

# ERICA Assessment Tool Help Documentation

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## 1. Assessment Details Screen – T1, T2, T3

*Assessment name:* Please enter a unique name for this assessment that you will be able to use to identify it in the future.

*Author:* Enter your name.

*Select start point:* At this point you have several choices regarding where to start the assessment:

If you started at an earlier tier then you will find that the information you entered previously has been pulled forward to this screen. The information should be modified as appropriate.

*Tier 1:* is a simple assessment which requires minimal input from you (basically, a site description and other details to allow the problem under assessment to be described fully, for example by including:

- which radionuclides are present;
- what is the ecosystem being assessed (freshwater, marine or terrestrial);
- how the media (water, sediment, soil or air) concentrations will be entered (through the use of screening transport models or site-specific measurement data etc);
- how time dependent or spatial data may be used (Section 10.13 and 10.15).

The results from this assessment are considered to be conservative and therefore can be used to screen out sites where there is a negligible radiological risk of the populations of non-human species being affected by the presence of the ionising radiation. Input media activity concentrations are compared against Environmental Media Concentration Limits (Section 10.7) which have been calculated for the most limiting organism for each radionuclide. This tier does not require specialist knowledge.

*Tier 2:* is a more detailed assessment which requires further input from you to better define the problem that is being assessed particularly with regard to the exposure conditions and the transfer parameters. For example, you are able to:

- select which radionuclides are present;
- select which reference organisms are present in your assessment scenario;
- add your own user-defined geometries (however you will need to be able to populate the tool with all the necessary parameters for the tool to function correctly – advice is given throughout the assessment tool in the help sections to assist you in deriving the necessary information);
- modify the default concentration ratios (CRs) and, for aquatic ecosystems, the distribution coefficient ( $K_d$ ) values to add, for example, values deriving from site-specific data (please note you are advised to read the help section before making these decisions for further information);
- describe how the media (water, sediment soil or air) concentrations will be entered (through the use of screening transport models or site-specific measurement data etc);
- describe how time dependent or spatial data may be used (Section 10.13 and 10.15).

For each organism of interest estimated absorbed dose rates are compared to the selected incremental screening dose rate. Results can be put into context by comparing to summarised tables of radiation effects and natural background exposure.

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

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

Selecting the appropriate radial button for the Tier that you wish to start with will determine the information that is requested on the following screens as you move through the assessment. You are free to start the assessment at any tier.

*Purpose of Assessment:* Within the purpose of the assessment you might be expected to provide a brief description of the assessment to be conducted, for example you might:

- describe the name and process of the facility that is the source of the radioactive substances in the environment;
- provide details of whether the assessment is prospective or retrospective;
- describe the aim of your assessment (i.e. why are you conducting it); and
- describe what the protection goal of the assessment is.

Another way of thinking about this section is that it is an abstract or summary of the entire assessment and would be the information that you might use to explain the background to an assessment to a stakeholder or other interested party using non-technical language.

*Next:* Click the next button once the screen has been completed to move to the next screen.

## **2. Stakeholder Involvement Screen T1, T2 & T3**

If you started at a lower tier, then you will find that the information you entered previously has been pulled forward to this screen. In this case, you should now review and refine the previous information that was entered in light of any new information that has come out of the earlier tier assessment results.

A stakeholder can be defined as anyone who has an interest in or considers that they have an interest in the issue under consideration and therefore it goes beyond representatives or groups to include interested members of the public.

*Do you need to engage stakeholders?:* This is a simple radial button which will determine the type of information that the following screens will request. Whether you wish to engage with stakeholders is a decision that you must make based on the situation that is being assessed. Guidance is provided

elsewhere (see ERICA Deliverables D8, D7d and D-ERICA) which discuss the reasons why you might wish to engage with stakeholders and provides advice on how you might conduct these engagements. Answering:

- *Yes - makes the stakeholder involvement box editable:* If you select yes then the assessment tool will ask you to provide a brief summary of the stakeholder involvement (e.g. who is involved, how are they involved, what is the aim of the involvement? etc.). Further help is provided on each subsequent screen.
- *No - makes the 'explain why not' box editable:* If you select no then the assessment tool asks you to provide a brief justification for your decision not to include stakeholders. This could be as simple as stating that there is a wider stakeholder consultation ongoing and that the ERICA tool is being used as part of the assessment and that the results from the tool will be discussed with stakeholders from this wider engagement.

*Back:* Click the back button to return to the previous screen to make further modifications to the input or to check on the information entered, any modifications made to either the current page before moving to the previous screen or any changes made to the previous screen are made in the tool record. This allows mistakes or omissions to be corrected at any time when using the tool.

*Next:* Click the next button once the screen has been completed to move to the next screen which will be the Problem Formulation screen if you click no or if you have selected yes, a screen will appear that allows you to record the stakeholder engagement process and what its key outcomes were before returning you to the Problem Formulation screen.

#### *References:*

Copplestone D., Zinger I., Oughton D. (2005) Deliverable D7d: Transcript from the Third Thematic EUG Event: Decision-making and stakeholder involvement. 79pp.

Zinger I., Copplestone D., Brown J., Sjöblom K-L., Jones S.R., Pröhl G., Oughton D., Garnier-Laplace J., Gómez-Ros, J-M. (2007) Deliverable D8: Considerations for applying the ERICA Integrated Approach. 122pp.

Beresford N.A., Brown J.E., Copplestone D., Garnier-Laplace J., Howard B.J., Larsson C-M., Oughton D., Pröhl G. and Zinger I., (2007) Deliverable D-ERICA: An Integrated Approach to the assessment and management of environmental risks from ionising radiation: Description of purpose, methodology and application. 69pp.

### **3. Stakeholder Involvement Record Screens T1, T2 and T3**

There are four parts to the stakeholder screens. This first screen should be used to record the process of stakeholder involvement in order to provide documentary evidence of that process. The four parts are:

- Identification of stakeholders and their involvement;
- Stakeholder interest, influence and engagement;
- Main method of communication with the stakeholders;
- Add more information.

Further details on each of these sections are provided below.

### 3.1 Identification of stakeholders and their involvement

You first need to insert a row and then you can select a category of stakeholder from the drop down list available in the cell below the ‘*Type of stakeholders*’ title. These generic groups (see list in Table 1) can be used to group the stakeholders.

Once you have selected the generic group of stakeholders, it is recommended that you provide the name and brief description of the stakeholder in the cell under ‘*Description of stakeholder*’. Within the column cell entitled ‘*Reason for involvement*’ you should include a brief reason for their inclusion.

You should then record when this stakeholder should be/was involved with the assessment process by ticking the check box in the appropriate columns for:

- At the problem formulation stage;
- Throughout the process;
- As a source of knowledge and/or data for a particular purpose;
- Reviewer of the assessment;
- Other reason – explain (this is a free form text box for you to enter your own description for the timing of the involvement).

You can add or delete rows from this table using the three buttons below the table heading (‘*1. Identification of stakeholders and timing of their involvement*’). These buttons are ‘*insert before*’, ‘*insert after*’ or ‘*delete row*’. These should be self explanatory and allow you to order the list of stakeholders according to your wishes.

Note that the size of the columns can be modified by selecting the column dividing line and dragging to make the column bigger or smaller.

*Back*: Click the back button to return to the previous screen to make further modifications to the input or to check on the information entered, any modifications made to either the current page before moving to the previous screen or any changes made to the previous screen are made in the tool record. This allows mistakes or omissions to be corrected at any time when using the tool.

*Next*: Click the next button once the screen has been completed to move to the next screen.

**Table 1: List of generic stakeholder groups**

‘Users’ of the environment (recreation, food production, etc)	NGO’s (particularly environmental and nature organisations)
Decision makers	Non-human species*
General public	Other NGOs
Independent experts (research and academia)	Other
Industry	People/organisations ‘who care’
International representatives (for transboundary questions)	Regulators
Local authorities and/or government representatives	Risk bearers
Media	Worker Representatives

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

### 3.2 Stakeholder interest, influence and engagement

This screen will be populated with the list and description of the stakeholders entered in the previous screen. You can then identify the category of the stakeholder and the way to engage with that stakeholder.

For category you should select the appropriate option (see Table 2) from the drop down menu in each cell in the column entitled ‘*Choose category*’. The category is classified as an understanding of the level of influence and interest in the assessment. Stakeholders with low influence and low interest are harder to reach and engage with and perhaps need not be involved. Those with a high interest and high influence would normally be included automatically, as their position is, by its nature, interactive. The other 2 groups are often more problematic and their involvement and method of involvement might depend upon a number of factors.

**Table 2: Categories for defining the level of stakeholder interest – the examples given are purely illustrative**

Hi influence/low interest e.g. civil servants	Hi influence/hi interest e.g. the developer/proposer, regulator
Low influence/low interest e.g. members of the public	Low influence/high interest e.g. local NGOs, protest groups

The method of engagement can also be recorded here by selecting the appropriate option from the drop down menu in each cell in the column entitled ‘*way to engage*’ and can be in the form of:

- Information provision;
- Consultation;
- Consensus building.

*Information provision:* This can be considered more or less a one-way process (although the stakeholders might also provide specific information to the assessment). Dissemination of information related to the project and associated processes may include the use of leaflets, websites, public relations and media, open house, exhibitions, dissemination of project information and of process information, seminars to explain issues and announcements.

*Consultation:* A process that can be used for the purpose of discussion on for example appropriate input values into the assessment and for gaining an understanding of the stakeholders’ points of view and arguments. In this particular case it is very useful to have an understanding of the category of stakeholder as described above.

*Consensus building:* A process which is aiming to reach agreement on particular points through informed debate and discussion. The aim is to produce an output that all stakeholders involved can agree with and sign up to. This is different to consultation because with consultation areas of disagreement are bound to remain because consultation is really about finding out the different opinions and views so that the decision makers can consider all aspects when making decisions. However consensus building is about attempting to bring all parties to some form of agreement. For example, it might be possible to get consensus on what might considered to be a trivial exposure to ionising radiation for non-human species or that the assessment tool was fit for purpose. However it should be recognised that, whilst the aim of the process might be to come to some form of consensus,

it will not always be possible to achieve this. In these cases, the reasons for dissensus should be recorded as this might shed light on key issues for consideration by decision-makers.

*Back:* Click the back button to return to the previous screen to make further modifications to the input or to check on the information entered, any modifications made to either the current page before moving to the previous screen or any changes made to the previous screen are made in the tool record. This allows mistakes or omissions to be corrected at any time when using the tool.

*Next:* Click the next button once the screen has been completed to move to the next screen.

### ***3.3 Main method of communication with the stakeholders***

This screen entitled ‘3. *Main communication methods to reach stakeholders*’ allows you to select the methods that will be or have been used under the way to engage heading in the previous screen for information provision, consultation or consensus building at different time periods during an assessment for example:

- At the problem formulation stage;
- Throughout the process;
- As a source of knowledge and/or data for a particular purpose;
- Reviewer of the assessment;
- Other reason – explain (this is a free form text box for you to enter your own description for the timing of the involvement.

Typical methods of engagement are provided in the matrix and you should highlight those that have been, or are being, used within the assessment process by ticking the relevant check boxes in the matrix.

### ***3.4 Add more information***

This section of the screen is a free form text box to allow you to add your own comments on the stakeholder engagement process. For example you might need to explain or justify why some stakeholders have been included and others not. Alternatively you might use this text box to record comments about how the stakeholder process has informed the assessment being conducted, for example, you might have amended your proposed input values or parameters through discussion and engagement or you might have agreed a different endpoint to the assessment than was originally conceived. Therefore it is recommended that you use this text box to record anything pertinent to the assessment that has come out of the stakeholder involvement process.

*Back:* Click the back button to return to the previous screen to make further modifications to the input or to check on the information entered, any modifications made to either the current page before moving to the previous screen or any changes made to the previous screen are made in the tool record. This allows mistakes or omissions to be corrected at any time when using the tool.

*Next:* Click the next button once the screen has been completed to move to the next screen.

## 4. Problem Formulation Screen T1, T2 and T3

It is important to note that the problem formulation text boxes or conceptual model (see Conceptual Model Section 10.5 below) are not linked in any way to the modelling that is conducted within the assessment tool. **The problem formulation/conceptual model is a theoretical evaluation of the situation under assessment and as such is used to ensure that all the relevant reference organisms or user-defined organisms etc are incorporated into the assessment.** However, you as the user have to enter the relevant information in the following screens of the assessment tool.

Therefore the problem formulation/conceptual model is used to:

- help to explain and support the decisions made by the assessor when determining, for example, what activity concentrations to input into the assessment tool; and to
- help to explain to any potential stakeholders how the problem under assessment has been defined.

It is expected that, wherever a site-specific conceptual model exists, this should be used in preference to the modification of one of the generic conceptual models provided with the assessment tool. However comparing the conceptual model with the simplifying assumptions and derivations made within the tool may provide insight into the limitations and uncertainties associated with the ERICA approach.

*Provide a detailed description of the assessment:* Information that could be entered in this dialogue box might include:

- specifications concerning the industrial site activity and its concomitant discharge regime (which radionuclides, how they will be released);
- for retrospective assessments you might need to consider the quality of the data available (e.g. when it was produced, instrumentation used, quantity, appropriateness of the data to the assessment under consideration);
- for prospective assessments you might need to consider the type of model to use to predict the environmental concentrations, the type of information to be included in the model, the robustness of the model and the outputs and you might need to consider the availability of existing data on the environmental concentrations of radionuclides;
- presence of other non-radioactive contaminants in the discharges;
- information on the receiving medium, i.e. characterise the area into which discharges will occur and to state whether the area has been exposed to inputs of contamination historically (and if so at what level);
- a description of the ecosystem, its dynamics, the presence of migrant species or prey species which should be considered in order to ensure protection of key or feature species, the stability of the ecosystem and whether it is necessary to consider how two or more ecosystems might be combined for say a flooding event;
- a list of any specific legal/regulatory considerations that need to be addressed.

*List the transfer pathways and your assessment endpoints:* In this dialogue box you should draw upon and record your knowledge related to:

- the behaviour and fate of radionuclides in the receiving environment drawing upon published data and/or modelling work to describe how the contaminants are likely to disperse and where in the environment they will concentrate;
- are the activity concentrations to be used based on measurements, transport models using concentrations for points or zones of mixing (Section 10.3) or spatially or temporally averaged data sets (Section 10.13 & 10.15).
- protection of individuals within a species (often one which is rare or endangered);
- protection of a population of an individual species; and/or
- protection of populations, maintain of biodiversity.

Often the assessment endpoint will be defined in legislation or by agreement with stakeholders. Implementation will however vary depending upon the tier of the assessment and the assessor should explain how their assessment endpoint will be addressed within a particular tier. In Tier 1 though it is important to note that the tool-specific assessment endpoints are, to a large extent, predefined and, under default conditions, are limited to the suite of ERICA reference organisms (**Table 5**).

*Attach illustration of a conceptual model:* By clicking the *Browse* button you will be given access to a normal windows dialog box from within which you can locate a file containing a conceptual model. The file can be in Word, Excel, an image file, text file etc.. Further details on how to derive a conceptual model are provided below. You might decide that you will complete all the problem formulation description within the conceptual model file – if this is the case you are advised to upload the whole document to the tool *via* this link and to note this in the *detailed description of the assessment* text box.

*View:* Click this button to open up the conceptual model document using whatever software package was used to create it – please note that this might cause problems if you share your assessment files with another user who does not have the same software packages available to them.

*Back:* Click the back button to return to the previous screen to make further modifications to the input or to check on the information entered, any modifications made to either the current page before moving to the previous screen or any changes made to the previous screen are made in the tool record. This allows mistakes or omissions to be corrected at any time when using the tool.

*Next:* Click the next button once the screen has been completed to move to the next screen.

*Additional notes for Tier 2:*

At this Tier, you might decide to define a geometry based on the particular species of interest. However, there are potentially significant data requirements that may need to be addressed (in terms of providing the assessment tool with information on concentration ratios (CRs) for each radionuclide in the assessment for the new geometry, occupancy factors etc.). Alternatively you might have to provide information on how the reference organisms are to be used in the assessment to represent species of particular interest in the assessment. In both of these cases you should provide a justification for your choices here in this screen.

A final step in the analyses then requires the link between the user-defined and tool specific assessment endpoints to be identified. All of these steps should be documented. This dialogue box provides you with the opportunity to identify and record uncertainties related to the processes under study at least in a qualitative sense in Tier 2.

The protection endpoints, which may be referred to in legislation e.g. EU habitats Directive, need to be translated by you into user-defined assessment endpoints, e.g. populations of particular species present

at a site. So in this case, you might need to explain how the reference organisms can be used to demonstrate protection of an individual species for example, you might be trying to protect salmon. These could be described using the reference organism approach as a pelagic fish. Note that the tool will use the default settings for a pelagic fish (e.g. the default occupancy factors and CRs) however within Tier 2 you can modify these parameters for example if you have site-specific CRs for the radionuclides of interest in salmon.

#### *Additional notes for Tier 3:*

At this Tier, you might decide to define a geometry based on the particular species of interest. However there are potentially significant data requirements that may need to be addressed (in terms of providing the assessment tool with information on concentration ratios (CRs) for each radionuclide in the assessment for the new geometry, occupancy factors etc.). Alternatively you might have to provide information on how the reference organisms are to be used in the assessment to represent species of particular interest in the assessment. In both of these cases you should provide a justification for your choices here in this screen.

A final step in the analyses then requires the link between the user-defined and tool specific assessment endpoints to be identified. All of these steps should be documented. This dialogue box provides you with the opportunity to identify and record uncertainties related to the processes under study at least in a qualitative sense in Tier 2.

The protection endpoints, which may be referred to in legislation e.g. EU habitats Directive need to be translated by you into user-defined assessment endpoints, e.g. populations of particular species present at a site. So in this case, you might need to explain how the reference organisms can be used to demonstrate protection of an individual species. For example, within the ERICA assessment approach you might be trying to protect salmon. These could be described using the reference organism approach as a pelagic fish. Note that the tool will use the default settings within the tool for a pelagic fish (e.g. the default occupancy factors and CRs) however within Tier 3 you can modify these parameters for example if you have site-specific CRs for the radionuclides of interest in salmon. In addition to the use of site-specific single data points you also have the option to use distributions of data to help to refine the assessment to account for uncertainties in the data sets by conducting a probabilistic risk assessment.

An important consideration in the problem formulation stages of Tier 3 is to consider what your endpoint to the assessment might be and to attempt to define this in advance of the assessment being conducted. For example you might define a benchmark dose rate which if the assessment comes out below you consider that no further assessment is required. In this case you might need to engage with stakeholders on what might be an acceptable dose rate which you can use. You might also wish to make use of the FREDERICA radiation effects database in order to establish appropriate benchmark values by pulling out available effects data on a particular wildlife group and endpoint and generating a species sensitivity distribution (SSD) curve for this specific subset of data if this can be justified (full details of how to conduct an SSD from the FREDERICA data are given in ERICA Deliverable D5). Such choices/approaches need to be considered and documented here in the problem formulation stage prior to conducting the assessment.

## **5. Assessment Context Screen, all tiers**

### ***5.1 Default ecosystems, radionuclides and reference organisms***

You can select the ecosystem that is being considered in the assessment. There are three to choose from: freshwater, marine or terrestrial.

The full list of default radioisotopes supported by the tool is shown in Table 3 – these are available for direct use at all tiers.

**Table 3: List of default ERICA radionuclides**

<b>Element</b>	<b>Isotopes</b>	<b>Element</b>	<b>Isotopes</b>
Ag	Silver Ag-110m	Ni	Nickel Ni-59, Ni-63
Am	Americium Am-241	Np	Neptunium Np-237
Ba	Barium Ba-140	P	Phosphorus P-32, P-33
C	Carbon C-14	Pa	Protactinium Pa-231
Ca	Calcium Ca-45	Pb	Lead Pb-210
Cd	Cadmium Cd-109	Po	Polonium Po-210
Ce	Cerium Ce-141, Ce-144	Pu	Plutonium Pu-238, Pu-239, Pu-240, Pu-241
Cf	Californium Cf-252	Ra	Radium Ra-226, Ra-228
Cl	Chlorine Cl-36	Ru	Ruthenium Ru-103, Ru-106
Cm	Curium Cm-242, Cm-243, Cm-244	S	Sulphur S-35
Co	Cobalt Co-57, Co-58, Co-60	Sb	Antimony Sb-124, Sb-1255
Cr	Chromium Cr-51	Se	Selenium Se-75, Se-79
Cs	Caesium Cs-134, Cs-135, Cs-136, Cs-137	Sr	Strontium Sr-89, Sr-90
Eu	Europium Eu-152, Eu-154	Tc	Technetium Tc-99
H	Tritium H-3	Te	Tellurium Te-129m, Te-132
I	Iodine I-125, I-129, I-131, I-132, I-133	Th	Thorium Th-227, Th-228, Th-230, Th-231, Th-232, Th-234
Ir	Iridium Ir-192	U	Uranium U-234, U-235, U-238
La	Lanthanum La-140	Zn	Zinc Zn-65
Mn	Manganese Mn-54	Zr	Zirconium Zr-95
Nb	Niobium Nb-94, Nb-95		

Radioactive daughter nuclides are included in the dose conversion coefficients of their parents, if their half-lives are shorter than 10 days. The daughter nuclides included are summarised in Table 4. Full details of the derivation of the DCCs are available in Section 10.6.

**Table 4: Daughter nuclides considered for the calculation of dose conversion factors**

Parent nuclide	Daughter nuclides considered to be in equilibrium with parent nuclide						
Sr-90	Y-90						
Ru-106	Rh-106						
Cs-137	Ba-137m						
Pb-210	Bi-210						
Ra-226	At-218	Po-218	Bi-214	Pb-214	Rn-222	Po-214	
Ra-228	Ac-228						
Th-228	Po-216	Tl-208	Bi-212	Pb-212	Rn-220	Po-212	Ra-224
Th-234	Pa-234m Pa-234						
U-235	Th-231						
Pu-241	U-237						

The default suite of reference organisms is shown in Table 5. These reference organisms are not explicitly reported at Tier 1 but have been used in the derivation of EMCL values. At tiers 2 and 3 selections of reference organisms can be made at the assessment context stage of the procedure.

**Table 5: List of default ERICA reference organisms**

<b>Freshwater</b>	<b>Marine</b>	<b>Terrestrial</b>
Amphibian	Benthic fish	Amphibian
Benthic fish	Bird	Annelid
Bird	Crustacean	Arthropod - detritivorous
Crustacean	Macroalgae	Bird
Insect larvae	Mammal	Flying insects
Mammal	Mollusc - bivalve	Grasses & Herbs
Mollusc - bivalve	Pelagic fish	Lichen & Bryophytes
Mollusc - gastropod	Phytoplankton	Mammal - large
Pelagic fish	Polychaete worm	Mammal - small-burrowing
Phytoplankton	Reptile	Mollusc - gastropod
Reptile	Sea anemones & True coral	Reptile
Vascular plant	Vascular plant	Shrub
Zooplankton	Zooplankton	Tree

## 5.2 Screening dose-rates and generic transport models – T1 & T2

At the assessment context stage of tiers 1 and 2 there are 3 dose rate screening values ( $\mu\text{Gy h}^{-1}$ ) that can be selected.

