E-04	1.4E-05

(g) Duck

Radionuclide	[a]Bq/m^3 in air or [b]Bg/kg dw in soil	CR Duck	Internal Bq/kg	Duck volume Internal DCC	External DCC	Internal dose	External dose	µGy/d Total dose	µGy/h Total dose
H-3[a]	4.7E+00	1.5E+02	7.0E+02	7.9E-05		1.7E-01	0.0E+00	1.7E-01	6.9E-03
C-14[a]	9.8E-02	1.3E+03	1.3E+02	6.8E-04		8.9E-02	0.0E+00	8.9E-02	3.7E-03
Co-58[b]	1.2E-01	3.0E-01	3.5E-02	4.7E-03	4.4E-03	1.6E-04	5.1E-04	6.8E-04	2.8E-05
Co-60[b]	1.5E-01	3.0E-01	4.4E-02	5.7E-03	1.1E-02	2.5E-04	1.7E-03	1.9E-03	7.9E-05
Sr-89[b]	1.1E-02	5.5E-01	6.0E-03	7.9E-03	3.8E-07	4.8E-05	4.2E-09	4.8E-05	2.0E-06
Sr-90[b]	2.2E-02	5.5E-01	1.2E-02	1.5E-02	3.5E-10	1.8E-04	7.6E-12	1.8E-04	7.4E-06
Zr-95[b]	4.8E-03	1.2E-05	5.7E-08	3.1E-03	3.3E-03	1.8E-10	1.6E-05	1.6E-05	6.5E-07
Nb-95[b]	6.4E-03	1.9E-01	1.2E-03	2.1E-03	3.5E-03	2.6E-06	2.2E-05	2.5E-05	1.0E-06
I-131[b]	7.0E-02	4.0E-01	2.8E-02	3.4E-03	1.7E-03	9.5E-05	1.2E-04	2.1E-04	8.9E-06
I-133[b]	2.6E-02	4.0E-01	1.0E-02	6.8E-03	2.7E-03	7.0E-05	6.9E-05	1.4E-04	5.8E-06
Cs-134[b]	3.6E-02	7.5E-01	2.7E-02	5.3E-03	7.0E-03	1.4E-04	2.5E-04	3.9E-04	1.6E-05
Cs-137[b]	6.5E-02	7.5E-01	4.9E-02	4.5E-03	2.6E-03	2.2E-04	1.7E-04	3.9E-04	1.6E-05

(h) Frog

Radionuclide	[a]Bq/m^3 in air or [b]Bg/kg dw in soil	CR Frog	Internal Bq/kg	Frog volume Internal DCC	External DCC	Internal dose	External dose	µGy/d Total dose	µGy/h Total dose
H-3[a]	4.7E+00	1.5E+02	7.0E+02	7.9E-05		1.7E-01	0.0E+00	1.7E-01	6.9E-03
C-14[a]	9.8E-02	1.3E+03	1.3E+02	6.8E-04		8.9E-02	0.0E+00	8.9E-02	3.7E-03
Co-58[b]	1.2E-01	3.0E-01	3.5E-02	3.4E-03	4.7E-03	1.2E-04	5.5E-04	6.7E-04	2.8E-05
Co-60[b]	1.5E-01	3.0E-01	4.4E-02	2.6E-03	1.2E-02	1.2E-04	1.8E-03	1.9E-03	8.0E-05
Sr-89[b]	1.1E-02	8.3E-01	9.1E-03	7.5E-03	4.1E-07	6.8E-05	4.5E-09	6.8E-05	2.8E-06
Sr-90[b]	2.2E-02	8.3E-01	1.8E-02	1.4E-02	3.8E-10	2.5E-04	8.2E-12	2.5E-04	1.0E-05
Zr-95[b]	4.8E-03	1.2E-05	5.7E-08	2.0E-03	3.6E-03	1.1E-10	1.7E-05	1.7E-05	7.1E-07
Nb-95[b]	6.4E-03	1.9E-01	1.2E-03	1.1E-03	3.7E-03	1.3E-06	2.4E-05	2.5E-05	1.0E-06
I-131[b]	7.0E-02	4.0E-01	2.8E-02	2.8E-03	1.9E-03	7.8E-05	1.3E-04	2.1E-04	8.8E-06
I-133[b]	2.6E-02	4.0E-01	1.0E-02	5.8E-03	3.0E-03	5.9E-05	7.7E-05	1.4E-04	5.7E-06
Cs-134[b]	3.6E-02	5.4E-01	1.9E-02	3.1E-03	7.6E-03	6.0E-05	2.7E-04	3.3E-04	1.4E-05
Cs-137[b]	6.5E-02	5.4E-01	3.5E-02	3.7E-03	2.7E-03	1.3E-04	1.7E-04	3.0E-04	1.3E-05