- ERICA's default incremental screening dose rate value of  $10 \mu\text{Gy h}^{-1}$  for all ecosystems which was derived in ERICA Deliverable D5 and a summary of which is available in [Table 9](#).
- $40 \mu\text{Gy h}^{-1}$  for terrestrial animals or  $400 \mu\text{Gy h}^{-1}$  for terrestrial plants. For aquatic species a value of  $40 \mu\text{Gy h}^{-1}$  is applied to mammals, reptiles, amphibians and birds or  $400 \mu\text{Gy h}^{-1}$  for all other species. These numbers are derived from the IAEA (1992) and UNSCEAR (1996) reports and are really benchmarks below which populations are unlikely to be significantly harmed based on reviews of the scientific literature. These also correspond to the US DoE dose limit of  $10 \text{ mGy/d}$  ( $\approx 400 \mu\text{Gy h}^{-1}$ ) for native aquatic animals and benchmarks of 400 and  $40 \mu\text{Gy h}^{-1}$  for terrestrial plants and terrestrial animals, respectively, (based on the intent of appropriate DoE orders as no dose limits statutory dose limits were in place as of 2006) as used in the US DoE's graded approach (US DoE, 2002).
- User defined value (you can enter your own numbers into this option). If you enter your own screening dose rate for use in the assessment you should ensure that you have justified its selection during the description of the problem formulation stages. You should also be aware that the tool deals with your user defined value by scaling the results of the risk quotients from the calculations made using the environmental media concentration limits (EMCLs) derived from the default ERICA value of  $10 \mu\text{Gy h}^{-1}$ . For example, if you have defined a screening dose-rate of  $20 \mu\text{Gy h}^{-1}$ , the tool simply divides the risk quotients by a factor of 2.

Generic models are available for deriving activity concentrations in various environmental media. This is explained in more detail in Section 10.14.

## 6. Tier 1 specific issues

### 6.1 T1 Assessment Context Screen

Within this screen, you should select the radionuclides that should be considered in the Tier 1 assessment, the ecosystem in which the radionuclides are being considered and whether you will be entering site-specific media concentrations or using simple, conservative transport models.

*Radionuclide list:* You should select the radionuclides to be considered from the list by scrolling up and down the list, clicking on the appropriate radionuclide(s) (the radionuclide will be highlighted with a blue bar once it is selected). To select more than one radionuclide use either the CTRL or SHIFT key in combination with the mouse clicks. To select multiple individual (i.e. not given adjacent to each other in the list) radionuclides then use the CTRL key. To select a number of radionuclides that are adjacent to each other in the list use the SHIFT key to select the first and then last radionuclide in the group to be highlighted.

Once you have highlighted the radionuclide(s) to be included in the assessment, use the button with the ">" symbol to 'move' the radionuclide(s) to the "selected" column. If you wish to select all the radionuclides in the list you can use the button with the ">>" symbol as a shortcut to moving all radionuclides to the selected list. Likewise if you wish to deselect one or more radionuclides from the selected list you can use the mouse with the CTRL or SHIFT key as above to select one or more radionuclides and then use the button with the "<" symbol to deselect the radionuclide(s). There are 71 radionuclides to choose from within the Tier 1 assessment (see **Table 3**).

If a radionuclide is selected and later removed from your assessment list it will appear at the bottom of the 'select from' listing.

Environmental Media Concentration Limits (Section 10.7) will be available that have been derived from the analyses of different ecosystem-specific reference organism lists as shown in **Table 5**. It should be noted that these lists are not shown explicitly at Tier 1.

The next radial button selection on the screen is used to select the *dose rate screening values* ( $\mu\text{Gy h}^{-1}$ ). There are three choices to select from as described in Section 5.2.

The dose rate screening values have been used, in conjunction with the default data and settings within the ERICA assessment tool, to back calculate to environmental media concentration limits (EMCLs) outside the tool. The databases containing these values for each ecosystem have been incorporated within the tool and are accessed at Tier 1 during the derivation of risk quotients. The full derivation of the EMCLs is given below (Section 10.7). Furthermore the numeric values for EMCLs derived using the ERICA screening dose rate are provided within this help function – see EMCL Tabulated Values (Section 10.19)

Selecting the “*use site-specific media concentration*” radial button will bring up the site-specific media concentration entry screen after clicking the *next* button.

Selecting the “*use IAEA SRS-19 models*” radial button will bring up a series of screens after clicking the *next* button. The content of the next screens will vary with the model selected. After selecting the “*use IAEA SRS-19 models*” radial button you will need to select the transport model to use from the adjacent drop-down box. Please note that the choices available within the drop down box are limited to the transport models appropriate to the *ecosystem* selected earlier.

*Back*: Click the back button to return to the previous screen to make further modifications to the input or to check on the information entered, any modifications made to either the current page before moving to the previous screen or any changes made to the previous screen are made in the tool record. This allows mistakes or omissions to be corrected at any time when using the tool.

*Next*: Click the next button once the screen has been completed to move to the next screen.

International Atomic Energy Agency (IAEA) (1992). Effects of ionising radiation on plants and animals at levels implied by current radiation protection standards. Technical Reports Series No. 332. Vienna: International Atomic Energy Agency.

UNSCEAR (1996). *Sources and effects of ionizing radiation*. Report to the general assembly with scientific annex A/AC.82/R.54; United Nations: Vienna, Austria, 1996.

US DoE (US Department of Energy) (2002). *A graded approach for evaluating radiation doses to aquatic and terrestrial biota*. Technical Standard DoE-STD-1153-2002. Washington DC, USA.

## **6.2 T1 Input Values**

In this screen you are asked to enter the media concentration for each radionuclide selected in the assessment context screen. Depending upon the ecosystem selected in the assessment context screen you will be asked to enter information in the following format:

- Terrestrial ecosystems: activity concentration in soil ( $\text{Bq kg}^{-1}$  dry weight) or for radioisotopes of C, S, P or H in air ( $\text{Bq m}^{-3}$ );
- Aquatic ecosystems: activity concentrations in water ( $\text{Bq l}^{-1}$ ) or sediment ( $\text{Bq kg}^{-1}$  dry weight) or both.

These values should be typed in to the appropriate cell by clicking into the cell, entering the number and either pressing the return key, using the cursor keys to move up or down to the next cell or double clicking a different entry. Please note that it is possible to edit numbers once they have been entered but you should be aware that clicking into a cell does not necessarily replace the value already there.

You must clear the contents of the cell using the delete or backspace key in order to replace the existing number.

Maximum available media activity concentrations are suggested for this Tier unless an alternative can be justified. Values to be input should be justified within the problem formulation.

*Back:* Click the back button to return to the previous screen to make further modifications to the input or to check on the information entered, any modifications made to either the current page before moving to the previous screen or any changes made to the previous screen are made in the tool record. This allows mistakes or omissions to be corrected at any time when using the tool.

*Next:* Click the next button once the screen has been completed to move to the Results screen. Note you will only be able to use this button once you have entered a value into each of the selected radionuclide input cells.

### **6.3 T1 Results**

On this screen you will see several tabs which identify the different windows as follows:

- Risk;
- Tables;
- Plots; and
- Record Decision.

The first 3 tabs (risks, tables, plots) contain different information to help you to make a decision regarding the results of the Tier 1 assessment. Each window is described below.

*Back:* Click the back button to return to the previous screen to make further modifications to the input or to check on the information entered.

*Record Decision:* Note that the ‘*Next*’ button is unavailable from this screen instead click the ‘*record decision*’ button once the screen has been completed to move to the final screen in this Tier where you will be asked to complete a series of free form text boxes where we recommend that you record the output of the assessment along with any comments that you might have as the assessor (e.g. you might identify areas for future refinement in the assessment or where new data is required before the assessment continues to Tier 2). Finally we suggest that you record either your decision regarding the assessment (i.e. do you end or continue the assessment) or if you are not the decision-maker then what you recommend should happen at this stage to help inform the decision-maker. Further details are given below (9. Record Decision – T1, T2 and T3.).

#### **6.3.1 Risk**

At Tier 1 the radionuclide activity concentrations in the soil, water or sediment that you entered either through the use of a model or as site-specific values are compared with Environmental Media Concentration Limits (EMCLs), the derivation of which is given elsewhere (Section 10.7) along with the numeric values under the section EMCL tabulated values (Section 10.19). This produces a risk quotient for each specific radionuclide selected for inclusion in the assessment. The risk quotient (RQ) is defined by:

$$RQ_n = \frac{M_n}{EMCL_n}$$

Where:

$RQ_n$  = Risk quotient for radionuclide “n”;

$M_n$  = measured activity concentration for radionuclide “n” in medium M in Bq l<sup>-1</sup> for water, Bq kg<sup>-1</sup> for soil or sediment or Bq m<sup>-3</sup> for air;

EMCL<sub>n</sub> = Environmental Media Concentration Limit for radionuclide “n” (same units) and defined elsewhere.

Note that the RQ values are unitless.

In the case of the terrestrial environment, the data provided by the assessor and the EMCL always refer to soil activity concentrations, except for isotopes of H, C, S and P which refer to air concentrations. In the case of the aquatic systems data can refer to either water or sediment activity concentrations. You are reminded that you can select the radionuclides to be considered in the assessment and the ecosystem type (terrestrial, marine or freshwater) but not the reference organism suite at Tier 1.

A single EMCL value is provided for each combination of radionuclide and environmental media (water, sediment and soil). These correspond to the lowest (*limiting media concentration*) values taken from across the whole suite of ERICA reference organisms (i.e. which will return the highest radionuclide specific RQ value) for each individual radionuclide. The RQs are then summed for all radionuclides that you included in the assessment.

You should note, however, that this approach means that when summing RQs across the radionuclides present in a given situation, the limiting reference organism may not be the same for each radionuclide (see Table 6). Although this approach might be deemed overly-conservative, it has been selected because

- it is reasonably consistent with other assessment approaches currently available (e.g. USDoE, 2002);
- provides only a single EMCL value for each radionuclide and can thus be considered simple; and
- does not lead to the suggestion that we have a greater detail of information than we actually have, reflecting the fact that for some of the radionuclide/reference organism combinations we have very little data.

If the sum of the risk quotients is <1, then it can be assured that there is a very low probability that the assessment dose rate to any organism exceeds the incremental screening dose rate and therefore the risk to non-human biota can be considered negligible. In the Risk screen, the individual RQ values are marked as follows:

- in the colour red if the value is greater than 1;
- the  $\sum$ Risk Quotients value will be in red if  $\geq 1$ .

The tool reports back a comment/recommendation based on whether the  $\sum$ Risk Quotients is <1 (below the screening dose-rate) or  $\geq 1$  (red, recommend continue the assessment to the next Tier).

**Table 6: Approach that is used for summing RQs at Tier 1 (note values in black above do not appear in risk summary within the tool)**

RQs			$\sum$ RQ
Cs-137	Po-210	Ra-226	

Zooplankton	0.10	0.2	0.35
Mollusc - bivalve	0.12	0.36	0.02
Polychaete worm	0.41	0.01	0.02
Vascular plant	0.14	0.03	0.05

## 1.12

The EMCLs derived at Tier 1 can be considered as conservative estimates in view of the fact that a screening dose-rate and the 95th percentile of the “F” value are used as described elsewhere (Section 10.7).

Note that, in the aquatic ecosystems, the RQ generated is that which is most conservative from either the sediment or water EMCL value depending upon how the media activity concentrations were entered as follows:

- If a water activity concentration only was input, then the RQ reported is based on the comparison of the water activity concentration with the EMCL derived for water;
- If a sediment activity concentration only was input, then the RQ reported is based on the comparison of the water activity concentration with the EMCL derived for sediment;
- If both water and sediment activity concentrations are provided, then the tool calculates the RQ for water and sediment separately against the respective EMCL (water or sediment) and then determines which of these two RQ values is more conservative and then it reports this value. However the tool does not tell you whether water or sediment activity concentrations result in the most conservative RQ. However, it is possible to determine this from but if this information is needed then it is possible to calculate this from the Tables or Plots tabs.

Note that the chemical toxicity of isotopes of U and Th will contribute to, and in some cases dominate, the risk to organisms. The ERICA Integrated Approach considers the radiological exposure only and hence will underestimate risk for such radionuclides.

### 6.3.2 Tables

Within the ‘*Tables*’ window, you are able to review both the input, output and parameter values used within the Tier 1 assessment. You can move the split in the window between the assessment data component of the window and the location where the information is displayed by placing the cursor over the split bar until you see the following symbol (←→). You can then click the left mouse button and, while holding the left mouse button down, drag the bar to the left or right to adjust the split on the window between these two areas. This is useful, for example, to expand the ‘*Assessment data*’ section so that you can read the full description of the options for the tables.

#### *Inputs:*

The exact composition of the available information will vary depending upon how the assessment has been set up earlier in the tool. For example, in the inputs section you will be presented with different options depending upon whether you are investigating a terrestrial or aquatic ecosystem. The input values are those that you either entered or were modelled using the appropriate SRS-19 model.

When your inputs have been based on site-specific media concentrations (normally empirically-derived but may be from bespoke models), the following options will be available:

- For an aquatic system: Activity concentrations in water and/or sediment

- For a terrestrial system: Activity concentration in soil or for isotopes of H, C, S and P in air

If you have used the SRS-19 models then this section will present the input variables that were entered for the implementation of the model.

Accessing the input values might be useful if you need to use these data elsewhere outside of the ERICA assessment tool. You can also check that the user defined inputs, i.e. activity concentrations or IAEA SRS-19 model variables have been entered and recorded correctly.

#### *Outputs:*

The outputs at Tier 1 also depend on whether you have selected input data in the form of site-specific media concentrations or simulated using the IAEA SRS-19 models. In the former case, the output will provide a basic summary of the risk quotient values and the sum of the risk quotients. There is no additional information provided here that you have not seen on the Risk window but structuring the data in this way simply allows the assessor to see clearly the distinction between information entered as input and those data calculated as output. In the latter case, accessing the tables allows the assessor to see information pertaining to activity concentrations in environmental media, i.e. the output data from the IAEA-SRS-19 models in addition to calculated risk quotients.

One key point though is that you can sort the RQ values in ascending/descending order and thus identify those radionuclides which are contributing the most to the  $\sum RQ$ . This might help you to identify radionuclides that, if you gathered more data or focused on their behaviour in the environment, might provide an extra insight into a revised assessment if needed.

#### *Parameters:*

As with the input values this section will vary depending upon the set up of the assessment and depends primarily on whether you have selected a terrestrial or aquatic ecosystem for the assessment. When you have provided the site-specific input values, this table essentially contains the EMCL values for the combination of radionuclides, ecosystem and incremental screening dose rate that was set earlier in the assessment tool. If you have used the IAEA SRS-19 models then additional parameter information is provided too. For example, you will also see the radioactive decay constant. Here you can see the actual activity concentration that was used to determine the RQ values. The ECML value shown for each radionuclide is that for the limiting organism for each radionuclide in your assessment at the screening level you selected.

### 6.3.3 Plots

Within the 'Plots' window, you are able to review the input, output and parameter values used within the Tier 1 assessment but in this case as a series of graphs. Note you can move the split in the window between the assessment data component of the window and the location where the information is displayed by placing the cursor over the split bar until you see the following symbol ( $\leftrightarrow$ ). You can then click the left mouse button and, while holding the left mouse button down, drag the bar to the left or right to adjust the split on the window between these two areas. This is useful, for example, to expand the 'Assessment data' section so that you can read the full description of the options for the tables.

It is also possible to resize the plot as required by dragging the mouse cursor over the figure (if you draw a box on the plot over the region of interest it will zoom in, if you drag the mouse cursor from left to right the plot will zoom out). It is also possible to click the right mouse button and this will bring up a mouse menu that allows you to zoom in/out, save and print the plot.

#### *Inputs:*

The exact composition of the available information will vary depending upon how the assessment has been set up earlier in the tool. The input values are those that you either entered or were modelled using the appropriate SRS-19 model.

When your inputs have been based on site-specific media concentrations (normally empirically-derived but also from bespoke models), the following options will be available:

- For an aquatic system: Activity concentrations in water and/or sediment
- For a terrestrial system: Activity concentration in soil or air

If you have used the SRS-19 models then this section will present the input variables that were entered for the implementation of the model.

Accessing the input values might be useful if you need to use these data elsewhere outside of the ERICA assessment tool. You can also check that the user defined inputs, i.e. activity concentrations or IAEA SRS-19 model variables have been entered and recorded correctly.

#### *Outputs:*

The outputs at Tier 1 also depend on whether you have selected input data in the form of site-specific media concentrations or simulated using the IAEA SRS-19 models. In the former case, the output will provide a basic summary of the risk quotient values and the sum of the risk quotients. There is no additional information provided here that you have not seen on the Risk window but structuring the data in this way simply allows the assessor to see clearly the distinction between information entered as input and those data calculated as output. In the latter case, accessing the tables allows the assessor to see information pertaining to activity concentrations in environmental media, i.e. the output data from the IAEA-SRS-19 models in addition to calculated risk quotients. You are advised to check that these outputs are reasonable in terms of available measured data from other similar operations to the one being assessed.

#### *Parameters:*

As with the input values this section will vary depending upon the set up of the assessment and depends primarily on whether you have selected a terrestrial or aquatic ecosystem for the assessment. Essentially, this table contains the EMCL values for the combination of radionuclides, ecosystem and incremental screening dose rate that was set earlier in the assessment tool. Here you can see the actual activity concentration that was used to determine the RQ values.

## 7. Tier 2 specific issues

### 7.1 T2 Assessment Context

Within this screen, you should select the radionuclides that should be considered in the Tier 2 assessment, the ecosystem in which the radionuclides are being considered and whether you will be entering site-specific media concentrations or using simple, conservative transport models.

#### 7.1.1 Select Radionuclides

*Radionuclide list:* You should select the radionuclides to be considered from the list by scrolling up and down the list, clicking on the appropriate radionuclide(s) (the radionuclide will be highlighted with a blue bar once it is selected). To select more than one radionuclide use either the CTRL or SHIFT key in combination with the mouse clicks. To select multiple individual (i.e. not given adjacent to each other in the list) radionuclides then use the CTRL key. To select a number of radionuclides that are adjacent to each other in the list use the SHIFT key to select the first and then last radionuclide in the group to be highlighted.

Once you have highlighted the radionuclide(s) to be included in the assessment, use the button with the “>” symbol to ‘move’ the radionuclide(s) to the “selected” column. If you wish to select all the radionuclides in the list you can use the button with the “>>” symbol as a shortcut to moving all radionuclides to the selected list. Likewise if you wish to deselect one or more radionuclides from the selected list you can use the mouse with the CTRL or SHIFT key as above to select one or more radionuclides and then use the button with the “<” symbol to deselect the radionuclide(s). There are 71 radionuclides to choose from within the Tier 2 assessment (see **Table 3**).

#### 7.1.2 Select Reference Organisms

*Ecosystem:* From this drop down list you can select the ecosystem that is being considered in the assessment. There are three to choose from: freshwater, marine or terrestrial. Depending upon your selection, different reference organism lists will be selected for use in the Tier 2 assessment.

*Organisms:* Once you have selected the ecosystem to use the appropriate reference organism list will be provided in the ‘Select from’ box. Using the mouse you can then highlight those reference organism(s) to be included in the assessment, use the button with the “>” symbol to ‘move’ the reference organism(s) to the “selected” column. If you wish to select all the reference organisms in the list you can use the button with the “>>” symbol as a shortcut to moving all reference organisms to the selected list. Likewise, if you wish to deselect one or more reference organisms from the selected list you can use the mouse with the CTRL or SHIFT key as above to select one or more reference organisms and then use the button with the “<” symbol to deselect the reference organism(s).

In addition to the default list of reference organisms (**Table 5**) you can also choose to create your own geometry for an organism for inclusion in the assessment. This is done by clicking the ‘Add organism’ button which is available underneath the list of reference organisms to select from. Full details of how to add a new reference organism are given in Section 10.2. Once the new geometry has been created using the ‘add new organism wizard’ it will appear in the reference organism list to select from and will need to be selected as described above. As the details of the new geometry are added to your own user defined database it will be available for use in other assessments that you conduct. Please note however that you still need additional information for the new geometry as you will be prompted for concentration ratios and occupancy factors within the tool. If you select a user defined geometry within the assessment but then do not have appropriate concentration ratios or occupancy factors available the assessment will not be able to continue at later screens. Further advice on this is given in the Add New Organism wizard help (Section 10.2).

#### 7.1.3 Dose rate screening values

The next radial button selection on the screen is used to select the *dose rate screening values* ( $\mu\text{Gy h}^{-1}$ ) as explained above (Section 5.2).

#### 7.1.4 Uncertainty factors

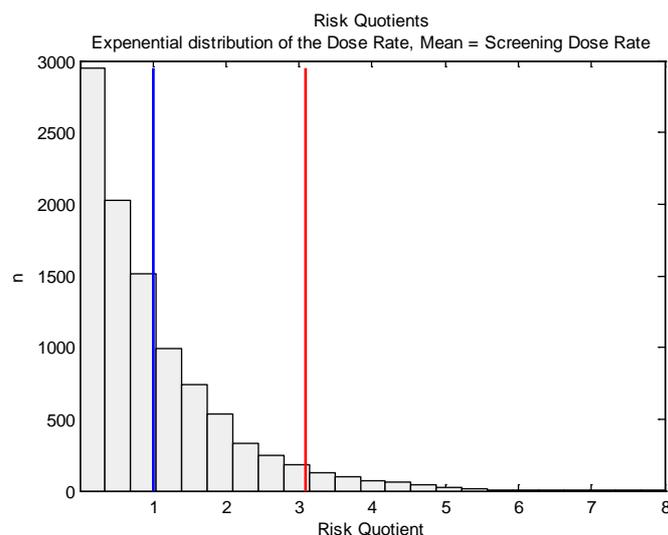
The objective of Tier 2 is to identify situations where there is a very low probability, for example a few percent, that the dose to any selected reference organism exceeds the adopted screening dose rate.

The screening test in Tier 2 is designed in the following way:

1. An expected value of the RQ is calculated using expected values for the input data and the parameters.
2. The 95<sup>th</sup> or 99<sup>th</sup> percentile of the RQ are estimated by multiplying the expected value of the RQ by an uncertainty factor (UF). The uncertainty factor is defined as the ratio between the 95<sup>th</sup>, 99<sup>th</sup> or any other percentile (above the expected value) and the expected value of the probability distribution of the dose rate (and RQ). To estimate the UF it is assumed that the dose rate and the RQ follow exponential distributions with means equal to the estimated expected values. In this case the UFs corresponding to the 95<sup>th</sup> and 99<sup>th</sup> percentiles are equal to 3 and 5 respectively.

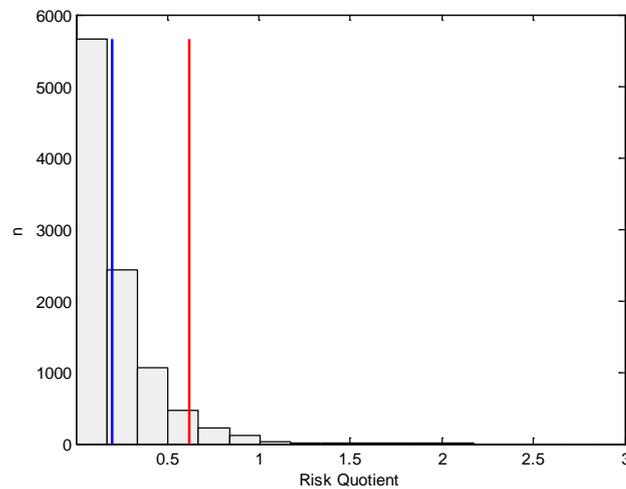
The UFs also maintain conservatism between Tiers 1 and 2. With the same input values and default settings, then the results for Tiers 1 and 2 should approximate to one another, because, essentially the user will not have thought in more detail about the problem they are facing and has not amended the problem formulation accordingly. The use of the UF=3 (i.e. 95<sup>th</sup> percentile) option results in conservative RQ estimates compatible with the results of Tier 1 (the EMCL value being derived from the 95<sup>th</sup> percentile F value).

Figure 1 shows the probability distribution of the RQ obtained from a Monte Carlo simulation, assuming that the estimated dose rate follows an exponential distribution with a mean value of  $10 \mu\text{Gy h}^{-1}$ , equal to the ERICA screening value. The blue vertical line represents the expected value, in this case equal to 1, whereas the red line corresponds to the 95<sup>th</sup> percentile. The ratio between the 95<sup>th</sup> percentile and the expected value, i.e. the UF, is equal to 3 for this and any exponential distribution.



**Figure 1** Probability distribution of the Risk Quotients obtained for the case when the dose rate follows an exponential distribution with a mean value equal to the screening dose rate. The vertical red and blue lines correspond to the 95<sup>th</sup> percentile and expected value of the RQ respectively

Under these assumptions and selecting a UF = 3, if the estimated expected value multiplied by the UF is equal to or lower than one, then the probability that the RQ exceeds 1 is equal to or lower than 5%. This is the same as saying that the probability of the estimated dose rate exceeding the screening dose rate is equal to or lower than 5%. An example of such a situation is presented in Figure 2, which shows the distribution of RQs that is obtained if it is assumed that the dose rate follows an exponential distribution with a mean of  $2\mu\text{Gy h}^{-1}$  and again using the screening dose rate of  $10\mu\text{Gy h}^{-1}$ . The 95<sup>th</sup> percentile of the RQ equals 0.6 in this case.



**Figure 2** Probability distribution of the Risk Quotients obtained for the case when the dose rate follows an exponential distribution with a mean value equal to  $2\mu\text{Gy h}^{-1}$  and assuming an incremental screening dose rate of  $10\mu\text{Gy h}^{-1}$ . The vertical red and blue lines correspond to the 95<sup>th</sup> percentile and expected value of the RQ respectively. It can be concluded that the probability that the dose rate is above 1 is below the accepted level, in this case 5%

The way in which this information is subsequently used in assessing whether the dose-rate fall above or below the screening benchmarks is described in Section 7.6.1.

The tool also allows the assessor to provide their own UF value. The user-defined UF may be substantially lower than the default settings, for example, when many site-specific data are available there may be some justification for refining the value. Such calculations require knowledge of the distribution of the RQ and propagation of the uncertainties in the dose calculations. In most cases, the RQ will be log-normally distributed and a simple equation for the UF, as a function of the coefficient of variation of the RQ can be obtained. The coefficients of variation can be estimated from the standard deviation of the input data and parameter values, either analytically or by Monte Carlo simulations. This should be considered as an advanced user option.

#### 7.1.5 Choose to use transport models or site-specific data

Selecting the “*use site-specific media concentration*” radial button will bring up the site-specific media concentration entry screen after clicking the *next* button.

Selecting the “*use IAEA SRS-19 models*” radial button will bring up a series of screens after clicking the *next* button. These models are described in Section xxx.

*Back:* Click the back button to return to the previous screen to make further modifications to the input or to check on the information entered, any modifications made to either the current page before moving to the previous screen or any changes made to the previous screen are made in the tool record. This allows mistakes or omissions to be corrected at any time when using the tool.

*Next:* Click the next button once the screen has been completed to move to the next screen.

## 7.2 T2 Radioecology Parameters

Depending upon whether you are working on a terrestrial or aquatic ecosystem you will see different tabs available here. For aquatic ecosystem assessments you will see two tabs:

- Distribution coefficient ( $K_d$ ) ( $l\text{ kg}^{-1}$ )
- Concentration ratio (CR) ( $\text{Bq kg}^{-1}$  (fresh weight) per  $\text{Bq l}^{-1}$ )

For terrestrial ecosystem assessments you will see one tab:

- Concentration ratio (CR) ( $\text{Bq kg}^{-1}$  (fresh weight) per  $\text{Bq kg}^{-1}$  soil (dry weight)) or  $\text{Bq m}^{-3}$  air (radioisotopes of H,C,S and P))

### 7.2.1 Distribution Coefficients Screen

A distribution coefficient defines the partitioning of the radionuclide of interest between the dissolved and solid phases. In other words it determines the water concentration if sediment concentrations are known and *vice versa*.

#### **Reviewing the parameter values**

On this screen you will be presented with the default information available within ERICA on the distribution coefficients for those radionuclides in ERICA that have been selected within the assessment you are conducting. Here you can review the numbers available by clicking once on to the cell containing the distribution coefficient of interest to you. Underneath the nuclide/distribution coefficient section of the screen you can then read the value and, in the comment box, the reference source where the default ERICA values have been derived from.

The majority of the distribution coefficients have been derived from compilations of data by the IAEA as follows:

- For freshwater ecosystems:
  - IAEA (2001) Generic Models for Use in Assessing the Impact of Discharges of Radioactive Substances to the Environment. IAEA Safety Reports Series 19. STI/PUB/1102 216pp.;
  - Coppelstone et al. (2001): Coppelstone D., Bielby S., Jones S.R., Patton D., Daniel P. and Gize I. (2001). Impact Assessment of ionising radiation on wildlife. R&D Publication 128. ISBN 1 85705590. Environment Agency, Bristol.
  - IAEA Technical Report Series-472
- For marine ecosystems:
  - IAEA, 2004. Sediment distribution coefficients and Concentration Factors for biota in the Marine Environment, Technical Reports Series No. 422, (International Atomic Energy Agency, Vienna, 2004).

#### **Editing the parameter values**

If you have site-specific information or alternative reference sources you may edit or change the default distribution coefficient by double clicking the cell of the number you would like to change. If you edit or change a number you should also record the source of the information into the comment box which is now editable as well (e.g. to say the data is from site-specific measurements).

**Please note** that if you have added a new organism geometry to the assessment you must ensure that a value is now recorded in the appropriate Kd value cells for each radionuclide in the assessment. The tool will not allow you to progress with the assessment unless all the Kd/radionuclide cells are filled.

If there is a data gap in the information in this screen then the tool prompts you by providing some information on where the gap is and the 'Next' button is unavailable.

**Note** that when you edit the cells in the tool if you do not double click the cell and select the existing number then when you type the new number that you wish to add these will be added to the end of the existing number. So if a cell contains the number 1 and you simply highlight the cell and type in 10 then the resulting number will be 101 **NOT** 10. **To edit a number you must double click the cell and then either highlight the number with the mouse or use the backspace key to delete the existing number.**

### 7.2.2 Concentration Ratios Screen

On this screen you will be presented with the default information available within ERICA on the concentration ratios (CRs) for those radionuclides and reference organisms in ERICA that have been selected for use in the assessment that you are conducting. You are likely to see that there are gaps in the matrix where no information is available and why and how this may be dealt with is described below.

The activity concentrations of radionuclides in biota within the ERICA tool are predicted from media activity concentrations using equilibrium CRs. The definitions of CR for the ERICA ecosystems are:

#### *Terrestrial*

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

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

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

#### *Aquatic*

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

Where possible the required reference organism-radionuclide CR values within the ERICA tool have been derived from a review of original publications (10.4). However, for many of the reference organism-radionuclide combinations there are no reported data from which to derive CR values. To provide estimates of CR for use within Tier 1 assessments the database originators followed an agreed approach. The values derived by these methods are identified within the Tier 2 CR values screen to allow the user to determine if they want to use them within their assessment or find alternatives. Within the default databases they are identified by numeric codes (below); the assumptions made in their derivation are listed in the default databases and also identified within the Tier 2 CR values screen.

The various options used to populate the default CR databases in the absence of reported values are described in the following text. The first four options (codes 1 - 4) were used in preference. With the

exception of the last two options described (codes 9 and 10), which were used as last resorts, the remaining options were applied depending upon availability of information (i.e. none were favoured more than others).

The approaches used by the ERICA project to provide default CR values when data were not available could also be used to help select CR values for newly defined reference organisms or added radionuclides within Tier 2 and 3 assessments.

*Selecting ERICA default CR values:*

<b>Code</b>	<b>Method used to derive ERICA default CR value when no empirical data</b>
1	<p><i>Use an available CR value for a similar reference within that ecosystem for the radionuclide under assessment</i></p> <p>Examples of application to derive default values in the ERICA databases are: applying macroalgae value to marine vascular plant; assuming pelagic fish value for benthic fish; assuming values for (e.g.) flying insects are applicable to other terrestrial invertebrate reference organisms. Note where there was more than one available value for different taxonomically similar reference organism then the highest available CR was generally used to provide missing values.</p>
2	<p><i>Use CR values recommended in previous reviews or derive them from previously published reviews</i></p> <p>In some instances, it was necessary to use broad reviews of stable element concentrations in media and biota to derive CR values or adopt previously recommended values without being able to go back to the source reference to confirm these.</p>
3	<p><i>Use a modelling approach</i></p> <p>This might include the use of Specific activity models to derive 3H and 14C CR values for all reference organisms in terrestrial ecosystems. Other approaches applied include kinetic allometric modelling.</p>
4	<p><i>Use an available CR value for the given reference organism for an element of similar biogeochemistry</i></p> <p>To derive default values in the ERICA databases this option involved the following: available CR for transuranic and lanthanide elements used if CRs are not available for another member of these series; Sr CR used for Ra (marine ecosystem only); Zr CRs used for Nb; Se CRs used for Te (terrestrial ecosystem only). Note where there was more than one available CR value for biogeochemical similar elements for the reference organism in question then the highest available value was generally assumed.</p>
5	<p><i>Use an available CR value for biogeochemically similar elements for a similar reference organism</i></p> <p>To derive default values in the ERICA databases examples of the use of this option are to: derive actinide element CR for marine reptiles by assuming the same value as for marine birds; provide Th CR values for terrestrial invertebrates from available U CRs; provide Zr CR values for terrestrial invertebrates from available Nb CRs.</p>
6	<p><i>Assume the highest available CR</i></p>

	To derive values for the ERICA default databases the use of this option was used on a few occasions only to provide: Po and Tc CR values for terrestrial invertebrate reference organisms; a small number of Ru and C CRs for freshwater reference organisms.
7	<p><i>Use an available CR value for a reference organism from an Estuarine ecosystem for the same reference organism in a marine environment</i></p> <p>A number of data from NIRS (Japan), although nominally estuarine, were from coastal marine locations where salinities were similar to those in the open sea. These provided suitable surrogate values.</p>
8	<p><i>Use highest animal CR value to derive appropriate CRs for another animal</i></p> <p>If there are no CR data available for a given animal but there are data for other (taxonomically) distantly related animals, the highest available animal value was selected for the sake of conservatism. An example might be a case where no data were available for fish, but CR data were available for mollusc and crustacean whereof mollusc provided the highest value. In this case the mollusc CR value would be selected.</p>
9	<p><i>Use highest plant/algae CR value to derive appropriate CRs for another plant/algae</i></p> <p>If there are no CR data available for a given plant/algae but there are data for other (taxonomically) distantly related animals, the highest available plant/algae value was selected for the sake of conservatism. An example might be a case where no data were available for phytoplankton, but CR data were available for macroalgae and vascular plant whereof vascular plant provided the highest value. In this case the vascular plant CR value would be selected.</p>
10	<p><i>Use a Combined method</i></p> <p>In some instances it was necessary to use combinations of the above approaches (e.g. assuming an allometrically derived CR value for a marine bird was applicable to a marine reptile). CR values derived using extrapolation methods were also defined under this category if methods were (including Bayesian approaches) to derive standard deviation values.</p>

### ***Reviewing parameter values***

You will therefore need to review the CRs available and where you agree with an approach taken above you should click the check box corresponding to the method code and short description as described above.

You can review individual values by clicking once on to the cell containing the number of interest to you. Underneath the radionuclide/CR section of the screen you can then read the value and, in the comment box, the reference source where the default ERICA values have been derived from.

### ***Editing parameter values***

You can also edit or replace individual values by clicking once on to the cell containing the number of interest to you. If you have site-specific information or alternative reference sources you may edit the default value by double clicking the cell of the number you would like to change. This makes the number editable. If you edit or change a number you should also record the source of the information into the comment box which is now editable as well (e.g. to say the data is from site-specific measurements). A wide range of reference sources have been used to derive the default CRs in the ERICA assessment tool.

Viewing the ERICA default databases, using the Database menu option, can provide you with further information on the default parameters values (e.g. number of data available to derive the default value) that may help you to judge if you should use them.

**Please note** that you will not be able to continue with the assessment if there is a blank cell on the concentration ratio tab because the tool will not be able to calculate the internal activity concentration for the organisms of interest without a CR value.

If there is a data gap in the information in this screen then the tool prompts you by providing some information on where the gap is and the 'Next' button is unavailable.

**Note** that when you edit the cells in the tool if you do not double click the cell and select the existing number then when you type the new number that you wish to add these will be added to the end of the existing number. So if a cell contains the number 1 and you simply highlight the cell and type in 10 then the resulting number will be 101 **NOT** 10. **To edit a number you must double click the cell and then either highlight the number with the mouse or use the backspace key to delete the existing number.**

*Back:* Click the back button to return to the previous screen to make further modifications to the input or to check on the information entered, any modifications made to either the current page before moving to the previous screen or any changes made to the previous screen are made in the tool record. This allows mistakes or omissions to be corrected at any time when using the tool.

*Next:* Click the next button once the screen has been completed to move to the next screen.

### ***7.3 T2 Occupancy Factors and Radiation Weighting Factors***

This screen allows you to modify the occupancy factors for each reference organism (or your own organism geometries). The row headings will be dependent on whether you are undertaking an aquatic or terrestrial ecosystem assessment:

For aquatic ecosystems your options are:

- Water-surface = this is for when an organism spends time say on the surface of the water (as a duck might for example)
- Water = this is for when a organism spends time swimming through the water column (e.g. a pelagic fish such as a salmon or trout)
- Sediment-surface = this is for when an organism spends time near the bottom of the water column (e.g. a benthic fish such as flounder or carp) or lives on the surface of the sediment (such as some macrophytes)
- Sediment = this is for when an organism spends time in the sediment (e.g. marine polychaete worms) and essentially is when they are buried in the sediment

For terrestrial ecosystems your options are:

- On-soil = this is for when an organism spends time on the surface of the soil for example when a mammal such as a mouse is foraging for food
- In-soil = this is for when an organism spends time in the soil (e.g. organisms like earthworms or a burrowing mammal) and essentially is when they are buried in the soil

- In-air = this is for when an organism spends time in the air and is essentially for flying organisms such as birds

For some reference organisms it is obvious that they can not spend time in one location type. For example, you would not have the ERICA reference large mammal geometry as being able to fly and therefore the in air option is unavailable. Of course you might need to conduct an assessment for a bat or something similar and then you may need to create your own geometry and add in the “in air” occupancy factor using the bird “specimen” option as the base geometry (see Section 10.2 Add Organism Wizard for further details).

To edit or replace an occupancy factor you should double click the cell for the reference organism/habitat that you would like to amend and then the cell becomes editable. You should also add an explanation of the changed value to the comment field below near the bottom of the screen so that someone else reviewing the assessment at a later stage will understand when the amended value has come from. All the values should be entered as a fraction. You should note that as it is not possible to spend more than 100% of your time in a particular ecosystem, the tool will prevent you from selecting values which add up to greater than 1 however it is possible to have a total occupancy that is less than 1 for example you might decide that, based on the spatial extent of the radionuclide contamination being assessed that a large organism such as a deer might have a much larger home range size than the contaminated area. In these circumstances you might be able to justify a lower occupancy than 1 to reflect the fact that the deer will only spend a proportion of their time in the contaminated area. This would need to be documented and described in the problem formulation screens.

On this screen it is also possible to amend the default ERICA radiation weighting factors which are 10 for alpha, 3 for low energy beta and 1 for other beta/gamma. Modifying these values is done by clicking into the relevant cell and amending the number. You are advised to document and describe your reasons for amending the radiation weighting factors in the problem formulation stage.

**Please note** that when you edit the cells in the tool, if you do not double click the cell and select the existing number then when you type the new number that you wish to add these will be added to the end of the existing number. So if a cell contains the number 1 and you simply highlight the cell and type in 10 then the resulting number will be 101 **NOT** 10. **To edit a number you must double click the cell and then either highlight the number with the mouse or use the backspace key to delete the existing number.**

*Back:* Click the back button to return to the previous screen to make further modifications to the input or to check on the information entered, any modifications made to either the current page before moving to the previous screen or any changes made to the previous screen are made in the tool record. This allows mistakes or omissions to be corrected at any time when using the tool.

*Next:* Click the next button once the screen has been completed to move to the next screen.

## **7.4 T2 Inputs**

The input screen allows you to enter the media or biota activity concentrations that you have collated for use in the assessment (note this screen is only available if you selected “use site-specific media concentrations” back on the Assessment Context screen otherwise you will be presented with the SRS-19 model parameter screen). You can enter the following depending upon the ecosystem selected:

For aquatic ecosystems:

- Enter water activity concentrations ( $\text{Bq l}^{-1}$ )

- Enter sediment activity concentrations (Bq kg<sup>-1</sup>, dry weight)
- Enter biota activity concentrations (Bq kg<sup>-1</sup>, fresh weight)

For terrestrial ecosystems:

- Enter soil activity concentrations (Bq kg<sup>-1</sup>, dry weight)
- Enter air activity concentrations (Bq m<sup>-3</sup>) for the isotopes of C, S, P and H
- Enter biota activity concentrations (Bq kg<sup>-1</sup>, fresh weight)

Depending upon the amount of data that you are able to enter the tool follows a set of user-defined rules the implementation of which is described below to calculate an input value for each radionuclide/reference organism combination included in the assessment. There must be an input activity concentration for each radionuclide/reference organism combination for the assessment to continue however the tool will deal with this for you provided that there is at least one activity concentration entered per radionuclide. The user-defined rules make use of the concentration ratios (CRs) (and for aquatic ecosystems the K<sub>d</sub> values) entered in the previous screen.

As the screen does not contain any numbers in the cells you can simply highlight the first cell that you wish to enter an activity concentration in and then type the number that you wish to enter. You can then use the cursor keys to move around the table to highlight the additional cells that you wish to enter data for. However **please note** that if you subsequently edit the cells you must **double click the cell and then either highlight the number with the mouse or use the backspace key to delete the existing number**. If you do not double click the cell and select the existing number then when you type the new number that you wish to add these will be added to the end of the existing number. So if a cell contains the number 1 and you simply highlight the cell and type in 10 then the resulting number will be 101 **NOT** 10.

Note whilst biota and water activity concentrations estimated via CRs and K<sub>d</sub>s require soil and sediment activity concentrations to be input on a dry weight basis, the estimation of external dose rates requires fresh weight activity concentrations. To enable a conversion to fresh weight activity concentrations you can enter a percentage dry weight sediment or soil value. Note if you do not have values for percent dry matter the assumption of 100% will lead to conservative (overestimated) dose rates.

You should note that when entering the data into the activity concentrations consideration needs to be given to how the data will be interpreted. For example, if you have 1000 crab concentrations and three plaice measurements then deriving a best estimate value for the water activity concentration based on a 1000 crab measurements may be arguably more robust than a best estimate for water based on three plaice measurements. In light of such considerations, the next step involving the 'Activity concentration rules selection' provides you with the opportunity to investigate and select which data are best suited in the process of filling data gaps.

*Back:* Click the back button to return to the previous screen to make further modifications to the input or to check on the information entered, any modifications made to either the current page before moving to the previous screen or any changes made to the previous screen are made in the tool record. This allows mistakes or omissions to be corrected at any time when using the tool.

*Next:* Click the next button once the screen has been completed to move to the next screen. Please note that you will not be able to press this button unless there is at least one data value entered in each row i.e. for each radionuclide included in the assessment you are conducting.

## ***7.5 T2 Activity concentration rules selection***

This screen allows you to select the values for those media and biota where you have data that will be used to calculate activity concentrations where you have no data.

### ***For freshwater and marine ecosystems***

In all cases where you have a water activity concentration datum (on its own or in combination with data for one or more organisms and/or sediment) this value will be used to calculate all other missing data via multiplication by appropriate  $K_d$ s or CRs. The cell showing a radionuclide activity concentration in water is highlighted in green and there is no option to select/deselect cells showing activity concentration values for sediment or organisms.

When you have no radionuclide activity concentration values in water but data for sediments and/or biota (whether for a single organism or many organisms), you can select which values will be used in the calculation of water activity concentrations and from that point all other missing data will be generated automatically via multiplication by appropriate  $K_d$ s or CRs. The selection is activated by clicking within any given cell where you have data. If the value is to be used in the subsequent calculation this will be denoted by a green tick and conversely, if the value is to be excluded from subsequent calculation, this will be denoted by a red cross. The calculation of the radionuclide activity concentration in water is performed within the tool by simply dividing the radionuclide activity concentration value by the corresponding  $K_d$ , in the case of sediment, or CR, in the case of biota. When multiple values are selected for this calculation, the result is based upon the average of the radionuclide calculated activity concentrations in water. Furthermore, the missing values are continually updated on the screen as the user selects and deselects the various values to be used in the calculation.

### ***For terrestrial ecosystems***

In all cases where you have a soil (or air) concentration (on its own or in combination with data for one or more organisms), this value will be used calculate all other missing data via appropriate CRs. The cell showing a radionuclide activity concentration in soil (or air) is highlighted in green and there is no option to select/deselect cells showing activity concentration values for organisms.

When you have no radionuclide activity concentration values in soil (or air) but data for biota (whether for a single organism or many organisms), you can select which values will be used in the calculation of soil concentrations and from that point all other missing data will be generated automatically via appropriate CRs. The selection is activated by clicking within any given cell where you have data. If the value is to be used in the subsequent calculation this will be denoted by a green tick and conversely, if the value is to be excluded from subsequent calculation, this will be denoted by a red cross. The calculation of the radionuclide activity concentration in soil (or air) is performed within the tool by simply dividing the radionuclide activity concentration value for the organism by the corresponding CR value. When multiple values are selected for this calculation, the result is based upon the average of the calculated radionuclide activity concentrations in soil (or air). Furthermore, the missing values are continually updated on the screen as the user selects and deselects the various values to be used in the calculation.

*Back:* Click the back button to return to the previous screen to make further modifications to the input or to check on the information entered, any modifications made to either the current page before moving to the previous screen or any changes made to the previous screen are made in the tool record. This allows mistakes or omissions to be corrected at any time when using the tool.

*Next:* Click the next button once the screen has been completed to move to the next screen. Please note that you will be able to press this button only if there is a data value in each cell.

## 7.6 T2 Results

On this screen you will see several tabs which identify the different windows as follows:

- Risk;
- Background;
- Effects;
- Tables;
- Plots; and
- Rules

Each of these windows contains different information to help you to make a decision regarding the results of the Tier 2 assessment. Each window is described below.

*Back:* Click the back button to return to the previous screen to make further modifications to the input or to check on the information entered.

*Record Decision:* Note that the 'Next' button is unavailable from this screen instead click the 'record decision' button once the screen has been completed to move to the final screen in this Tier where you will be asked to complete a series of free form text boxes where we recommend that you record the output of the assessment along with any comments that you might have as the assessor (e.g. you might identify areas for future refinement in the assessment or where new data is required before the assessment continues to Tier 3). Finally we suggest that you record either your decision regarding the assessment (i.e. do you end or continue the assessment) or if you are not the decision-maker then what you recommend should happen at this stage to help inform the decision-maker. Further details are given below (9. Record Decision – T1, T2 and T3.).