Table 18. Summary of the input data and the output dose rates predictions for the scenario exposed human population group (inhaling and being exposed to the radiation plume at 100m from source and consuming foodstuffs from a distance of 500m from the source)

Radionuclide	***Discharge** Bq/y*	***Local Habitant Dose** µSv/y*	***% Contribution***
Tritium	1.30E+13	9.3E-01	9.12%
Carbon-14	2.70E+11	2.5E+00	24.85%
Argon-41	1.30E+12	2.4E-02	0.24%
Cobalt-58	8.50E+08	6.7E-03	0.07%
Cobalt-60	3.20E+08	7.9E-02	0.77%
Krypton-85	4.10E+14	1.5E-02	0.14%
Strontium-89	1.10E+08	8.4E-04	0.01%
Strontium-90	4.40E+07	9.2E-03	0.09%
Zirconium-95	3.70E+07	3.9E-04	0.00%
Niobium-95	9.30E+07	3.0E-04	0.00%
Iodine-131	4.40E+09	6.1E+00	59.93%
Iodine-133	1.50E+10	4.5E-01	4.44%
Caesium-134	8.50E+07	1.2E-02	0.11%
Caesium-137	1.30E+08	2.3E-02	0.22%
Total dose		1.0E+01	

Table 19. Discharges during 2006 from the Sizewell nuclear power plant in the UK

Radionuclide	***Discharge** TBq*
Sizewell 'A'	
Tritium	0.916
Caesium-137	0.569
Other radionuclides	0.398
Sizewell 'B'	
Tritium	55.1
Other radionuclides	0.0217

Table 20. Comparison of dose rates estimated using the ICRP DCC values and the ERICA Tool for the same geometries and using the same assumptions. Results presented as the ratio of the ICRP estimate to the ERICA Tool estimate.

Radionuclide	Deer	Rat	Bee	Earthworm	Pine tree (trunk)	Wild grass (spike)	Duck	Frog
H-3	1.19	1.19	1.28	1.19	1.19	1.19	1.19	1.19
C-14	0.95	0.95	1.00	1.00	0.95	1.00	0.95	0.99
Co-58	1.15	1.06	0.98	0.97	0.45	1.07	1.03	1.11
Co-60	0.99	1.02	1.00	0.97	0.48	1.04	0.94	1.02
Sr-89	1.01	0.98	1.03	1.00	0.98	1.02	1.01	1.00
Sr-90	1.02	0.99	1.00	0.99	1.02	0.81	0.99	0.95
Zr-95	1.02	1.02	0.99	1.00	0.42	0.99	0.91	0.99
Nb-95	0.98	1.01	0.98	0.99	0.46	1.03	0.93	0.93
I-131	1.00	0.99	1.03	1.03	0.61	1.02	0.96	1.01
I-133	1.02	0.96	1.02	1.00	0.62	1.03	0.97	1.03
Cs-134	0.99	1.01	1.03	1.00	0.55	1.03	0.94	1.00
Cs-137	1.00	1.01	0.97	0.99	0.63	1.04	0.98	1.06

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