### 7.6.1 Risk

At Tier 2 the estimated total (internal and external summed) dose rates for each reference organism included in the assessment are compared with the dose rate screening value that was selected by the assessor for use in the assessment. This produces a risk quotient for each specific radionuclide selected for inclusion in the assessment. The risk quotient (RQ) is defined by:

$$RQ_n = \frac{DR_n}{SDR_n}$$

Where:

$RQ_n$  = Risk quotient for reference organism "n";

$DR_n$  = estimated total dose rate ( $\mu\text{Gy h}^{-1}$ ) for each reference organism "n";

$SDR_n$  = the screening dose rate ( $\mu\text{Gy h}^{-1}$ ) selected by the assessor in the assessment context screen

Note that the RQ values are unitless. Note that the screen provides information for each reference organism (first column) for both the total dose rate per organism and the screening dose rate applied in the first second and third columns.

It should be noted that if the assessment at Tier 2 is based on exactly the same input values and default settings, then the results for Tiers 1 and 2 should be approximately the same. However, at Tier 2, it is

expected that the assessor will consider the scenario in more detail and amend their problem formulation accordingly. The Tool provides the ability for the input activity concentrations, concentration ratios and occupancy factors to be modified prior to running the assessment. In order to account for the possibility that an assessment might be run at Tiers 1 and 2 with no alteration to the input values, the ERICA assessment tool makes use of the uncertainty factor defined by the assessor in the Assessment Context screen. Full details on the uncertainty factor and how it can be derived is given in Section 10.16.

The method using Uncertainty factors is based on the assumption that the estimated doses, and RQs, are exponentially distributed, which is supported by the principle of maximum entropy. The exponential distribution is the least biased distribution that can be assumed if only the expected value of the distribution is known. However, experience shows that the doses and the RQ are commonly log-normally distributed. Unfortunately, the use of a lognormal distribution requires additional information concerning the standard deviation of the doses, which depend on the standard deviation of the inputs and parameters. Furthermore, when the standard deviation has a similar magnitude to the mean, the 95<sup>th</sup> and other percentiles (above the expected value), estimated from the lognormal distribution are close to the values estimated from an exponential distribution with the same mean. When the standard deviation is numerically smaller than the mean, the 95<sup>th</sup> and other percentiles estimated using a lognormal distribution tend to be lower than the corresponding values estimated from an exponential distribution and the same mean. From this it can be concluded that the assumption of an exponential distribution provides cautious estimates of the percentiles as long as the Coefficient of Variation (i.e.  $SD/Mean * 100$ ) of the estimates is under 100%.

Furthermore, the UF approach has implications for the “degree of conservatism” at Tier 1 compared to Tier 2. Taking the case where the assessor selects one radionuclide, the EMCL is derived through the application of “real” probability distribution functions in many cases e.g. where data are numerous a log-normal distribution for the CR is applied in the calculation. The EMCL corresponds to the limiting organism. If we select the same radionuclide and limiting organism at Tier 2 and use the same input data (note that normally “expected values” for input data are required at Tier 2 but that maximum values might be stipulated in the problem formulation) then the RQs at Tiers 1 and 2 do not necessarily match. This is because the 95<sup>th</sup> percentile (of the RQ) derived from applying a UF at Tier 2 assumes an exponential distribution using an expected value as mean whereas the 95<sup>th</sup> percentile derived at Tier 1 will not take the form of an exponential but instead reflects a combination of various distributions. It should be emphasised that the UF is an approximation for allowing uncertainty in the dose-rate estimation at Tier 2 to be addressed.

In Tier 2, two RQ values are reported for every organism selected in the assessment (the expected value RQ and the conservative RQ). Used in combination with the other information provided within the Tier 2 assessment screens (as discussed below) these enable the assessor to make a decision on concluding the assessment or having to conduct a more detailed assessment:

- If the conservative RQs is below 1 for all organisms then the assessment has not exceeded the screening level at Tier 2. If a UF of 3 or 5 (or higher) is used there is low probability that the estimated dose rate to any organism exceeds the incremental screening dose rate but the resulting risk to non-human biota can be considered to be trivial (on the basis of the analyses of effects data conducted to derive the ERICA incremental screening dose rate). The ERICA Tool will recommend the user to exit the assessment.
- 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 UF). 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 likely risk is minimal. The ERICA Tool will recommend the assessment and results are reviewed.

- If the expected value RQ (and by implication the conservative RQ) is above 1 for any organism then the assessment has exceeded the screening value at Tier 2 and the ERICA Tool will recommend that further assessment be conducted.

In those cases where it is recommended that ‘the assessment is continued’ or ‘the assessment and results are reviewed’ this does not necessarily mean an automatic progression to a Tier 3 assessment. For instance, it may be possible to refine the input data or Tool parameters (e.g. obtain CR values applicable to the site) if justifiable and to then rerun the assessment at Tier 2. In instances where the conservative RQ is above 1 whilst the best estimate RQ is below 1 interpretation of the results may lead to a decision that the assessment can be justifiably exited. These issues are expanded upon below.

For any given reference organism if:

- both RQ values are <1 the RQ cells are highlighted green;
- the conservative RQ is >1 but the expected RQ is <1 the RQ cells are highlighted amber;
- both RQ values are >1 the RQ cells are highlighted red.

Note that the chemical toxicity of isotopes of U and Th will contribute to, and in some cases dominate, the risk to organisms. The ERICA Integrated Approach considers the radiological exposure only and hence will underestimate risk for such radionuclides.

The output values are listed by the radionuclide and can be sorted in ascending or descending order by clicking in the cell of the chosen column (i.e. where the column title is). A small arrow will appear next to the column title which indicates whether the data is sorted as ascending (▲) or descending (▼).

One point to note is that the ERICA approach is known to predict relatively low dose rates for terrestrial animals from some beta emitters (e.g. <sup>90</sup>Sr) when compared to other approaches that are available. ERICA has used a mass interpolation method using original data from the FASSET (see Table 7 below). For the terrestrial ecosystem, some (but not all) of these original data were based on models (phantoms) where the skin and fur of animals acts as a shielding layer from beta radiation. Therefore the external dose from beta radiation is lower than that predicted by other approaches which do not consider shielding effects. In contrast, ERICA external DCCs for some radionuclides may be greater than approaches using shielding configurations explicitly, reflecting the fact that the interpolation is based on some data that accounts for shielding and some data that does not.

Table 7 : FASSET geometries used in DCC derivations

Example animal	3D Shape	Full <sup>a</sup> : length, width, height (cm)	Mass (g)	Shielding layer (cm)
Woodlouse	Ellipsoid	1.7, 0.6, 0.3	0.17	0
Earthworm	Cylinder	12, 0.8, 0.8	6	0
Mouse/bird, small	Ellipsoid	7, 3, 3	35	0.1
Mole	Ellipsoid	11, 4, 4	97	0.1
Snake	Cylinder	100, 3, 3	740	0
Rabbit/bird, large	Ellipsoid	30, 11, 11	2 x 10 <sup>3</sup>	0.1
Fox	Ellipsoid	40, 15, 20	6.6 x 10 <sup>3</sup>	0.1
Deer	Ellipsoid	60, 27, 27	2.4 x 10 <sup>4</sup>	0.1
Cattle	Ellipsoid	160, 70, 90	5.5 x 10 <sup>5</sup>	0.3
Bird egg, small	Ellipsoid	2.4, 1.7, 1.7	4	0.1
Bird egg, large	Ellipsoid	4.5, 3, 3	22	0.1

<sup>a</sup> For an ellipsoid the dimensions are the lengths of the major axes; for a cylinder width equals height and represents diameter. The triplet corresponds to x-, y- and z- dimensions of the phantom in Monte Carlo simulations. Note that for terrestrial animals no beta radiation external radiation determination is made.

## 7.6.2 Background

The background tab provides ranges in background exposure rates due to naturally occurring radionuclides (weighted using the ERICA default radiation weighting factors of 10 for alpha, 3 for low energy beta and 1 for other beta and gammas). The ERICA Integrated Approach should be used to assess incremental doses from human activities only. If dose rates estimated within Tier 2 result in RQ values in excess of 1 but are within or close to natural background exposure rates the user could conclude that there is negligible cause for concern (Pentreath, 2002). If activity concentrations of naturally occurring radionuclides are available for the assessment site the assessor could estimate site-specific absorbed doses rates due to these for comparison to dose rates resulting from exposure to radionuclides from anthropogenic sources (obviously if you have site-specific background dose rates then these should be used in preference to the values provided here in this tab).

If a selection is made to include total activity concentrations of naturally occurring radionuclide in the assessment, it is possible that the Tool will estimate RQs in excess of unity at Tier 1 (or at Tier 2 if all reference organisms are selected and default setting applied) for the normal ranges that can be measured in the environment. In other words, the EMCL values fall at a level that is similar to or within the natural variation observed in some environments. This is the case for, *inter alia*, <sup>226</sup>Ra, <sup>234</sup>U and <sup>238</sup>U EMCLs for freshwater water and sediments; this is also the case for <sup>228</sup>Th, <sup>230</sup>Th, <sup>234</sup>Th and <sup>238</sup>U EMCLs for marine sediments and <sup>210</sup>Po EMCLs for terrestrial soils. The initial point to note is the fact that the ERICA methodology is intended for application to incremental dose-rates and therefore the entry of natural background activity concentrations is not consistent with the intended application of the tool. However, the very fact that these EMCLs are commensurate with background levels imposes a requirement for caution in their application and interpretation. A case in point can be given for <sup>210</sup>Po in the terrestrial system. The 'Lichen and Bryophyte' reference organism is the limiting organism for a number of radionuclides (predominantly natural series isotopes). For example, Lichen and Bryophyte is the limiting organism for <sup>210</sup>Po, the associated EMCL value of 25 Bq kg<sup>-1</sup> DW soil is the lowest terrestrial EMCL value and falls within the activity concentration range for <sup>210</sup>Po occurring naturally in soils. The predominant reason for this reference organism sometimes being the limiting organism is the comparatively high CR values within the ERICA Tool database. Both lichens and bryophytes receive their nutrients, and pollutants, as particulates and in solution from atmospheric deposition (Burton 1986). The use of a soil-biota CR may not, therefore, always be applicable to this reference organism. It is also possible that some of the contamination of lichen and bryophyte samples is external deposit and not internal contamination. If this is the case, the dose-rate per unit activity concentration would be reduced and the EMCL increased (as these parameters are inversely correlated) especially for an alpha-emitter such as <sup>210</sup>Po. Whilst FREDERICA contains no chronic dose effects data for lichens or bryophytes, acute exposure data (for mortality) suggest that they are amongst the least radiosensitive of organisms (UNSCEAR 1996). The implementation of a predicted no effects dose rate (as used to define the screening dose-rate at Tiers 1 and 2) that has been derived to be protective of all organism types within terrestrial ecosystems may therefore be overly conservative if applied specifically to lichens and mosses. These factors should be taken into account when making judgement on the outputs of Tier 2 and 3 assessments if 'Lichen and Bryophyte' are identified as being organisms of concern. Similar reservations with respect to radiosensitivity may be expressed for the aquatic environment EMCLs that, for the examples given above, pertain to vascular plants, phytoplankton and sea anemones or true coral.

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

Pentreath R.J. (2002) Radiation protection of people and the environment: developing a common approach. *Journal of Radiation Protection* 22 (1): 45-56.

### 7.6.3 Effects

The effects tab contains a series of tables, one for each reference organism group e.g. mammals, plants, fish etc) depending on whether the ecosystem under assessment is an aquatic or terrestrial one. The full list of wildlife groups that is available in the look up tables is given below (Table 8):

**Table 8: Wildlife groups and their associated reference organisms used in the effects lookup tables at Tier 2**

Wildlife Group	Associated reference organism(s)
Amphibian	Amphibian
Aquatic invertebrate	Insect larvae, Polychaete worm
Aquatic plant	Macroalgae, Phytoplankton, Vascular plant
Bacteria	
Bird	Bird
Crustacean	Crustacean
Fish	Benthic fish, Pelagic fish
Fungi	
Insect	Flying insect
Mammal	Mammal
Mollusc	Mollusc – bivalve, Mollusc - gastropod
Moss & Lichen	Lichen and Bryophytes
Plant	Grasses and Herbs, Shrub, Tree
Reptile	Reptile
Soil fauna	Annelid, Arthropod - detritivorous
Zooplankton	Zooplankton

The information is provided to allow you to compare the predicted dose rates for your reference organisms to a summary of information about the known biological effects of ionising radiation on non-human species collated within the FREDERICA database.

The effects lookup table is constructed in a way to provide you with a short statement on the types of biological effect that may be occurring at particular dose rates. The available data has been combined into dose rate ranges (e.g. 0-50, 50-100, 100-200, 200-400  $\mu\text{Gy h}^{-1}$  etc.) and then within each of these bands the available information has been summarised to provide you with:

- Information on the dose rate at which the biological effect has been observed in an experiment or field controlled study;
- The species on which the experiment was conducted;
- The endpoint (MB = morbidity, MT = mortality, RC = reproductive capacity, MUT = mutation);
- A brief statement of the type of biological effect observed.

As you select the different wildlife groups in the drop down list at the top of the tab screen, you will see that the dose rate range highlighted in red may change. The reason for this is because the red highlight is identifying the dose rate range within which the dose rate has been predicted for the reference organism which belongs to the wildlife group currently visible on the screen. This should allow you to identify the dose rate range in which the dose rate is predicted so that you can quickly identify any biological effects that might be occurring. This information may allow you to identify areas for research and/or targeted sampling and monitoring to look for known biological effects that may be occurring based on the data in the effects look up tables. Each effect is listed as being:

- No effect
- Minor effect (10-20% reduction; up to 50% increase)
- Moderate effect (20-40% reduction; 50-100% increase)
- Major effect (40-60% reduction; 100-200% increase)
- Severe effect (>60% reduction; >200% increase)

You should note that partly because of the coverage of the biological effects data and partly because of the number of dose rate range bands that have been used there is not always information available and these are given by statements of ‘no data available’.

If there are no effects data for a specific wildlife group close to the estimated dose rate, options to progress the assessment (if either Tier 2 RQ is >1) could include: (i) access the FREDERICA data base which may contain more relevant recent data; (ii) conduct effects experiments for the organism. Either of these options could lead to a justifiable reassessment at Tier 2 rather than the need to progress to Tier 3. If the effects data for a given wildlife group are sufficient and demonstrate insignificant effects at the estimated dose rate then the assessment could be justifiably exited.

Please note that the information used in the construction of these effects look up tables was based on the content of the FREDERICA database as of January 2007. It may well be that there is now additional information available within the FREDERICA database that has been added to the database since this date. You are therefore advised to check the contents of the FREDERICA database (available at [www.frederica-online.org](http://www.frederica-online.org)) if you either suspect that there is other biological effects literature available or if a significant time period has passed since January 2007 alternatively if you proceed to a Tier 3 assessment you will have the opportunity to link directly to the FREDERICA database from within the effects tab in the results screen of Tier 3.

#### 7.6.4 Tables

Within the ‘*Tables*’ window, you are able to review both the input, output and parameter values used within the Tier 1 assessment. You can move the split in the window between the assessment data component of the window and the location where the information is displayed by placing the cursor over the split bar until you see the following symbol (←→). You can then click the left mouse button and, while holding the left mouse button down, drag the bar to the left or right to adjust the split on the window between these two areas. This is useful, for example, to expand the ‘*Assessment data*’ section so that you can read the full description of the options for the tables.

##### *Inputs:*

The exact composition of the available information will vary depending upon how the assessment has been set up earlier in the tool. For example, in the inputs section you will be presented with different options depending upon whether you are investigating a terrestrial or aquatic ecosystem. The input values are those that you either entered or were modelled using the appropriate SRS-19 model.

When your inputs have been based on site-specific media concentrations (normally empirically-derived but also from bespoke models), the following options will be available:

- For an aquatic system: Activity concentrations in water, sediment and biota; percentage by mass dry material

- For a terrestrial system: Activity concentration in soil or air and biota.

If you have used the SRS-19 models then this section will present the input variables that were entered for the implementation of the model.

Accessing the input values might be useful if you need to use these data elsewhere outside of the ERICA assessment tool. You can also check that the user defined inputs, i.e. activity concentrations or IAEA SRS-19 model variables have been entered and recorded correctly.

*Outputs:*

At Tier 2 the outputs provided are:

- External dose rate
- Internal dose rate
- Sum of internal and external dose rate for each reference organism by radionuclide
- Total dose rate per reference organism
- Activity concentration in biota
- Activity concentration in media (soil for terrestrial ecosystems, or sediment and water for aquatic ecosystems)
- The calculated risk quotient

The risk quotient results page provides a basic summary of the risk quotient values and the sum of the risk quotients. There is no additional information provided here that you have not seen on the Risk window but it provides a useful check if you are looking at the input activity concentrations. One key point though is that you can sort the RQ values in ascending/descending order and thus identify those radionuclides which are contributing the most to the  $\sum RQ$ . This might help you to identify radionuclides that if you gathered more data or focused on their behaviour in the environment might provide an extra insight into a revised assessment if needed.

Site-specific data will always provide a useful comparison with predictions generated using the Tools generic parameters. A reasonable level of agreement would be for predicted and observed data to fall within an order of magnitude of each other (consistent with the approach taken in the development of the SRS-19 screening models). However, if there is consistent under, or over, prediction at a given site, alternative transfer parameters should be considered or sufficient measurements of biota conducted. It is also likely that the default CR and  $K_d$  databases included within the ERICA Tool will not be applicable to certain specific ecosystems (e.g. saltmarshes).

*Parameters:*

As with the input values this section will vary depending upon the set up of the assessment depending primarily on whether you have selected a terrestrial or aquatic ecosystem for the assessment. The type of information that is available is given in the following list:

- Concentration ratio (and for aquatic ecosystem assessments the distribution coefficient)
- Dose conversion coefficients for internal low energy beta (on the screen shown as *int-low-beta*)
- Dose conversion coefficients for internal beta gamma (on the screen shown as *int-beta-gamma*)
- Dose conversion coefficients for internal alpha (on the screen shown as *int-alpha*)

- Dose conversion coefficients for external low energy beta (on the screen shown as *ext-low-beta*)
- Dose conversion coefficients for external beta gamma (on the screen shown as *ext-beta-gamma*)
- Weighting factor of internal low energy beta (on the screen shown as internal low beta)
- Weighting factor of internal beta gamma (on the screen shown as internal beta gamma)
- Weighting factor of internal alpha
- Occupancy factor
- Dose rate screening value selected
- Information on the uncertainty factor that was applied in the assessment

In each case by clicking on the relevant parameter that you are interested in viewing you will see a table of data appear on the right hand side of the screen where you can check the data entered.

#### 7.6.5 Plots

Within the 'Plots' window, you are able to review both the input, output and parameter values used within the Tier 1 assessment but in this case as a series of graphs. Note you can move the split in the window between the assessment data component of the window and the location where the information is displayed by placing the cursor over the split bar until you see the following symbol ( $\leftarrow\rightarrow$ ). You can then click the left mouse button and, while holding the left mouse button down, drag the bar to the left or right to adjust the split on the window between these two areas. This is useful, for example, to expand the 'Assessment data' section so that you can read the full description of the options for the tables.

It is also possible to resize the plot as required by dragging the mouse cursor over the figure (if you draw a box on the plot over the region of interest it will zoom in, if you drag the mouse cursor from left to right the plot will zoom out). It is also possible to click the right mouse button and this will bring up a mouse menu that allows you to zoom in/out, save and print the plot.

#### *Inputs:*

The exact composition of the available information will vary depending upon how the assessment has been set up earlier in the tool. For example, in the inputs section you will be presented with different options depending upon whether you are investigating a terrestrial or aquatic ecosystem. The input values are those that you either entered or were modelled using the appropriate SRS-19 model.

When your inputs have been based on site-specific media concentrations (normally empirically-derived but also from bespoke models), the following options will be available:

- For an aquatic system: Activity concentrations in water, sediment and biota; percentage by mass dry material
- For a terrestrial system: Activity concentration in soil or air and biota.

If you have used the SRS-19 models then this section will present the input variables that were entered for the implementation of the model.

Accessing the input values might be useful if you need to use these data elsewhere outside of the ERICA assessment tool. You can also check that the user defined inputs, i.e. activity concentrations or IAEA SRS-19 model variables have been entered and recorded correctly.

*Outputs:*

At Tier 2 the plots provided are for:

- External dose rate
- Internal dose rate
- Sum of internal and external dose rate for each reference organism by radionuclide
- Total dose rate per reference organism
- Activity concentration in biota
- Activity concentration in media (soil for terrestrial ecosystems, or sediment and water for aquatic ecosystems)
- The calculated risk quotient

*Parameters:*

As with the input values this section will vary depending upon the set up of the assessment depending primarily on whether you have selected a terrestrial or aquatic ecosystem for the assessment. The type of information that is available is given in the following list:

- Concentration ratio (and for aquatic ecosystem assessments the distribution coefficient)
- Dose conversion coefficients for internal low energy beta (on the screen shown as *int-low-beta*)
- Dose conversion coefficients for internal beta gamma (on the screen shown as *int-beta-gamma*)
- Dose conversion coefficients for internal alpha (on the screen shown as *int-alpha*)
- Dose conversion coefficients for external low energy beta (on the screen shown as *ext-low-beta*)
- Dose conversion coefficients for external beta gamma (on the screen shown as *ext-beta-gamma*)
- Occupancy factor
- Dose rate screening value selected

#### 7.6.6 Rules

This tab shows the rules used to calculate the missing activity concentrations (see T2 Activity concentration rules selection).

## 8. Tier 3 specific issues

### 8.1 T3 Assessment Context

If you started at Tiers 1 or 2 then you will find that the information you entered previously for the radionuclides and reference organisms and ecosystem type has been pulled forward to this screen. You should now review and refine the previous information that was entered in light of any new information that has come out of the Tier 1/2 assessment results.

If you are starting at Tier 3 then you should follow the instructions below. Within this screen, you should select the radionuclides that should be considered in Tier 3 assessments, and the ecosystem in which the radionuclides are being considered.

#### 8.1.1 Select Radionuclides

*Isotopes:* You should select the radionuclides to be considered from the list by scrolling up and down the list, clicking on the appropriate radionuclide(s) (the radionuclide will be highlighted with a blue bar once it is selected). To select more than one radionuclide use either the CTRL or SHIFT key in combination with the mouse clicks. To select multiple individual (i.e. not given adjacent to each other in the list) radionuclides then use the CTRL key. To select a number of radionuclides that are adjacent to each other in the list use the SHIFT key to select the first and then last radionuclide in the group to be highlighted.

Once you have highlighted the radionuclide(s) to be included in the assessment, use the button with the “>” symbol to ‘move’ the radionuclide(s) to the “selected” column. If you wish to select all the radionuclides in the list you can use the button with the “>>” symbol as a shortcut to moving all radionuclides to the selected list. Likewise if you wish to deselect one or more radionuclides from the selected list you can use the mouse with the CTRL or SHIFT key as above to select one or more radionuclides and then use the button with the “<” symbol to deselect the radionuclide(s). There are 71 default radionuclides to choose from within the Tier 3 assessment (see **Table 3**).

*Add isotope:* This option is enabled by pressing the button “Add isotope” directly beneath the list of default ERICA radionuclides and might be selected in cases where the radionuclide under consideration is not included within the ERICA default database (see Section 10.1).

#### 8.1.2 Select Reference Organisms

*Ecosystem:* From this drop down list you can select the ecosystem that is being considered in the assessment. There are three to choose from: freshwater, marine or terrestrial. Depending upon your selection, different reference organism lists will be available for use in the Tier 3 assessment (see **Table 5**).

*Organisms:* Once you have selected the ecosystem to use the appropriate reference organism list will be provided in the ‘Select from’ box. Using the mouse you can then highlight those reference organism(s) to be included in the assessment, use the button with the “>” symbol to ‘move’ the reference organism(s) to the “selected” column. If you wish to select all the reference organisms in the list you can use the button with the “>>” symbol as a shortcut to moving all reference organisms to the selected list. Likewise if you wish to deselect one or more reference organisms from the selected list you can use the mouse with the CTRL or SHIFT key as above to select one or more reference organisms and then use the button with the “<” symbol to deselect the reference organism(s).

*Add organism:* In addition to the default list of reference organisms you can also choose to create your own geometry for an organism for inclusion in the assessment. This is done by clicking the ‘Add organism’ button which is available underneath the list of reference organisms to select from. Full details of how to add a new reference organism are given in Section 10.2. Once the new geometry has been created using the ‘add new organism wizard’ it will appear in the reference organism list to select from and will need to be selected as described above. As the details of the new geometry are added to

your own user defined database it will be available for use in other assessments that you conduct. Please note however that you still need additional information for the new geometry as you will be prompted for concentration ratios and occupancy factors within the tool. If you select a user defined geometry within the assessment but then do not have appropriate concentration ratios or occupancy factors available the assessment will not be able to continue at later screens. Further advice on this is given in the Add New Organism wizard help (Section 10.2).

## **8.2 T3 Radioecology Parameters**

Radioecological parameters, i.e. CRs and  $K_d$ s can be inspected and edited in a similar way to that described for Tier2 (7.2).

### **Additional notes for Tier 3:**

#### **8.2.1 Single values or distributions for inclusion in a probabilistic risk assessment?**

##### *Single values:*

When entering single values for the parameters you should select the “Edit Value” tab in the bottom left hand corner.

##### *Distributions:*

If you wish to enter a distribution for a given parameter then you need to select the “Edit Distribution” tab. This will take you to a distribution version of the parameter entry screen.

In order to use a distribution you should select the specific parameter to be modified (e.g. you need to select the specific radionuclide  $K_d$  value to add a distribution to. Once you have selected the cell to add a distribution to you should select the distribution type to add from the drop down list under the “Distribution Functions” heading. The following distributions are available.

- Exponential (enter mean, and optionally lower cut off and upper cut off values)
- Normal (enter mean, standard deviation, and optionally lower cut off and upper cut off values)
- Triangular (enter minimum, maximum and mode values)
- Uniform (enter minimum and maximum values)
- Lognormal (enter mean, standard deviation, and optionally lower cut off and upper cut off values)
- Logtriangular (enter minimum, maximum and mode values)
- Loguniform (enter minimum and maximum values)

You can then enter the parameter values for the distribution into the text boxes that appear next to the distribution functions drop down box (note that typical values are given as a default). The exact list of parameters requested will depend upon the distribution type and the details are given in the distribution descriptions. A brief description is also provided in Section 10.8.

Once you have entered all the necessary parameters you click on “Enter” button in order to enter the distribution information into the cell. You should then repeat this exercise for each parameter that you wish to amend to a distribution. This information will then be utilised within the later stages of Tier 3 where you will be given the option to conduct a probabilistic risk assessment.

##### *Final points to note:*

You should note that where sufficient data is available, default distributions have been provided for some of the parameters. The form of the default distributions depends on availability and quality of the underlying data. Simple rules have been adopted. When empirical data are available allowing the derivation of an arithmetic mean and standard deviation, the default distribution has been set to log-normal. When the value is derived (as is the case for numerous CR values) or recommended (the case for most Kd values) an exponential default distribution has been allocated.

Viewing the ERICA default databases, using the Database menu option, can provide you with further information on the default parameters values (e.g. number of data available to derive the default value) that may help you to judge if you should use them.

**Please note** that if you have added a new organism geometry to the assessment you must ensure that a value or distribution is now recorded in the appropriate CR value cells for each radionuclide in the assessment. The tool will not allow you to progress with the assessment unless all the CR radionuclide cells are filled.

If there is a data gap in the information in this screen then the tool prompts you by providing some information on where the gap is and the 'Next' button is unavailable.

*Back:* Click the back button to return to the previous screen to make further modifications to the input or to check on the information entered, any modifications made to either the current page before moving to the previous screen or any changes made to the previous screen are made in the tool record. This allows mistakes or omissions to be corrected at any time when using the tool.

*Next:* Click the next button once the screen has been completed to move to the next screen.

### ***8.3 T3 Occupancy Factors and Radiation Weighting Factors***

This screen allows you to modify the occupancy factors for each reference organism (or your own organism geometries). The procedure is identical to that described for T2 (Section 7.3 T2 Occupancy Factors and Radiation Weighting Factors), although the tool allows distributions to be specified for radiation weighting factors. The same distributions are supported as for other parameters such as CRs and  $K_{ds}$  (Section 8.2 T3 Radioecology Parameters).

### ***8.4 T3 Inputs***

The input screen allows you to enter the media or biota activity concentrations that you have collated for use in the assessment. You can enter a single value or a probability distribution for the following depending upon the ecosystem selected. The set-up, including the derivation of values for each radionuclide/reference organism, is similar to that for Tier 2 (Section 7.4).

When entering single values for the parameters you should select the Edit Value tab in the bottom left hand corner. Then you can enter the values as given below. If you wish to enter a distribution for a given parameter then you need to select the Edit Distribution tab and then enter the information about the type of distribution to be used (first select the parameter cell to modify and then select the distribution type and enter in values for that distribution in the text boxes along the bottom of the screen).

Within the input table you can enter as much or as little information (**subject to there being at least one entered activity concentration or distribution per radionuclide**) as you have available to you during the assessment. Depending upon the amount of data that you are able to enter the tool follows a set of rules which are described below to calculate an input value for each radionuclide/reference

organism combination included in the assessment. There must be an input activity concentration for each radionuclide/reference organism combination for the assessment to continue however the tool will deal with this for you provided that there is at least one activity concentration entered per radionuclide. The rules make use of the concentration ratios (CRs) (and for aquatic ecosystems the  $K_d$  values) entered in the previous screen.

### **8.5 T3 Probabilistic Simulation Settings**

On this screen you are provided with a list of the parameters that: (i) have distribution functions associated with them within the ERICA databases (under the *Select from* column); (ii) you have assigned distribution functions to (under the *Selected* column). You should select those parameters which you would like to use within your probabilistic assessment. Parameters to be included within the assessment should be moved to the *Selected* column. You do this by using the button with the “>” symbol to ‘move’ the reference organism(s) to the “selected” column. If you wish to select all the parameters in the list you can use the button with the “>>” symbol as a shortcut to moving all to the selected list. Likewise if you wish to deselect one or more parameters from the selected list you can use the mouse with the CTRL or SHIFT key as above to select one or more parameters and then use the button with the “<” symbol to deselect them.

Once you have selected the parameters for inclusion in the probabilistic assessment you need to determine the number of simulations that you wish to perform. This essentially will determine the number of times that the code samples a parameter from each distribution and uses it to calculate the dose rate to the reference organisms of interest. Typically you might run the assessment 1000 or 10000 times but the exact choice of number of simulations will depend on factors such as the required precision of the output statistics and computational limits (available memory and acceptable time for the simulation to be performed). Simply enter the number into the ‘*number of simulations*’ box.

The seed number is used if you want to constraint the simulations so that each run that is conducted calculates the same result. This is commonly used when you are undertaking a sensitivity analysis.

*Back:* Click the back button to return to the previous screen to make further modifications to the input or to check on the information entered, any modifications made to either the current page before moving to the previous screen or any changes made to the previous screen are made in the tool record. This allows mistakes or omissions to be corrected at any time when using the tool.

*Next:* Click the next button once the screen has been completed to move to the next screen and to view the results screen.

### **8.6 T3 Activity concentration rules selection**

This screen allows you to select the values for those media and biota where you have data that will be used to calculate activity concentrations where you have no data.

#### ***For freshwater and marine ecosystems***

In all cases where you have a water activity concentration datum (on its own or in combination with data for one or more organisms and/or sediment) this value (either as a single values or a distribution depending on how data were entered earlier and which parameters were selected for probabilistic simulation) will be used to calculate all other missing data via multiplication by appropriate  $K_d$ s or CRs. The cell showing a radionuclide activity concentration in water is highlighted in green and there is no option to select/deselect cells showing activity concentration values for sediment or organisms.

When you have no radionuclide activity concentration values in water but data for sediments and/or biota (whether for a single organism or many organisms), you can select which values will be used in the calculation of water activity concentrations and from that point all other missing data will be generated automatically via multiplication by appropriate  $K_d$ s or CRs. The selection is activated by

clicking within any given cell where you have data. If the value is to be used in the subsequent calculation this will be denoted by a green tick and conversely, if the value is to be excluded from subsequent calculation, this will be denoted by a red cross. The calculation of the radionuclide activity concentration in water is performed within the tool by simply dividing the radionuclide activity concentration value by the corresponding  $K_d$ , in the case of sediment, or CR, in the case of biota. When multiple values are selected for this calculation, the result is based upon the average of the radionuclide calculated activity concentrations in water.

### ***For terrestrial ecosystems***

In all cases where you have a soil (or air) concentration (on its own or in combination with data for one or more organisms), this value (either as a single values or a distribution depending on how data were entered earlier and which parameters were selected for probabilistic simulation) will be used calculate all other missing data via appropriate CRs. The cell showing a radionuclide activity concentration in soil (or air) is highlighted in green and there is no option to select/deselect cells showing activity concentration values for organisms.

When you have no radionuclide activity concentration values in soil (or air) but data for biota (whether for a single organism or many organisms), you can select which values will be used in the calculation of soil concentrations and from that point all other missing data will be generated automatically via appropriate CRs. The selection is activated by clicking within any given cell where you have data. If the value is to be used in the subsequent calculation this will be denoted by a green tick and conversely, if the value is to be excluded from subsequent calculation, this will be denoted by a red cross. The calculation of the radionuclide activity concentration in soil (or air) is performed within the tool by simply dividing the radionuclide activity concentration value for the organism by the corresponding CR value. When multiple values are selected for this calculation, the result is based upon the average of the calculated radionuclide activity concentrations in soil (or air).

*Back:* Click the back button to return to the previous screen to make further modifications to the input or to check on the information entered, any modifications made to either the current page before moving to the previous screen or any changes made to the previous screen are made in the tool record. This allows mistakes or omissions to be corrected at any time when using the tool.

*Next:* Click the next button once the screen has been completed to move to the next screen. Please note that you will be able to press this button unless there is at least one data value selected in each row where concentrations in media (soil for terrestrial ecosystems, or water for aquatic ecosystems) are missing.

### ***8.7 T3 Run simulation***

On this screen you are provided with a list of all parameters and selected values to use within your probabilistic assessment. You can also review the previous entered number of simulations and seed value.

Once the parameters and settings have been reviewed then you should press the '*run*' button to perform the probabilistic assessment. You will be kept informed of progress during the simulations by the bar to the right of the Run/Stop buttons. Depending upon how the assessment has been set up and the number of simulations etc this could potentially take up a lot of computer processing power. In the event that this is taking too much time, you can press the '*stop*' button which is activated during the calculations phase.

*Back:* Click the back button to return to the previous screen to make further modifications to the input or to check on the information entered.

*Next:* Once the calculations have been completed you can click the '*next*' button to move to the results screen.

## 8.8 T3 Results screen

On this screen you will see several tabs which identify the different windows as follows:

- Deterministic values;
- Probabilistic data;
- Sensitivity Analysis;
- Effects;
- Rules;
- Record Decision.

Each of these tabs (with the exception of Record Decision) contains different information to help you to make a decision regarding the results of the Tier 3 assessment. Each tab is described below:

Note that the chemical toxicity of isotopes of U and Th will contribute to, and in some cases dominate, the risk to organisms. The ERICA Integrated Approach considers the radiological exposure only and hence will underestimate risk for such radionuclides.

*Back:* Click the back button to return to the previous screen to make further modifications to the input or to check on the information entered.

*Record Decision:* Note that the 'Next' button is unavailable from this screen instead click the 'Record decision' button to move to the final tab on this screen where you will be asked to complete a series of free form text boxes where we recommend that you record the output of the assessment along with any comments that you might have as the assessor. Further details are given below (9. Record Decision – T1, T2 and T3.).

### 8.8.1 Deterministic values

Within this window, you are able to review the deterministic (single-value) input, output and parameter data used within the Tier 3 assessment. You can move the split in the window between the assessment data component of the window and the location where the information is displayed by placing the cursor over the split bar until you see the following symbol ( $\leftrightarrow$ ). You can then click the left mouse button and, while holding the left mouse button down, drag the bar to the left or right to adjust the split on the window between these two areas. This is useful, for example, to expand the 'Assessment data' section so that you can read the full description of the options for the tables.

#### *Inputs:*

The exact composition of the available information will vary depending upon how the assessment has been set up earlier in the tool. For example, in the inputs section you will be presented with different options depending upon which values you have selected as being single-value inputs into the simulation or whether you are investigating a terrestrial or aquatic ecosystem. So:

In the marine and freshwater ecosystems, you may be presented with the following options:

- Activity concentration in environmental media (water and sediment) if these were selected as single-value inputs
- Activity concentrations in organisms if these were selected as single-value inputs

Whereas for a terrestrial ecosystem you will be presented with:

- Activity concentration in environmental media (soil or air) if these were selected as single-value inputs
- Activity concentrations in organisms if these were selected as single-value inputs

For all ecosystems, the following input data report will be available:

- Percent dry weight (relating to sediment for marine and freshwater and soil for terrestrial)

The input values are those that you entered in earlier screens: the report enables the assessor to check on whether these values have been entered correctly.

*Outputs:*

As for the inputs, the exact content of this file will depend on the selections made earlier in setting up the Tier 3 assessment. The file will report single value outputs from the simulation and will therefore be determined by the selection of single-value inputs on previous screens. In the most comprehensive case the following single-value outputs will be available:

- External dose rate (separated into components defined by radionuclide and reference organism)
- Internal dose rate (separated into components defined by radionuclide and reference organism)
- Total dose rate (sum of internal and external) for each organism by radionuclide
- Activity concentration in biota (for each radionuclide and organism)
- Activity concentration in media (soil for terrestrial ecosystems, or sediment and water for aquatic ecosystems)
- Total dose rate per organism

If one or more probability distributions were selected for (user-specified) inputs or parameters to be used in the calculation of dose-rates for a given organism, the single-value, deterministic output will not be subsequently available for this particular case. The data can only be presented in probabilistic form and therefore the “Probabilistic data” tab should be selected. If probability distributions are selected for any component required in the dose calculation for all selected organisms, the output under this category may be completely void. All relevant data will then be stored under the “Probabilistic data” tab.

Site-specific data will always provide a useful comparison with predictions generated using the Tools generic parameters. A reasonable level of agreement would be for predicted and observed data to fall within an order of magnitude of each other (consistent with the approach taken in the development of the SRS-19 screening models). However, if there is consistent under, or over, prediction at a given site, alternative transfer parameters should be considered or sufficient measurements of biota conducted. It is also likely that the default CR and  $K_d$  databases included within the ERICA Tool will not be applicable to certain specific ecosystems (e.g. saltmarshes).

*Parameters:*

As with the input values this section will vary depending upon the set up of the assessment on earlier screens (essentially which parameters have been selected as being represented by single values or distributions) and on whether you have selected a terrestrial or aquatic ecosystem for the assessment. In the most comprehensive case the following single-value parameter outputs will be available:

- Concentration ratio

- Distributions coefficients (marine and freshwater ecosystems only)
- Weighting factor of internal low energy beta (on the screen shown as internal low beta)
- Weighting factor of internal beta gamma (on the screen shown as internal beta gamma)
- Weighting factor of internal alpha (on the screen shown as internal alpha)

If all have these parameters have been assigned distributions, they will not be enabled under the “Deterministic values” tab – the user will need to access the “Probabilistic data” tab. In addition, those parameters that are always represented by single value data will be included under the “Deterministic values” tab. These parameters are:

- Dose conversion coefficients for internal low energy beta (on the screen shown as *int-low-beta*)
- Dose conversion coefficients for internal beta gamma (on the screen shown as *int—beta-gamma*)
- Dose conversion coefficients for internal alpha (on the screen shown as *int-alpha*)
- Dose conversion coefficients for external low energy beta (on the screen shown as *ext-low-beta*)
- Dose conversion coefficients for external beta gamma (on the screen shown as *ext- beta-gamma*)
- Occupancy factor

In each case by clicking on the relevant parameter that you are interested in viewing you will see a table of data appear on the right hand side of the screen where you can check the data entered.

### 8.8.2 Probabilistic data

The results of the probabilistic assessment are visualised in this tab for individual groups of assessment data (input data, output data and parameters). The individual data can be selected from the list to the left hand side of the screen near to the browser window by clicking on the “+” sign next to the parameter category. In so doing, it is possible to extend the list of available data. Once you have selected the parameter to be visualised, a histogram will appear in the centre of the tab which shows the probability distribution for that parameter and to the right hand side of the screen the results of some summary statistics are presented. These include the:

- Mean and variance
- Median
- Minimum and maximum
- 5<sup>th</sup>, 25<sup>th</sup>, 75<sup>th</sup> and 95<sup>th</sup> percentiles.

It is also possible to request different percentile values or to provide an input value and then to get the tool to tell you the percentile position of that value within the distribution by editing the value or percentile text boxes below the histogram.

It is also possible to change the number of bins used as described in the following:

The bin count can be altered by the user if the ‘arbitrary’ bin count rule option is selected from the drop-down menu under the bin count rule heading. This and the other available options are used to select the number of bins (or analogously, the size of each bin) that are used when constructing the histogram. In the below formulas,  $x$  denotes the sample for which a histogram is being constructed, and  $h$  denotes the number of bins and  $R$  is the sample range.

#### *Freedman-Diaconis*

$$h = \text{ceiling}(N^{1/3} * R / (2 * IQR(x)))$$

Reference: Freedman, D. and Diaconis, P. (1981) On the histogram as a density estimator. *Zeitschrift für Wahrscheinlichkeitstheorie und verwandte Gebiete* **57**, 453–476.

#### *Scott*

$$h = \text{ceiling}(N^{1/3} * R / (3.49 * s)), \text{ where } s \text{ is the standard deviation of } x.$$

Reference: Scott, D. W. (1979) On optimal and data based-histograms. *Biometrika* **66**, 605–610.

#### *Sturges*

$$h = 1 + \log_2 n$$

Reference: The problem with Sturges' rule for constructing histograms, Rob J Hyndman, Department of Econometrics and Business Statistics, Monash University, Clayton VIC 3168, Australia

#### *Inputs*

The exact composition of the available information will vary depending upon how the assessment has been set up earlier in the tool. For example, in the inputs section you will be presented with different options depending upon which values you have selected as being inputs defined by probability distributions into the simulation or whether you are investigating a terrestrial or aquatic ecosystem. so:

In the marine and freshwater ecosystems, you may be presented with the following options:

- Activity concentration in environmental media (water and sediment) if these were selected as inputs defined by probability distributions
- Activity concentrations in organisms if these were selected as inputs defined by probability distributions

Whereas for a terrestrial ecosystem you will be presented with:

- Activity concentration in environmental media (soil or air) if these were selected as inputs defined by probability distributions
- Activity concentrations in organisms if these were selected as inputs defined by probability distributions

#### *Outputs:*

As for the inputs, the exact content of this file will depend on the selections made earlier in setting up the Tier 3 assessment. The file will report probabilistic outputs from the simulation and will therefore be determined by the selection of inputs defined by probability distributions on previous screens. In the most comprehensive case the following probabilistic outputs will be available:

- External dose rate (separated into components defined by radionuclide and reference organism)

- Internal dose rate (separated into components defined by radionuclide and reference organism)
- Total dose rate (sum of internal and external) for each organism by radionuclide
- Activity concentration in biota (for each radionuclide and organism)
- Activity concentration in media (soil for terrestrial ecosystems, or sediment and water for aquatic ecosystems)
- Total dose rate per organism

If all (user-specified) inputs or parameters to be used in the calculation of dose-rates for a given organism were selected as being single-values, output will not be subsequently available as a probability distribution for this particular case. The data can only be presented in single-value form and therefore the “Deterministic value” tab should be selected.

### *Parameters*

As with the input values this section will vary depending upon the set up of the assessment on earlier screens (essentially which parameters have been selected as being represented by single values or distributions) and on whether you have selected a terrestrial or aquatic ecosystem for the assessment. In the most comprehensive case the following probabilistic parameter outputs will be available:

- Concentration ratio
- Distributions coefficients (marine and freshwater ecosystems only)
- Weighting factor of internal low energy beta (on the screen shown as internal low beta)
- Weighting factor of internal beta gamma (on the screen shown as internal beta gamma)
- Weighting factor of internal alpha (on the screen shown as internal alpha)

### 8.8.3 Sensitivity Analysis

Sensitivity analysis is used to apportion the relative effect of the uncertain inputs and parameters on the variation and uncertainty of the simulation endpoints. Several sensitivity analysis methods of varying degrees of complexity have been proposed in the literature (Sartelli *et al.* 2004). The choice on an appropriate method depends on several factors, such as the time needed for performing a simulation with the model, the number of uncertain parameters and the type of dependency between the inputs/parameters and the simulation endpoints of interest. For linear dependencies, simple methods based on correlations are sufficient; while for complex non-monotonic dependencies more advanced methods, based on decomposition of the variance, are required.

The models for calculation of dose rates implemented in the ERICA tool are relatively simple. It is possible to perform sensitivity analyses using simple correlation coefficients between the inputs/parameters and the endpoints. In the present version of the tool, two correlation coefficients are computed every time a probabilistic simulation is carried out: the Pearson Correlation Coefficient (CC) and the Spearman Rank Correlation Coefficient (SRCC). The CC assumes linear relationship between variables whereas the SRCC does not.

In the ERICA tool, the results of the sensitivity analysis are presented as tornado plots for each parameter. You can view the tornado plot for each parameter where a distribution has been provided by clicking on + next to the outputs option in the list and then choosing the parameter to view. The tornado plot is a simple bar graph where the sensitivity statistics, i.e. the CC or the SRCC, is visualised vertically in order of descending absolute value. The longer the horizontal bar the larger is the effect of the parameter on the simulation endpoint. The parameters that have positive values of the sensitivity measures have a positive effect on the endpoint, while the ones with negative values have a negative

effect. It is possible to choose the results to be viewed using the Pearson Correlation Coefficient (by selecting Pearson in the drop down list underneath the tornado plot) or the Spearman Rank Correlation Coefficient by selecting Spearman from the drop down list. You can also select the number of parameters to visualise on the tornado plot (default is 3).

In the simplest sense, the sensitivity analysis included in the tool can be used to identify those parameters that are having an overriding influence on the total dose-rate (or components of this dose-rate). If it is found that the parameter/value under investigation is having a large effect on the output, it might be worth investigating/examining this parameter in more detail. If the parameter is a  $K_d$  or CR this might simply involve conducting more field or laboratory studies to characterise the value more robustly.

One point to note is that the ERICA approach is known to predict relatively low dose rates for terrestrial animals from some beta emitters (e.g.  $^{90}\text{Sr}$ ) when compared to other approaches that are available. This is because, within the terrestrial ecosystem, the ERICA approach considers that skin and fur of animals acts as a shielding layer from beta radiation and therefore the external dose from beta radiation is lowered than that predicted by other approaches which do not consider this.

#### 8.8.4 Effects

The effects tab contains a direct link to the online FREDERICA database and for this aspect of the tool to work correctly you must have internet access enabled. The information is provided to allow you to compare the predicted dose rates for your reference organisms to the biological effects information resulting from exposure to ionising radiation on non-human species that is collated within the FREDERICA database. By providing this direct link to FREDERICA this will ensure that you will always see the most up to date version of the data available within the FREDERICA database.

The search conducted is linked to the reference organism and the wildlife group that it belongs to. By selecting the reference organism, the wildlife group will be automatically selected for you, the search conducted within the FREDERICA database will then identify all the endpoints (e.g. MB = morbidity, MT = mortality, RC = reproductive capacity, MUT = mutation) contained within the database and the dose that has been predicted by the assessment tool for the reference organism is used as the middle point of a dose rate range that will be transferred to the FREDERICA database. Once you select the reference organism type the effects tab will report back a screen containing the results from the FREDERICA database search query and here you will be able to view information as follows:

- The reference information from which the dose data has been taken;
- Details of the experiment that was conducted to obtain the dose effect data;
- Information on the dose rate at which the biological effect has been observed in an experiment or field controlled study;
- The species on which the experiment was conducted;
- The endpoint (MB = morbidity, MT = mortality, RC = reproductive capacity, MUT = mutation);
- A brief statement of the type of biological effect observed.

As you select the different wildlife groups in the drop down list at the top of the tab screen, you will see that the information may change. This information may allow you to identify areas for research and/or targeted sampling and monitoring to look for known biological effects that may be occurring based on the available data. You can also modify the dose rate range that is being searched using the two boxes (called lower and upper value) to the right of the organism drop down list. By default the lower value is always 0 and the upper value is the dose rate at the 95<sup>th</sup> percentile has been predicted by

the Tool for the selected organism. You can modify this simply by typing a different value into either the lower or upper value box and clicking the search button to submit the query to the database.

Full details of the available information and how to use the FREDERICA database is provided at the FREDERICA website ([www.frederica-online.org](http://www.frederica-online.org)), this includes a manual on the searches available and the ways to export the data from the FREDERICA database.

At Tier 3, you may also wish to make use of the FREDERICA database directly to extract information that may be used for example to generate benchmarks for comparison with the dose rates that are predicted. In these cases, the assessor can consult the FREDERICA database directly and use its search capability to locate information specific to the assessment being conducted. Access to the biological effects information contained within the FREDERICA database, either directly or through the assessment tool, requires an active internet connection.

The output of the searches conducted in the FREDERICA database is displayed in the window tab. If more than one result is available these can be browsed on the screen by clicking the arrows at the bottom right of each section of the data on the screen.

If you wish to export the results then you will need to use the full version of the FREDERICA database ([www.frederica-online.org](http://www.frederica-online.org)) where there is the option to export the search output as a comma separated file (CSV) file that can be read directly into programmes such as Microsoft<sup>®</sup> Excel. There is a full help function available online within the FREDERICA database, which describes how to conduct searches, view and export the outputs and add new biological effects literature to the database. Please note that new data will not immediately be available within the database as, after addition, there is a quality assurance process in place to ensure that the data added to the database is suitable and fit for purpose.

#### 8.8.5 Rules

This tab shows the rules used to calculate the missing activity concentrations (see T3 Activity concentration rules selection).

## 9. Record Decision – T1, T2 and T3.

*Please provide and justify your recommendation or decision regarding the assessment outcome*

We recommend that you record the output of the assessment along with any comments that you might have as the assessor (e.g. you might identify areas for future refinement in the assessment or where new data is required before the assessment continues). Finally we suggest that you record either your decision regarding the assessment (i.e. do you end or continue the assessment) or if you are not the decision-maker then what you recommend should happen at this stage to help inform the decision-maker. This dialogue box will be activated whether or not you recorded that stakeholders would be involved in the process.

However, if you selected to engage with stakeholders the following text boxes will also appear:

*Have stakeholders been engaged as defined during problem formulation?*

This is a simple yes or no radial button and if the answer is yes, then the following free form text boxes allow you to record information regarding the outcome of the stakeholder involvement process and to record how that process has influenced the assessment. This completes the transparency and openness component of the tool. If the answer is no then there is no requirement to complete the remaining text boxes and you can click the ‘finish’ button.

*Did the assessor do as intended?*

This box simply allows you to record whether the stakeholder involvement for the assessment proceeded as expected and recorded in the Stakeholder Involvement Record Screen. If there were differences, then these should be listed here for transparency.

*Where is the supporting documentation?*

This text box allows you to record the physical or electronic location of any relevant files that might be useful or that should be associated with the assessment. This might also include reference to other documents for example related to a wider stakeholder engagement process or wider assessment.

*Did the stakeholder involvement impact on the way the assessment was carried out? If so how?*

This text box allows you to record how the assessment set up might have been modified in consultation with stakeholders. For example it might be that you were proposing to use a particular set of input values based perhaps on the maximum activity concentration present at the end of a pipeline discharge. However, during the consultation period with stakeholders it might have been decided that there were no sessile organisms present at the end of the pipeline that required assessment and that therefore the application of the point of discharge activity concentrations was over conservative for the populations under investigation. Consequently you might have agreed a different set of input activity concentrations based on a mixing zone around the pipeline. This would be the place to record such an outcome that has influenced how the assessment was undertaken. This open and transparent documentation of key changes will help if anyone was to review the outputs from the assessment and look to challenge certain decisions which might have already been thought through and consulted on.

*How did the stakeholder involvement impact on the final decision?*

This final text box allows you to record any stakeholder involvement in making the decision regarding the final outcome of the assessment. Here for example you might want to record that although the Tier 1 assessment RQ values when summed were  $>1$ , in consultation with stakeholders and examining aspects other than the potential environmental impact on non-human species it was decided that the practice could be supported because of higher social or economic concerns. In this case, these discussions should be documented for openness and transparency and here would be the location to do it.

*Finish:* Click the '*finish*' button once you have added all the information relevant to the assessment output that you feel is necessary. This will complete the Tier 1 assessment and return you to the assessment details screen where you will see the information that you entered previously available for review and/or amendment as necessary. It is then possible to repeat the Tier 2 assessment or to start a Tier 3 assessment from this point by selecting the appropriate radial button and working through the screens again.

## 10. General Sections

### 10.1 Add Isotope Wizard

On the Assessment Context screen, the user has the option to derive Dose conversion coefficients for any radioisotope included within the electronic version of ICRP-38. This option is enabled by pressing the button “Add isotope” directly beneath the list of default ERICA radionuclides and might be selected in cases where the radionuclide under consideration is not included within the ERICA default database. The function generates DCCs for all reference organisms (in all 3 ecosystems) using the same configurations used in the calculation performed for the ERICA list of radionuclides, i.e. source depth and positioning of the source relative to the target etc. and splits the dosimetric data into alpha, low (< 10keV beta) and gamma-beta (> 10keV) radiations, sub-dividing under internal and external DCC components.

Having selected the Add isotope option, a comprehensive list of isotopes is shown on the next screen. You should select the radionuclides to be considered from the list by scrolling up and down the list, clicking on the appropriate radionuclide(s) (the radionuclide will be highlighted with a blue bar once it is selected). To select more than one radionuclide use either the CTRL or SHIFT key in combination with the mouse clicks. To select multiple individual (i.e. not given adjacent to each other in the list) radionuclides then use the CTRL key. To select a number of radionuclides that are adjacent to each other in the list use the SHIFT key to select the first and then last radionuclide in the group to be highlighted. Once you have highlighted the radionuclide(s) to be included in the assessment, use the button with the “>” symbol to ‘move’ the radionuclide(s) to the “selected” column. If you wish to select all the radionuclides in the list you can use the button with the “>>” symbol as a shortcut to moving all radionuclides to the selected list. Please note that you should avoid selecting more than 20 radioisotopes at one time owing to computational limitations. If you have more than radioisotopes that require analyses, the calculations need to be performed in several batches. If you wish to deselect one or more radionuclides from the selected list you can use the mouse with the CTRL or SHIFT key as above to select one or more radionuclides and then use the button with the “<” symbol to deselect the radionuclide(s).

Once the selection has been made, you should press the “Next” button – This initiates the calculations, the progress for which is reported under the screen as each component DCC is generated. This may take some seconds. There is also an option to “Cancel” the process at any stage by pressing the button in the bottom left hand corner. Once the calculations are complete, you should Click “Next” to review and edit the parameters or “Finish” to save the organism data and parameters values.

In order to use the new isotope in subsequent assessments, you will need to provide information manually on transfer parameters including CRs and  $K_d$ . this can be achieved, either by accessing the data base directly using the show database functionality or by entering the data at the appropriate stage during the assessment, i.e. where the assessor is prompted to Review and Edit radioecological parameters as described in Sections 7.2 & 8.2, for tiers 2 and 3 respectively (in fact the assessment cannot continue beyond a certain point without this information being added).

### 10.2 Add Organism Wizard

#### 10.2.1 Organism Details – Name & Description

In some cases, you may wish to define a specific geometry for assessment. At the assessment context stage in Tiers 2 and 3 you may select the “Add organism” button located underneath the list of reference organisms box. You might wish to do this if the geometry of the organism of interest to you (for example a protected species) is sufficiently different in size to one of the default reference organisms (a table of the default reference organism geometries is provided below). Assessors are also directed to the assessment of Uncertainty in the Tool section (10.17) as this will help also in understanding the consequences of using different sized geometries.

**Table 9:** ERICA default reference organism geometries

<b>Reference Organisms</b>	<b>M(kg)</b>	<b>A(cm)</b>	<b>B(cm)</b>	<b>C(cm)</b>
<i>Terrestrial Ecosystem</i>				
Amphibian (ICRP Frog)	3.14E-02	7.99E+00	3.00E+00	2.50E+00
Annelid (ICRP Earthworm)	5.24E-03	1.00E+01	1.00E+00	1.00E+00
Arthropod - detritivorous (FASSET Woodlouse)	1.70E-04	1.74E+00	6.13E-01	3.05E-01
Bird (ICRP Duck)	1.26E+00	3.00E+01	1.00E+01	8.02E+00
Flying insects (ICRP Bee)	5.89E-04	2.00E+00	7.50E-01	7.50E-01
Grasses & Herbs (ICRP Wild grass)	2.62E-03	5.00E+00	1.00E+00	1.00E+00
Lichen & Bryophytes (ICRP Bryophyte)	1.70E-04	4.01E+00	2.29E-01	2.29E-01
Mammal - large (ICRP Deer)	2.45E+02	1.30E+02	6.00E+01	6.00E+01
Mammal - small-burrowing (ICRP Rat)	3.14E-01	2.00E+01	6.00E+00	5.00E+00
Mollusc - gastropod (ICRP Snail)	1.40E-03	1.88E+00	1.54E+00	9.27E-01
Reptile (FASSET snake note this is an ellipsoid)	7.44E-01	1.16E+02	3.49E+00	3.49E+00
Tree (ICRP Pine tree)	4.71E+02	1.00E+03	3.00E+01	3.00E+01
<i>Marine Ecosystem</i>				
Benthic fish (ICRP Flat fish)	1.31E+00	3.99E+01	2.49E+01	2.51E+00
Bird (ICRP Duck, Wading bird)	See above			
Crustacean (ICRP Crab)	7.54E-01	2.00E+01	1.20E+01	6.00E+00
Macroalgae (ICRP Brown seaweed)	6.52E-01	5.00E+01	5.00E-01	5.00E-01
Mammal (FASSET Mammal)	1.82E+02	1.80E+02	4.39E+01	4.39E+01
Mollusc - bivalve (FASSET Benthic mollusc)	1.64E-02	5.00E+00	2.50E+00	2.50E+00
Pelagic fish (FASSET Pelagic fish)	5.65E-01	3.00E+01	6.00E+00	6.00E+00
Phytoplankton (ERICA Phytoplankton) <sup>(a)</sup>	1.00E-06	5.00E-03	5.00E-03	5.00E-03
Polychaete worm (FASSET Benthic worm)	1.73E-02	2.30E+01	1.20E+00	1.20E+00
Reptile (ICRP Turtle)	1.39E+02	8.50E+01	3.90E+01	8.00E+01
Sea anemones & True coral (ICRP Polyp)	1.77E-03	1.50E+00	1.50E+00	1.50E+00
Vascular plant (FASSET Vascular plant)	2.62E-02	9.29E+00	2.32E+00	2.32E+00
Zooplankton (FASSET Zooplankton)	6.14E-05	6.20E-01	6.10E-01	3.10E-01
<i>Freshwater Ecosystem</i>				
Amphibian (ICRP – Frog)	See above			
Benthic fish (FASSET Benthic fish)	1.47E+00	5.00E+01	8.01E+00	7.01E+00
Bird (ICRP Duck)	See above			
Crustacean (FASSET Crustacean)	1.57E-05	1.00E+00	3.00E-01	1.00E-01
Insect larvae (FASSET Insect larvae)	1.77E-05	1.50E+00	1.50E-01	1.50E-01
Mammal (FASSET Mammal)	3.90E+00	3.30E+01	1.50E+01	1.50E+01
Mollusc - bivalve (FASSET Bivalve mollusc)	7.07E-02	1.00E+01	4.50E+00	3.00E+00
Mollusc - gastropod (FASSET Gastropod)	3.53E-03	3.00E+00	1.50E+00	1.50E+00
Pelagic fish (ICRP Salmonid/Trout)	1.26E+00	5.00E+01	8.01E+00	6.01E+00
Phytoplankton (ERICA Phytoplankton) <sup>(a)</sup>	1.00E-06	7.97E-03	7.01E-04	7.01E-04
Reptile (ERICA Freshwater reptile) <sup>(b)</sup>	1.00E+00	1.80E+01	1.20E+01	6.00E+00
Vascular plant (FASSET Vascular plant)	1.05E-03	1.00E+02	1.00E-01	2.00E-01
Zooplankton (FASSET Zooplankton)	2.35E-06	2.00E-01	1.40E-01	1.60E-01

(a) For technical reasons (i.e. the lower bound of the dosimetric extrapolation tool (see the “add organism” function) has a lower cutoff which exceeds selected default masses) the mass of both marine and freshwater phytoplankton has been set to 1.00E-06 Kg replacing the old values of 6.54E-11 kg and 2.05E-12 kg for FASSET marine and freshwater phytoplankton respectively. This is a relatively small geometry and can be considered to represent an accreted mass of phytoplankton cells.

(b) Representative of adult female European pond turtle (*Emys orbicularis*).

After pressing the “Add organism” button, you are prompted to provide some basic information:

- A name for the organisms’ geometry by entering text in the text box
- Select appropriate wildlife group to link to the effects look-up tables
- Any additional comment (in the freeform text box) as needed.

The “Ecosystem” to which the new organism belongs is also shown on this screen. This is coloured grey, however, to denote the fact that the text box is not editable as the ecosystem selection was made on the previous “Assessment Context” screen. If the terrestrial ecosystem is selected, an additional dialogue box is activated. This text box is listed as “specimen” and has the options “vegetation”, “ground-living animal” or “bird or flying insect” in a drop down list. This information is needed in order for the correct implementation of the dosimetry module as the selection activates the relevant occupancy factor dialogue boxes on the following screen for these organism types. Please note that if you are setting up a new geometry for a mammal (e.g. a bat) then you are advised to use the specimen “bird or flying insect” as this will provide an occupancy factor for in air. Then click the next button.

*Back:* Click the back button to return to the previous screen to make further modifications to the input or to check on the information entered, any modifications made to either the current page before moving to the previous screen or any changes made to the previous screen are made in the tool record. This allows mistakes or omissions to be corrected at any time when using the tool.

*Next:* Click the next button once the screen has been completed to move to the next screen.

### 10.2.2 Organism Details – Occupancy Factors

Depending upon the ecosystem selected you will now see a set of occupancy factor options as follows:

For terrestrial ecosystems:

- On soil (i.e. an organism foraging on the surface of the soil)
- In soil (i.e. time spent underground whilst burrowing for example)
- In air (i.e. time spent above the soil surface say whilst flying for example)
- Maximum height over ground (m) (for bird specimen only)

For aquatic ecosystems:

- Water-surface (i.e. time spent on the surface of water for example by a duck)
- Water (time spent in the water column say for example a fish swimming through the water)
- Sediment-surface (time spent at the bottom of the water column perhaps by a bottom dwelling fish or a sedentary species such as a mussel which lives in the top few cm of the sediment)
- Sediment (time spent in the sediment for example if you are a polychaete worm)

All the values should be entered as a fraction and the total of the boxes can not exceed 1 although the tool will accept values that add up to less than 1. You will not be able to proceed if total fraction exceeds 1 as the ‘next’ button will be greyed out and unavailable to press. Modifying the numbers to 1 or less will make the ‘next’ button available to be pressed. Also please note that you can not continue unless there is a value entered into each available box. This means for example that if you have a fish species that spends all its time swimming in the water column then the “in water” box should contain 1 and that the water surface, sediment surface and sediment boxes all must contain 0 in order for you to proceed.

An additional feature with the terrestrial ecosystem is the parameter “isource”. The tool provides the option of calculating DCCs based on 2 different source configurations these being:

- An infinite plane isotropic source of depth  $0.5 \text{ g cm}^{-2}$
- An infinite volume isotropic source uniformly distributed up to 10cm in depth

The choice of the source will obviously depend on the depth distribution of the contamination being assessed. If the radionuclides under assessment are associated with surface soils, then option 1 might be suitably selected. If the radionuclides are well mixed or uniformly distributed to a substantial depth, then option 2 may be appropriate.

Note that there are limitations on which reference organisms appear under which ecosystems. For example it is not possible to calculate a DCC for a marine bird in air. This is related to the way the Tool has been constructed. Potential options to alleviate problems caused by these restrictions are:

- use the default or create an appropriately sized geometry for a marine bird but assume that it spends all its time on the water or sediment. This will generally be conservative particularly for the latter occupancy.
- create geometries for each habitat type separately. For instance, create a geometry in the terrestrial habitat using appropriate occupancy factors and then conduct the assessment using the terrestrial ecosystem model and assume that the activity concentration when entered into the soil category is equivalent to that of the water activity concentration for the aquatic situation. Then create a geometry for the aquatic habitat and follow the normal approach to estimating the dose rate to the organism geometry in the aquatic ecosystem of interest.

*Back:* Click the back button to return to the previous screen to make further modifications to the input or to check on the information entered, any modifications made to either the current page before moving to the previous screen or any changes made to the previous screen are made in the tool record. This allows mistakes or omissions to be corrected at any time when using the tool.

*Next:* Click the next button once the screen has been completed to move to the next screen.

### 10.2.3 Organism Geometry

On this screen, you must enter information concerning the mass (in kg) and the dimensions (of height, width and length in metres) of your organism. The dimensions represent the dimensions of 3 axis of an ellipsoid. The tool reports the mass range (min and max values in greyed out boxes) for which the calculation is valid. This is in the section “Mass” and is defined under the heading “Mass range allowed for ... in the Biota DCC tool”). The mass you enter must be between these values otherwise the next button remains unavailable.

For terrestrial organisms the create organism tool has predefined the mass ranges for the different ‘specimen’ categories as follows:

- 0.0017 to 550 kg for animals living above ground
- 0.0017 to 6.6 kg for animals living in a homogeneously contaminated soil layer
- 0.035 to 2 kg for birds

In some cases, an assessor might want to estimate exposures outside the permitted mass ranges for the terrestrial ecosystem. In this case, the table below provides the expected deviations for lower or higher masses. These deviations are summarised in the following text:

- The difference between the external exposure for an organism (in soil, on soil and above soil) with a mass of < 0.00017 kg and an organism with the permitted lower limit mass of 0.00017 kg is < 2 % in all cases. The exposure for a mass of < 0.00017 kg is greater than that defined for a 0.00017 kg organism.
- The difference between external exposure for an on soil organism with a mass of 1000 kg and the permitted upper limit mass of 550 kg is < 10 %. The difference for in soil organisms with a mass of  $\approx$  25 kg and the permitted upper limit mass of 6.6 kg is < 30 %. The difference for an above soil organism with a mass of  $\approx$  7 kg and the permitted upper limit mass of 2 kg is < 10

% . The external exposure for all masses (in all configurations in soil, on soil and above soil) above the allowed mass maximum limit are lower than the exposure specified at the limit.

- The difference between internal exposure from a 1MeV photon for a mass of 0.0001 kg and the permitted minimum mass of 0.00017 is < 40 % for on soil and in soil organisms. For above soil organisms the difference between a 0.01 kg organism and the permitted minimum mass of 0.035 kg for a 1 MeV photon is < 35 %. The difference between internal exposure from alpha and beta irradiation for a mass below the permitted range and the exposure at the minimum allowable masses of 0.00017 or 0.035 kg is small (<2 % in the example cases given in the table). The internal exposures for masses below the permitted range are lower in all cases.
- The difference between the exposure from a 1 MeV photon for a mass of 1000 kg and the permitted maximum mass of 550 kg is < 25 % for the on-soil configuration. For in soil organisms, the difference between a 10 kg mass and the permitted maximum mass of 6.6 kg is < 25 % and for in air the difference is < 50 % for a mass of  $\approx 7$  kg compared to the maximum permitted mass of 2 kg. For the case of exposure from alpha and beta irradiation, differences between exposures associated with masses above the maximum permissible level and those at the maximum mass range are small (< 2 % for the example cases given in Table 10). The internal exposures for masses above the permitted range are higher in all cases.

Details for all ‘specimen’ types are given in Table 10 below.

**Table 10: Guidance to assess exposure to terrestrial biota outside the defined mass ranges**

Habitat	Mass range (kg)	General trend	Difference to lower/upper mass limit
<b>External exposure</b>			
On soil	< 0.00017	Higher than for m = 0.00017	<2%
	> 550	Lower than for m=550 kg	< 10% for m=1000 kg
In soil	< 0.00017	Higher than for m = 0.00017	< 2%
	> 6.6	Lower than for m=6.6 kg	< 30% for m $\approx$ 25 kg
Above soil (birds)	< 0.035	Higher than for m = 0.00017	< 2%
	> 2	Lower than for m=2 kg	Less than 10% for m $\approx$ 7 kg
<b>Internal exposure</b>			
On soil	< 0.00017	Lower than for m=0.00017 kg	< 40% for 1-MeV-photons for m = 0.0001 kg < 2% for 0.5-MeV-betas for m = 0.0001 kg < 1% for alphas
	> 550	Higher than for m = 550 kg	< 25% for photons for m = 1000 kg < 2% for betas < 1% for alphas < 25%
In soil	< 0.00017	Lower than for m=0.00017 kg	< 40% for 1-MeV-photons for m = 0.0001 kg < 2% for 0.5-MeV-betas for m = 0.0001 kg < 1% for alphas
	> 6.6	Higher than for m =6.6 kg	< 25% for photons for m = 10 kg < 2% for betas < 1% for alphas
Above soil (birds)	< 0.035	Lower than for m=0.035 kg	< 35% for 1-MeV-photons for m = 0.01 kg < 2% for betas for 1-MeV-photons for m = 0.0001 kg < 1% for alphas
	> 2	Higher than for m = 2 kg	< 50% for photons for m = 6.6 kg < 2% for betas < 1% for alphas

Potential options to account for the over or under-predictions in dose-rate caused by these mass restrictions are:

- use available mass range and accept that the calculated dose rates will differ from what they should be as defined in the table above

- if the user defined organism is within the on-soil mass ranges assume 100% occupancy on soil. For flying animals this would be conservative although for animals residing in the soil this will underestimate dose rates (the magnitude of this depending upon the overall time spent in soil)
- create geometries for each habitat type separately. For instance, a wolf is in excess of 6.6 kg but does spend some time underground. Therefore the user could create an ‘on-soil’ organism with the correct mass (e.g. 15 kg) and also an ‘in-soil’ organism with the maximum allowable mass (6.6. kg). For on-soil and internal dose rates estimate would then be correct but the in-soil dose rates from external radiation would deviate as suggested in the table above.

For all aquatic organisms the allowable mass range is 1E-6 to 1000 kg.

The calculation box on this screen provides some background information in relation to how the calculations are performed. Essentially mass is used as the primary parameter within the calculations assuming a density of 1 g cm<sup>-3</sup>. The dimensions provided by you are used to calculate scaling factors, Chi and Ksi that are subsequently used in the DCC calculation module.

The fourth box on this screen defines the scaling parameters Chi and Ksi and reports their values (based on the user entered dimensions) for reference.

A frequently asked question at this stage is how or where do you obtain the dimensions for your new organism? There are several methods that have been employed to good effect to locate this information assuming that you have a species in mind that you wish to determine the doses to. Typically the approaches have focused either on:

- Web or literature based searches for the information regarding the occupancy factors, dimensions and weight of a particular species of interest.
- The use of photographs of the species of interest from which measurements can be made using a ruler and then used to calculate the size of the organism. Note that this approach requires at least one dimension to be known from the literature to scale the measurements.

*Back:* Click the back button to return to the previous screen to make further modifications to the input or to check on the information entered, any modifications made to either the current page before moving to the previous screen or any changes made to the previous screen are made in the tool record. This allows mistakes or omissions to be corrected at any time when using the tool.

*Next:* Click the next button once the screen has been completed to calculate the DCCs for the new organism geometry and to move to the next screen which will allow you to review all the parameters that have been entered and created by the tool.

*Finish:* Once you are satisfied with the data that has been entered pressing the ‘Finish’ button will complete the new geometry information and return you to the Assessment Context screen where the new organism geometry will appear now in the select from list for the organisms. This new organism geometry will also be available to other assessments that you conduct in the future.

#### 10.2.4 Add Organism Review Parameters

On this screen you have the opportunity to review and check the numbers calculated for the new organism geometry. Depending upon the choices made in the previous screen different options will be available but essentially these consist of the radioecology parameters (e.g. concentration ratios (CRs)), the dose conversion coefficients that have been calculated and the occupancy factors that you entered.

For the concentration ratios you now have the opportunity for as many of the radionuclides listed as you wish to enter information on the single value to represent the concentration ratio (see the text on

the derivation of the CRs – Section 10.4) and to enter, if there is sufficient data and it is of good enough quality, a probability distribution function for the data along with details of the reference(s) and comments on the data source that you may wish to add to the database for use later on in the assessment tool. *Note that you can also enter the information on these specific radionuclides that are included in the assessment at a later stage in the tool if you do not enter any CR information here.* However you must provide a CR value for each radionuclide/reference organism combination in the assessment tool before you can complete the calculations for the dose rates but the tool will force you to provide this information later if it is not added here.

Note that it is possible to edit the DCCs that have been calculated but we would not advise you to do this unless you have a very good reason for doing so and that you provide a justification for this within the comments box for the parameter that you change. You can also enter a distribution function for any of the DCC parameters.

Note that you can also edit these parameters in the future via the Database menu (Section 10.10 Database window).

*Back:* Click the back button to return to the previous screen to make further modifications to the input or to check on the information entered, any modifications made to either the current page before moving to the previous screen or any changes made to the previous screen are made in the tool record. This allows mistakes or omissions to be corrected at any time when using the tool.

*Finish:* Once you are satisfied with the data that has been entered pressing the ‘Finish’ button will complete the new geometry information and return you to the Assessment Context screen where the new organism geometry will appear now in the select from list for the organisms. This new organism geometry will also be available to other assessments that you conduct in the future.

### ***10.3 Assessments of adjacent ecosystems***

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

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

#### **10.3.1. An assessment of a transitional environment (e.g. saltmarsh)**

The assessment tool should first be run to assess the dose rates to each reference organism (including assessor specified organisms at Tiers 2 and 3) in the terrestrial environment. The assessment tool should then be run to assess the dose rates to each reference organism (including assessor specified organisms at Tiers 2 and 3) in the marine environment. In both cases, for a retrospective assessment, where sufficient measured data are available, these should be used as input into the tool. In the case of a prospective assessment or where there is limited or no measured data available, then the assessor will need to use a model to determine the activity concentrations for use as the input values into the assessment tool. The assessor may use the SRS-19 models or their own site-specific model.

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

A third option might be to determine a spatially averaged input value. This can be achieved in a number of different ways but perhaps using a geographical information system (GIS) using a weighted average approach. You will need information on the time a particular species spends in a particular part of the environment along with the activity concentrations from within given spatial areas.

#### ***10.4 Concentration Ratios - Derivation of ERICA values from the literature***

The activity concentrations of radionuclides in biota within the ERICA tool are predicted from media activity concentrations using equilibrium concentration ratios (CRs). The definitions of CR for the ERICA ecosystems are:

##### *Terrestrial*

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

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

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

##### *Aquatic*

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

By preference, values of CR were derived from reviews of original publications.

However, data were not always available in the format required. Common issues which had to be addressed were: (i) presentation of biota activity concentrations on a dry or ashed weight basis; (ii) data available only for specific tissues (i.e. not whole body); (iii) soil activity concentrations being presented as  $\text{Bq m}^{-2}$ .

##### 10.4.1 Data manipulation

Where information was not given within the source publications to enable manipulation of the data into the format required for the ERICA default databases a set of standard assumptions were followed. Tables 11-13 respectively present: (i) conversion factors for data presented on an ash or dry weight basis to fresh weight; (ii) percentages of total animal live-weight comprised by given tissues; (iii) distribution of radionuclides within different tissues. If source publications lacked the required information to convert soil activities from  $\text{Bq m}^{-2}$  to  $\text{Bq kg}^{-1}$ , a soil bulk density of  $1400 \text{ kg m}^{-3}$  and a sampling depth of 10 cm were assumed.

There are some uncertainties within the default database resulting from additional compromises that had to be made. For instance, some CR values for aquatic systems were estimated using unfiltered water. Similarly, soil sampling depths were often not given. Furthermore, whilst the CR is supposed to

represent an equilibrium transfer value it is likely that many of the values within the default databases were not derived under equilibrium conditions. See Beresford et al. (2004) for a full discussion of these issues when deriving CR values for wild species.

For terrestrial ecosystems data collected during either the period of above ground nuclear weapons testing fallout (assumed to be before 1970) or the year of the Chernobyl accident (1986) were not used to derive transfer parameter values to avoid effects of surface contamination of vegetation. Some CR values have been derived using stable element data. In terrestrial ecosystems these data were generally associated with studies of heavy metal pollution, only data for control ('uncontaminated') sites were used.

In the case of marine crustaceans, a 'concentrating organ' has been defined to encompass all body parts that have been shown to concentrate selected radionuclides. For some crustaceans, e.g. crabs and lobsters, gills appear to be the critical organs in terms of their accumulation of Pu and Am. For Tc uptake in lobster, the green gland and hepatopancreas are critical organs in the same crustacean groups (Busby *et al.*, 1997). For other radionuclides, other body parts/organs exhibit elevated uptake as exemplified by higher uptake of Sr to the exoskeleton of crustaceans (Templeton, 1962). 'Concentrating' organ is not easily defined - different radionuclides exhibit markedly different affinities. Where differentiation does occur, hepatopancreas, green gland and gills appear to be important accumulating body parts. A mean of these values is thus derived.

For marine mammals, many of the data reported in published literature are for (stable element) concentrations in individual organs, e.g. Yeats *et al.*, (1999). For seals the organs/body parts mainly studied can be classified under 5 headings: muscle, liver, kidney, blubber and other (often brain and blood). For sake of convenience these distinctions have been used in this study to derive equivalent whole body concentration CRs. In the case of Pu, Po and Sr, skeleton has been treated separately owing to the fact that these radionuclides are known to concentrate in this biological compartment.

Owing to lack of information in some cases, fish data have been supplemented by data for mammals, i.e. human based on Schmidt-Nielsen (1990).

#### 10.4.2 Statistical analyses

Where possible weighted arithmetic mean CR values and standard deviations have been estimated. Lack of information in source publications again resulted in some assumptions and compromises sometimes having to be made to achieve this. These were: (i) a sample number of one was assumed if information was not given; (ii) if a measure of error (e.g. standard deviation or standard error) was reported but no sample number it was assumed that the sample number was three; (iii) if a measure of error was reported for either only media or biota activity concentrations this was carried through (proportionally) to give a standard deviation estimate on the calculated CR values; (iv) a sample number of two was assumed if a minimum and maximum were reported with no details of sample number. Note, for reference organism-radionuclide combinations for which there were many reported values, references which did not give all the required information were rejected.

**Table 11** Assumed ash or dry weight to fresh weight conversion factors (expressed as ash or dry weight as a fraction of fresh weight).

Organism	Dry weight fraction	Ash weight fraction	Reference
<i>Terrestrial</i>			
Lichen	0.36	0.07	CEH; Sheard et al.1988
Grass/herb	0.25		CEH

Shrub (wood)	0.5	0.013	Assumed to be same as tree wood
Shrub (other parts)	0.1	0.003	CEH; Sheard et al. 1988
Tree (wood)	0.5	0.013	<a href="http://www.woodycrops.org/mechconf/nurmi.html">http://www.woodycrops.org/mechconf/nurmi.html</a> ; Sheard et al. 1988
Tree (other parts)	0.1	0.003	Assumed to be the same as shrub
Small mammals (whole body)	0.3		D. Copplestone (Environment Agency, UK) pers comm.
Mammal (bone)	0.8	0.5	CEH
Mammal (muscle)	0.25		CEH
Amphibians (whole body)	0.21		S. Gaschak (IRL Slavutych, Ukraine) pers. comm.
Bird (whole body)	0.3		Assumed to be same as small mammal
Detritivorous invertebrate	0.25	0.024	CEH; Mietelski et al 2004
Flying insect	0.25		Assumed to be the same as detritivorous invertebrate
Soil invertebrate (worm)	0.17		CEH
Gastropod	0.2		Gasó et al. (2002)
<i>Marine</i>			
All biota	0.18	0.01	IAEA (2004)
<i>Freshwater</i>			
Phytoplankton	0.2		
Vascular plant	0.25		
Bi-valve mollusc	0.25		
Crustacean	0.25		
Insect larvae	0.25		
Amphibians (whole body)	0.21		

**Table 12** Assumed organ weights as percentage of live-weight.

Organism	Assumption	Reference
<i>Terrestrial</i>		

Mammal	Bone comprises 10% of body	CEH
Bird	Bone comprises 7% of live-weight	S. Gaschak (IRL Slavutych, Ukraine) pers. comm.
Bird	Bird is 25% muscle by dry matter	Brisben 1993.
<i>Marine</i>		
Fish	Liver, hepatopancreas comprises 1% of total body mass	Lanno & Dixon (1996); Chellappa et al. (2003); Ben Ekanem et al. (2004); Shmidt-Nielsen (1990).
Fish	Skeleton comprises 15% of total body mass	Cameron (1985)
Fish	Viscera/gastro-intestinal tract comprises 17% of total body mass	Nonnis-Marzano & Triulzi (1993)
Fish	Muscle comprises 13% of total body mass	Nonnis-Marzano & Triulzi (1993); Shmidt-Nielsen (1990).
Crustaceans	'Concentrating organ' (e.g. gill, hepatopancreas and green gland) comprises 5% of total body mass	Skwarec & Falkowski (1988); Guary & Fowler (1990)
Crustaceans	Exoskeleton comprises 54% of total body mass	Skwarec & Falkowski (1988); Guary & Fowler (1990)
Crustaceans	Viscera/gastro-intestinal tract comprises 3% of total body mass	Skwarec & Falkowski (1988); Guary & Fowler (1990)
Crustaceans	Muscle comprises 23% of total body mass	Skwarec & Falkowski (1988); Guary & Fowler (1990)
Mammals	Liver and kidney comprises 0.85% of total body mass	Lydersen et al. (1992); NRPA
Mammals	Blubber comprises 33% of total body mass	Lydersen et al. (1992); NRPA
Mammals	Muscle comprises 30% of total body mass	Lydersen et al. (1992); NRPA
Mammals	Skeleton comprises 5% of total body mass	Lydersen et al. (1992); NRPA

**Table 13** Assumed distribution of radionuclides.

Organism	Radionuclide	Assumption <sup>1</sup>	Reference
<i>Terrestrial</i>			
Mammal	Pu	45% body burden in bone	Coughtrey et al. 1984a
Mammal	Am	45% body burden in bone	Coughtrey et al. 1984b
Mammal	Po	60% body burden in bone	ICRP 1979
Mammal	Sr	90% body burden in bone	Coughtrey & Thorne 1983

Mammal	Pb	70% body burden in bone	Morgan 1991
Bird	Pu	55% body burden in bone	Assumed to be the same as mammal
Mammal	Cs, U, Th	Muscle assumed to represent whole body	Coughtrey & Thorne 1983 (Cs); assumed same as birds (U & Th)
Bird	Cs, U, Th	Muscle/soft tissues assumed to represent whole body	Assumed to be the same as for mammals (Cs); Beresford et al. 2006 (U & Th)
Plants	All	Uniform distribution	
<i>Marine</i>			
Fish	Co	$C_{liver}:C_{muscle}=171$ $C_{skeleton}:C_{muscle}=3$ $C_{viscera}:C_{muscle}=10$ $C_{other}:C_{muscle}=10$ $C_{whole\ body}:C_{muscle}=6^*$	Ishii et al. (1976); Ichikawa & Ohno (1974); Ancellin (1979); Van As et al. (1975); Bourlat et al. (1997); Jenkins (1969).
Fish	Po	$C_{liver}:C_{muscle}=28$ $C_{skeleton}:C_{muscle}=19$ $C_{viscera}:C_{muscle}=4$ $C_{other}:C_{muscle}=6$ $C_{whole\ body}:C_{muscle}=7$	Carvalho (1988); Nevissi & Schell (1975)
Fish	Pu	$C_{liver}:C_{muscle}=82$ $C_{skeleton}:C_{muscle}=66$ $C_{viscera}:C_{muscle}=110$ $C_{other}:C_{muscle}=3$ $C_{whole\ body}:C_{muscle}=30^*$	Rissanen et al. (1997); Wong et al., (1970); Bourlat et al. (1997); Guary et al. (1976); Nevissi & Schell (1975); Pentreath & Lovett (1978)
Fish	Sr	$C_{skeleton}:C_{muscle}=4.2$ $C_{whole\ body}:C_{muscle}=2^*$	Templeton (1959); NRPA(1995); NRPA(2000); AMAP(1999); Yamato et al. (1977).
Fish	Ra	$C_{skeleton}:C_{muscle}=6$ $C_{whole\ body}:C_{muscle}=2$	Meinhold & Hamilton (1991)
Crustaceans	Po	$C_{conc.org}:C_{muscle}=60$ $C_{exoskeleton}:C_{muscle}=6$ $C_{other}:C_{muscle}=19$	McDonald et al. (1993); Skwarzec & Falkowski (1988)

		$C_{\text{whole body}}:C_{\text{muscle}}=7^*$	
Crustaceans	Sr	$C_{\text{exoskeleton}}:C_{\text{muscle}}=2$ $C_{\text{whole body}}:C_{\text{muscle}}=1.5$	NRPA(2000)
Crustaceans	Tc	$C_{\text{conc.org}}:C_{\text{muscle}}=17$ $C_{\text{exoskeleton}}:C_{\text{muscle}}=1$ $C_{\text{other}}:C_{\text{muscle}}=2$ $C_{\text{whole body}}:C_{\text{muscle}}=2.5$	Busby <i>et al.</i> (1997); Kolstad & Rudjord (2005).
Mammal	Po	60% associated with mineral bone $C_{\text{liver/kidney}}:C_{\text{muscle}}=3$	ICRP (1979); Ilus(2006)
Mammal	Pu	90% of Pu associated with mineral bone and liver (split equally)	Based upon ICRP (1979)
Mammal	Sr	$C_{\text{skel}}:C_{\text{muscle}} = 14$	Rissanen (1999)

$C_{\text{tissue}}$  is concentration (g kg<sup>-1</sup>) or activity concentration (Bq kg<sup>-1</sup>)

\*Direct measurements available and used in the derivation

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### ***10.5 Conceptual Models***

A conceptual model is a textual or graphical representation of the relationship(s) between source(s), pathway(s) and receptor(s) developed on the basis of an understanding of the ecosystem being considered with the following definitions of source, pathway and receptor:

*Source:* the location of, in this case, radioactive substances in the environment from which exposure to non-human species can occur.

*Pathway:* The means by which a hazardous substance or agent comes into contact with or otherwise affects a receptor.

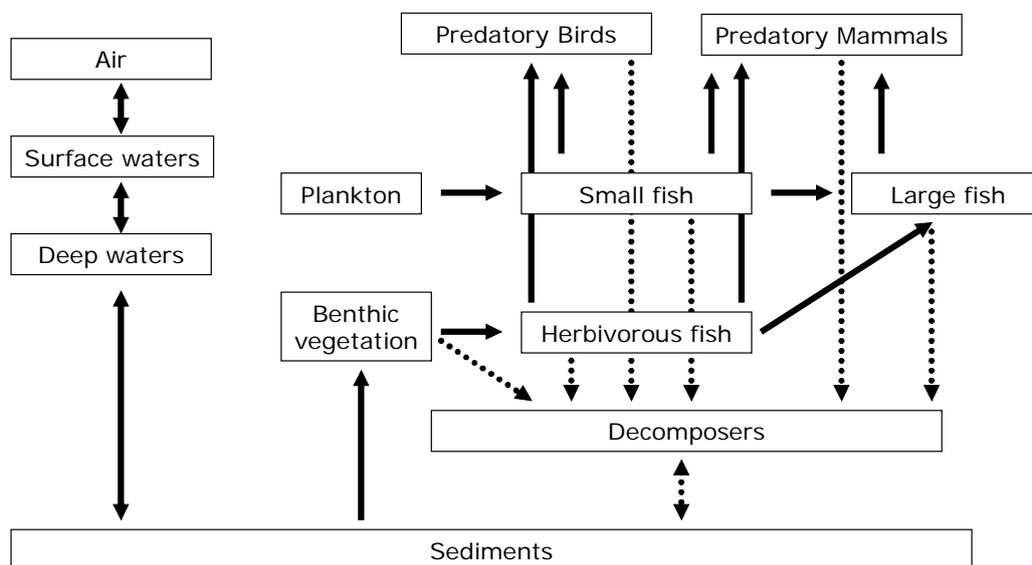
*Receptor:* The organism, population or community that might be affected by exposure to a contaminant of concern.

Tables and Figures 3 and 4 provide examples of the types of conceptual model that can be prepared to illustrate the source-pathway-receptor linkages.

The assessment tool comes with three examples of a conceptual model (one for each ecosystem type) that you can modify to suit your own purposes. It is important to think through what the source(s) of the radioactive substances is and how they might reach your receptors of interest (as defined in your problem formulation). The key point here is that this is the first point at which you might decide that there is no requirement for further assessment if you can establish that there is no source-pathway-receptor link. An example of this might be a site discharging radioactivity into a coastal system but where your assessment endpoint is to demonstrate the protection of non-human species inhabiting a terrestrial or freshwater site say 10km inland. In these circumstances it is unlikely that there will be a significant pathway for the migration of the radionuclides to the sites of interest and you could terminate the assessment here with this as the justification.

<b>Substrate</b>	a)Settlement b)Deposition	a)Settlement b)Consumption	a)Settlement b)Consumption	a)Settlement b)Consumption	a)Settlement b)Consumption	a)Settlement b)Consumption c)Material supply	a) Water transport b) Dehydration	Seeping Throughflow
Root growth	<b>Primary producers (a)</b>	a)Stimul./Inhib. b)Food supply	a)Stimul./Inhib. b)Food supply	a)Stimul./Inhib. b)Food supply	a)Stimul./Inhib.	a)Stimul./Inhib. b)Food supply d)Material supply	Root uptake	
a)Decomposition b)Bioturbation	a)Stimul./Inhib	<b>Decomposers (a,b,c)</b>	a)Stimul./Inhib. b)Food supply	a)Stimul./Inhib. b)Food supply	a)Stimul./Inhib. b)Food supply	a)Stimul./Inhib. b)Food supply d)Material supply	Decomposition	a)Interception b)Retard./Accel. c)Uptake/Excret. d)Covering
Bioturbation	a)Stimul./Inhib. b)Feeding	a)Stimul./Inhib. b)Food supply c)Feeding	<b>Filter feeders (a,b,c)</b>	a)Stimul./Inhib. c)Feeding	a)Stimul./Inhib. b)Food supply c)Feeding	a)Stimul./Inhib. b)Food supply d)Material supply		a)Decomposition b)Retard./Accel. c)Uptake/Excret. d)Movement
Bioturbation	a)Stimul./Inhib. c)Feeding	a)Stimul./Inhib. b)Food supply c)Eating mushrooms	a)Stimul./Inhib. b)Food supply	<b>Herbivores (a)</b>	a)Stimul./Inhib. b)Food supply	a)Stimul./Inhib. b)Food supply d)Resource		a)Water-pumping b)Retard./Accel. c)Uptake/Excret.
Bioturbation	a)Stimul./Inhib.	a)Stimul./Inhib. b)Food supply c)Feeding	a)Stimul./Inhib. b)Food supply c)Feeding	a)Stimul./Inhib. c)Feeding	<b>Carnivores (a,b,c)</b>	a)Stimul./Inhib. b)Food supply c)Feeding d)Resource		a)Movement b)Retard./Accel. c)Uptake/Excret.
Disturbance (dredging, digging)	a)Stimul./Inhib. b)Feeding c)Dispersal/ d)Extermination	a)Stimul./Inhib. b)Food supply c)Feeding d)Dispersal/ d)Extermination	a)Stimul./Inhib. c)Feeding d)Dispersal/ d)Extermination	a)Stimul./Inhib. c)Feeding d)Dispersal/ d)Extermination	a)Stimul./Inhib. b)Food supply c)Feeding d)Dispersal/ d)Extermination	<b>Humans (a)</b>	a)Water extraction b)Artific.infiltr.	a)Movement b)Retard./Accel. c)Uptake/Excret.
a)Erosion b)Water content change	a) Settlement b) Water uptake	a) Settlement b) Water uptake		a) Settlement b) Water uptake	a) Settlement b) Water uptake	a) Settlement b) Water use	<b>Groundwater</b>	a)Movement b)Retard./Accel. c)Uptake/Excret. d)Covering
Runoff	a)Settlement b)Relocation c)Water uptake	a)Settlement b)Relocation c)Water uptake	a)Settlement b)Relocation c)Water uptake	a)Settlement b)Relocation c)Water uptake	a)Settlement b)Relocation c)Water uptake	a)Settlement b)Relocation c)Water use	Richarge/discharge	<b>Surface water</b>

**Figure 3** CSM matrix figure - Generic conceptual model developed with the interaction matrix method. The Leading diagonal elements (LDEs) correspond to the components identified as being relevant conceptual model objects in the contaminant migration within the ecosystem. The Off-diagonal elements (ODEs) are interactions between LDEs (transfer processes between components). To identify the transfer processes the matrix should be read clockwise.



**Figure 4** CSM graphical figure for a marine ecosystem

## 10.6 Dose Conversion Coefficients - Derivation of the DCCs

To plants and animals may be exposed to ionising radiation from radionuclides in the environment by both external and internal exposure. Radionuclides distributed in the environment lead to the external radiation exposure of the organisms living in or close to a contaminated medium. The external exposures of biota are the result of complex and non-linear interactions of various factors:

- The contamination levels in the environment.
- The radionuclide-specific decay properties characterised by the radiation type, the energies emitted and the yield.
- The geometrical relationship between the source of the radiation and the target organisms.
- The composition and shielding properties of materials/media in the environment.
- The habitat and size of the organism.

The geometric relationship between radiation source and the exposed organism is a very important factor in relation to the received absorbed dose rate. The intensity of the radiation field around a source decreases with distance and it is influenced by the material between the radiation source and the target. The number of possible source target configurations is infinite, therefore, a number of limited and representative situations need to be selected for detailed consideration.

The exposure due to radioactivity incorporated into the organism is determined by the activity concentration in the organism, the size of the organisms, the type and the energy of the emitted radiation.

A key quantity for estimating internal doses is an absorbed fraction  $\phi$  which is defined as the fraction of energy emitted by a radiation source that is absorbed within the target tissue, organ or organism. In the simplest case, the organism is assumed to be in an infinite homogeneous medium and has uniformly distributed activity throughout its body. The densities of the medium and the organism's body are the same. Under these conditions, both internal ( $D_{\text{int}}$ ) and external ( $D_{\text{ext}}$ ) dose conversion coefficients (defined as absorbed dose rate per activity concentration in organism or medium) for mono-energetic radiation can be expressed as function of the absorbed fraction:

$$D_{\text{int}} = E \times \phi(E) \quad (1)$$

$$D_{\text{ext}} = E \times (1 - \phi(E)) \quad (2)$$

where  $E$  is the energy of a mono-energetic source. Eq. (2) is an approximation that – in strict sense – only holds if the organism and the surrounding medium are of the same density and elemental composition.

Absorbed fractions for photon and electron sources uniformly distributed in soft-tissue spheres and ellipsoids immersed in infinite water medium have been systematically calculated by Monte Carlo simulation. The calculations have covered an energy range of 10 keV to 5 MeV, a mass range from  $10^{-6}$  to  $10^3$  kg and shapes from sphere to ellipsoids with varying degree of non-sphericity (Ulanovsky and Pröhl, 2006). From the computed absorbed fractions a set of re-scaling factors has been derived, which allow to evaluate dose coefficients for ellipsoidal shape organisms from the data for spheres, using mass and proportions of the organism. An analytical approximation has been found relating the derived re-scaling factors and the non-sphericity parameter of the organism's body.

The approach was applied also for calculation of the absorbed fractions for non-aquatic animals and their internal exposures. With the use of the absorbed fractions for spheres and suggested re-scaling

and interpolation technique a set of the internal dose conversion coefficients has been calculated for all reference organisms.

For the derivation of dose conversion coefficients for external exposure, a differentiation is made between aquatic and terrestrial reference animals and plants. For aquatic organisms, which are immersed in water, there is no substantial difference between the density in water and the organism. So, the conditions for radiation transport are relatively homogeneous. Under those circumstances, the application of the approximation provides sufficient accuracy.

For terrestrial reference animals and plants, the estimation of external exposures is more complex than in the aquatic environment. Soil, air and organic matter differ considerably in composition and density, which cannot, in general, be adequately taken into account by the application of analytical solutions. Therefore, the derivation of DCCs is based on radiation transport simulated for mono-energetic photons by means of Monte Carlo techniques. Due to the complexity of the processes and the variability of life-forms, it is impossible to cover all possible exposure conditions. Therefore, generalised, representative cases as defined by energy, contaminated media, organism sizes are selected for detailed consideration. Exposure conditions, for which detailed calculations are not available, can then be deduced by interpolation between these cases. The following source–target relationships are taken into account:

External exposure of on- and above-soil reference animals and plants to a uniformly contaminated volume radionuclide source with a thickness of 10 cm,

External exposure of in-soil reference animals and plants that live in the middle of a uniformly contaminated volume radionuclide source with a thickness of 50 cm.

From the calculations for mono-energetic radiation sources, nuclide-specific dose conversion coefficients (DCC) are derived for external and internal exposure, taking into account the type of radiation as well as energy and intensity of the emission for any radionuclide included in ICRP 38.

The DCCs for internal exposure were derived, assuming a homogeneous distribution of the radionuclide in the organism. Unweighted DCCs for internal exposures are given. To illustrate the possible impact of the weighting factors of different kinds of radiation, weighted DCC for internal exposure are given assuming weighting factors of 10 for  $\alpha$ -radiation, 3 for low- $\beta$  radiation ( $E < 10$  keV), and 1 for  $\beta$ -radiation with energies above 10 keV and  $\gamma$ -radiation.

The units of the obtained dose conversion coefficients are [ $\mu\text{Gy h}^{-1}$  per  $\text{Bq kg}^{-1}$  or  $\mu\text{Gy h}^{-1}$  per  $\text{Bq m}^{-2}$ ] for volume and planar sources respectively. Radioactive daughter nuclides are included in the calculation of the DCCs, if their half-lives are shorter than 10 days. The two-dimensional linear and spline interpolation and extrapolation method over the energy and mass was applied.

### ***10.7 Environmental Media Concentration Limits - Derivation of the EMCLs***

Environmental Media Concentration Limits, EMCLs (in  $\text{Bq l}^{-1}$  or  $\text{kg}^{-1}$  of medium), are defined in Equation 1.

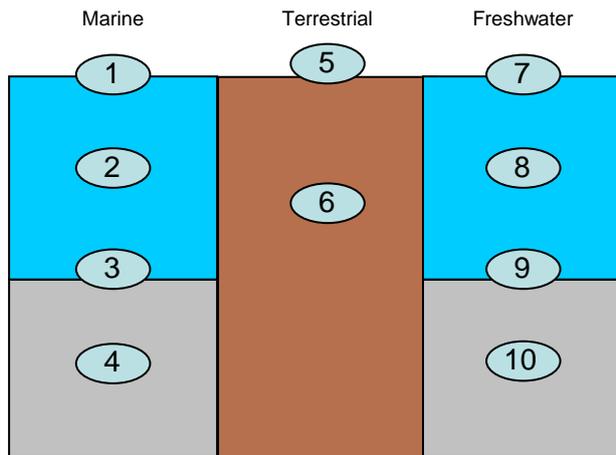
$$\text{EMCL} = \frac{\text{PNEDR}}{F} \quad (1)$$

Where:

PNEDR = Predicted no Effects dose rate or screening dose-rate ( $\mu\text{Gy h}^{-1}$ ); and

F is the dose rate that an organism will receive for the case of a unit concentration in environmental media ( $\mu\text{Gy h}^{-1}$  per  $\text{Bq l}^{-1}$  or  $\text{kg}$  (or  $\text{Bq m}^{-3}$  – terrestrial C, H, S, P only) of medium).

The incremental screening dose rate is  $10 \mu\text{Gy h}^{-1}$  for all ecosystems, as recommended by ERICA D5 (Garnier-Laplace et al., 2006) although the tool does allow the assessor to enter their own values in this screen. The value 'F' depends upon the reference organism type (as it is affected by the DCC values, CRs and position within habitat) and radionuclide (affected by the DCC values, CRs and  $K_d$ s). The habitats defined for the derivation of default occupancy factors and EMCLs are provided in Figure 5.



**Figure 5 The ten habitats in ERICA**

In deriving EMCLs, the selection of the default location within the habitat is based on the configuration that will result in maximum exposure of the organism, e.g. for the terrestrial soil invertebrate (**Annelid**), the assumption is made that the organism spends 100% of its time underground. The equations used to calculate the 'F' values for reference organisms are given below in Tables 14 to 18.

**Table 14 Habitats occupied by the ERICA marine reference organisms. In the case of several habitats for an organism, the equation is given for the habitat giving the highest dose-rate**

Organism	Habitat	Equation
Phytoplankton	2	$F = [DCC_{int} \cdot CR + DCC_{ext}^M]$
Macroalgae	3	$F = [DCC_{int} \cdot CR + 0.5 \cdot DCC_{ext}^M (1 + K_d^M)]$
Vascular plant	3	$F = [DCC_{int} \cdot CR + 0.5 \cdot DCC_{ext}^M (1 + K_d^M)]$
Zooplankton	2	$F = [DCC_{int} \cdot CR + DCC_{ext}^M]$
Polychaete worm	4	$F = [DCC_{int} \cdot CR + DCC_{ext}^M \cdot K_d^M]$
Mollusc - bivalve	3	$F = [DCC_{int} \cdot CR + 0.5 \cdot DCC_{ext}^M (1 + K_d^M)]$

Crustacean	3	$F = [DCC_{int} \cdot CR + 0.5 \cdot DCC_{ext}^M (1 + K_d^M)]$
Benthic fish	3	$F = [DCC_{int} \cdot CR + 0.5 \cdot DCC_{ext}^M (1 + K_d^M)]$
Pelagic fish	2	$F = [DCC_{int} \cdot CR + DCC_{ext}^M]$
Bird	1 & 2	$F = [DCC_{int} \cdot CR + DCC_{ext}^M]$
Mammal	1 & 2	$F = [DCC_{int} \cdot CR + DCC_{ext}^M]$
Reptile	1 & 2	$F = [DCC_{int} \cdot CR + DCC_{ext}^M]$
Sea anemones & True coral (Polyp)	3	$F = [DCC_{int} \cdot CR + 0.5 \cdot DCC_{ext}^M (1 + K_d^M)]$

CR = Concentration ratio (Bq kg<sup>-1</sup> fresh weight per Bq l<sup>-1</sup> or Bq kg<sup>-1</sup>); K<sub>d</sub> = distribution coefficient (l kg<sup>-1</sup>); DCC = dose Conversion coefficient (μGy h<sup>-1</sup> per Bq kg<sup>-1</sup>); subscript “int” = internal; subscript “ext” = external. DCC’s are always provided for a volumetric source (i.e. we do not use a planar source).

**Table 15 Habitats occupied by the ERICA freshwater reference organisms. In the case of several habitats for an organism, the equation is given for the habitat giving the highest dose-rate.**

Organism	Habitat	Equation
Phytoplankton	8	$F = [DCC_{int} \cdot CR + DCC_{ext}^F]$
Vascular plant	9	$F = [DCC_{int} \cdot CR + 0.5 \cdot DCC_{ext}^F (1 + K_d^F)]$
Zooplankton	8	$F = [DCC_{int} \cdot CR + DCC_{ext}^F]$
Insect larvae§	7, 8, 9, 10	$F = [DCC_{int} \cdot CR + DCC_{ext}^F \cdot K_d^F]$
Mollusc - bivalve	9	$F = [DCC_{int} \cdot CR + 0.5 \cdot DCC_{ext}^F (1 + K_d^F)]$
Mollusc - gastropod	9	$F = [DCC_{int} \cdot CR + 0.5 \cdot DCC_{ext}^F (1 + K_d^F)]$
Crustacean	9	$F = [DCC_{int} \cdot CR + 0.5 \cdot DCC_{ext}^F (1 + K_d^F)]$
Benthic fish	9	$F = [DCC_{int} \cdot CR + 0.5 \cdot DCC_{ext}^F (1 + K_d^F)]$
Pelagic fish	8	$F = [DCC_{int} \cdot CR + DCC_{ext}^F]$
Bird	7 & 8	$F = [DCC_{int} \cdot CR + DCC_{ext}^F]$
Mammal	7 & 8	$F = [DCC_{int} \cdot CR + DCC_{ext}^F]$
Amphibian	7 & 8	$F = [DCC_{int} \cdot CR + DCC_{ext}^F]$

§ If  $K_d < 1$ , this equation should be used:  $F = [DCC_{int} \cdot CR + DCC_{ext}^F]$

CR = Concentration ratio (Bq kg<sup>-1</sup> fresh weight per Bq l<sup>-1</sup> or Bq kg<sup>-1</sup>); K<sub>d</sub> = distribution coefficient (l kg<sup>-1</sup>); DCC = dose Conversion coefficient (μGy h<sup>-1</sup> per Bq kg<sup>-1</sup>); subscript “int” = internal; subscript “ext” = external. DCC’s are always provided for a volumetric source (i.e. we do not use a planar source).

‘F’ is calculated for each reference organism by using all available information, i.e. not just single deterministic parameter values but relevant statistical information relating to the parameter (e.g. , where there is sufficient data to justify the calculation of an arithmetic mean and standard deviation etc). There are several cases of information coverage:

- Well-defined datasets with mean, standard deviations and (assumed) PDFs – this is the case for some reference organism/radionuclide CR values.
- Poorly defined datasets with expected values only – e.g. K<sub>d</sub>s for aquatic environments and many of the CR values. In this case we apply an exponential distribution.
- Precisely calculated values for which the uncertainty is assumed to be zero e.g. all DCC values.

Probabilistic methods are currently employed in the derivation of a robust defensible conservative EMCL. Probabilistic calculations are made using the equations through Monte Carlo simulation. For example in the aquatic environment we may be using a CR value with lognormal distribution, a K<sub>d</sub> with exponential PDF and a single value for DCC. The output is in the form of a PDF for the parameter ‘F’.

Once we have the PDF of F then we can readily calculate any percentile of the EMCL for each organism. We have opted to select a conservative EMCL value, set at 5%. An example of how this works in practice is provided in Figure 6.

**Table 16 Habitats occupied by the ERICA Terrestrial reference organisms. In the case of several habitats for an organism, the equation is given for the habitat giving the highest dose-rate.**

Organism	Habitat	Equation
Annelid	6	$F = [DCC_{int} \cdot CR + DCC_{6,vol}^T]$
Arthropod - detritivorous	6	$F = [DCC_{int} \cdot CR + DCC_{6,vol}^T]$
Flying insects	5	$F = [DCC_{int} \cdot CR + DCC_{5,vol}^T]$
Mollusc - gastropod	6	$F = [DCC_{int} \cdot CR + DCC_{6,vol}^T]$
Lichen & bryophytes	5	$F = [DCC_{int} \cdot CR + DCC_{5,vol}^T]$
Grasses & Herbs	5*	$F = [DCC_{int} \cdot CR + DCC_{5,vol}^T]$
Shrub	5*	$F = [DCC_{int} \cdot CR + DCC_{5,vol}^T]$
Tree	5*	$F = [DCC_{int} \cdot CR + DCC_{5,vol}^T]$
Mammal - small-burrowing	6	$F = [DCC_{int} \cdot CR + DCC_{6,vol}^T]$

Mammal - large	5	$F = [DCC_{int} \cdot CR + DCC_{5,vol}^T]$
Bird	5	$F = [DCC_{int} \cdot CR + DCC_{5,vol}^T]$
Reptile	6	$F = [DCC_{int} \cdot CR + DCC_{6,vol}^T]$
Amphibian	6	$F = [DCC_{int} \cdot CR + DCC_{6,vol}^T]$

CR = Concentration ratio (Bq kg<sup>-1</sup> fresh weight per Bq kg<sup>-1</sup> or Bq m<sup>-3</sup> – C, H, S, P only); DCC = dose Conversion coefficient (μGy h<sup>-1</sup> per Bq kg<sup>-1</sup>); subscript “int” = internal; subscript “ext” = external. DCC’s are always provided for a volumetric source (i.e. we do not use a planar source). \* Calculated for meristem above ground.

**Table 17 “F” values for the derivation of sediment EMCLs in the marine environment**

Organism	Habitat	Equation
Phytoplankton	2	$F = \left[ DCC_{int} \cdot \frac{CR}{K_d^M} + DCC_{ext}^M \cdot \frac{1}{K_d^M} \right]$
Macroalgae	3	$F = \left[ DCC_{int} \cdot \frac{CR}{K_d^M} + 0.5 \cdot DCC_{ext}^M \left( 1 + \frac{1}{K_d^M} \right) \right]$
Vascular plant	3	$F = \left[ DCC_{int} \cdot \frac{CR}{K_d^M} + 0.5 \cdot DCC_{ext}^M \left( 1 + \frac{1}{K_d^M} \right) \right]$
Zooplankton	2	$F = \left[ DCC_{int} \cdot \frac{CR}{K_d^M} + DCC_{ext}^M \cdot \frac{1}{K_d^M} \right]$
Polychaete worm	4	$F = \left[ DCC_{int} \cdot \frac{CR}{K_d^M} + DCC_{ext}^M \right]$
Mollusc - bivalve	3	$F = \left[ DCC_{int} \cdot \frac{CR}{K_d^M} + 0.5 \cdot DCC_{ext}^M \left( 1 + \frac{1}{K_d^M} \right) \right]$
Crustacean	3	$F = \left[ DCC_{int} \cdot \frac{CR}{K_d^M} + 0.5 \cdot DCC_{ext}^M \left( 1 + \frac{1}{K_d^M} \right) \right]$
Benthic fish	3	$F = \left[ DCC_{int} \cdot \frac{CR}{K_d^M} + 0.5 \cdot DCC_{ext}^M \left( 1 + \frac{1}{K_d^M} \right) \right]$
Pelagic fish	2	$F = \left[ DCC_{int} \cdot \frac{CR}{K_d^M} + DCC_{ext}^M \cdot \frac{1}{K_d^M} \right]$
Bird	1 & 2	$F = \left[ DCC_{int} \cdot \frac{CR}{K_d^M} + DCC_{ext}^M \cdot \frac{1}{K_d^M} \right]$

Mammal	1 & 2	$F = \left[ \text{DCC}_{\text{int}} \cdot \frac{\text{CR}}{\text{K}_d^{\text{M}}} + \text{DCC}_{\text{ext}}^{\text{M}} \cdot \frac{1}{\text{K}_d^{\text{M}}} \right]$
Reptile	1 & 2	$F = \left[ \text{DCC}_{\text{int}} \cdot \frac{\text{CR}}{\text{K}_d^{\text{M}}} + \text{DCC}_{\text{ext}}^{\text{M}} \cdot \frac{1}{\text{K}_d^{\text{M}}} \right]$
Sea anemones & True coral (Polyp)	3	$F = \left[ \text{DCC}_{\text{int}} \cdot \frac{\text{CR}}{\text{K}_d^{\text{M}}} + 0.5 \cdot \text{DCC}_{\text{ext}}^{\text{M}} \left( 1 + \frac{1}{\text{K}_d^{\text{M}}} \right) \right]$

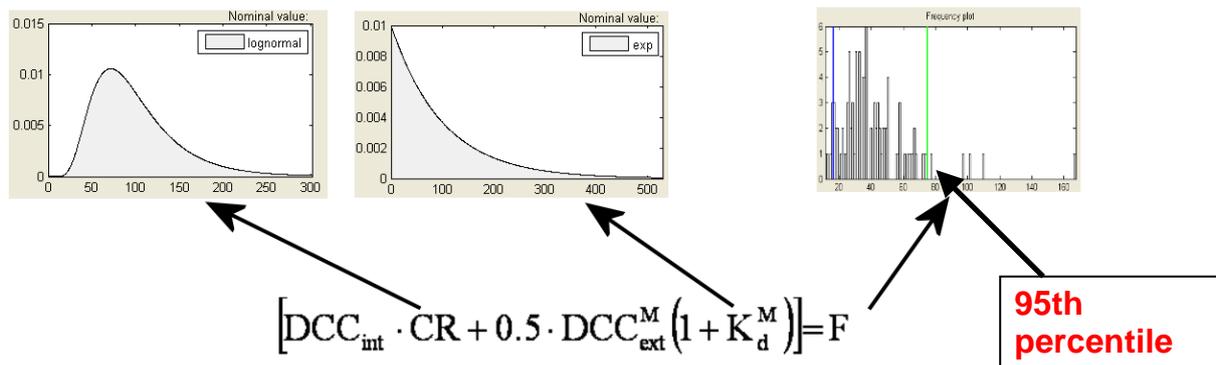
CR = Concentration ratio (Bq kg<sup>-1</sup> fresh weight per Bq l<sup>-1</sup> or Bq kg<sup>-1</sup>); K<sub>d</sub> = distribution coefficient (l kg<sup>-1</sup>); DCC = dose Conversion coefficient (μGy h<sup>-1</sup> per Bq kg<sup>-1</sup>); subscript “int” = internal; subscript “ext” = external. DCC’s are always provided for a volumetric source (i.e. we do not use a planar source).

**Table 18 “F” values for the derivation of sediment EMCLs in the freshwater environment**

Organism	Habitat	Equation
Phytoplankton	8	$F = \left[ \text{DCC}_{\text{int}} \cdot \frac{\text{CR}}{\text{K}_d^{\text{F}}} + \text{DCC}_{\text{ext}}^{\text{F}} \cdot \frac{1}{\text{K}_d^{\text{F}}} \right]$
Vascular plant	9	$F = \left[ \text{DCC}_{\text{int}} \cdot \frac{\text{CR}}{\text{K}_d^{\text{F}}} + 0.5 \cdot \text{DCC}_{\text{ext}}^{\text{F}} \left( 1 + \frac{1}{\text{K}_d^{\text{F}}} \right) \right]$
Zooplankton	8	$F = \left[ \text{DCC}_{\text{int}} \cdot \frac{\text{CR}}{\text{K}_d^{\text{F}}} + \text{DCC}_{\text{ext}}^{\text{F}} \cdot \frac{1}{\text{K}_d^{\text{F}}} \right]$
Insect larvae	7, 8, 9, 10	$F = \left[ \text{DCC}_{\text{int}} \cdot \frac{\text{CR}}{\text{K}_d^{\text{F}}} + \text{DCC}_{\text{ext}}^{\text{F}} \right]$
Mollusc - bivalve	9	$F = \left[ \text{DCC}_{\text{int}} \cdot \frac{\text{CR}}{\text{K}_d^{\text{F}}} + 0.5 \cdot \text{DCC}_{\text{ext}}^{\text{F}} \left( 1 + \frac{1}{\text{K}_d^{\text{F}}} \right) \right]$
Mollusc - gastropod	9	$F = \left[ \text{DCC}_{\text{int}} \cdot \frac{\text{CR}}{\text{K}_d^{\text{F}}} + 0.5 \cdot \text{DCC}_{\text{ext}}^{\text{F}} \left( 1 + \frac{1}{\text{K}_d^{\text{F}}} \right) \right]$
Crustacean	9	$F = \left[ \text{DCC}_{\text{int}} \cdot \frac{\text{CR}}{\text{K}_d^{\text{F}}} + 0.5 \cdot \text{DCC}_{\text{ext}}^{\text{F}} \left( 1 + \frac{1}{\text{K}_d^{\text{F}}} \right) \right]$
Benthic fish	9	$F = \left[ \text{DCC}_{\text{int}} \cdot \frac{\text{CR}}{\text{K}_d^{\text{F}}} + 0.5 \cdot \text{DCC}_{\text{ext}}^{\text{F}} \left( 1 + \frac{1}{\text{K}_d^{\text{F}}} \right) \right]$
Pelagic fish	8	$F = \left[ \text{DCC}_{\text{int}} \cdot \frac{\text{CR}}{\text{K}_d^{\text{F}}} + \text{DCC}_{\text{ext}}^{\text{F}} \cdot \frac{1}{\text{K}_d^{\text{F}}} \right]$
Bird	7 & 8	$F = \left[ \text{DCC}_{\text{int}} \cdot \frac{\text{CR}}{\text{K}_d^{\text{F}}} + \text{DCC}_{\text{ext}}^{\text{F}} \cdot \frac{1}{\text{K}_d^{\text{F}}} \right]$

Mammal	7 & 8	$F = \left[ \text{DCC}_{\text{int}} \cdot \frac{\text{CR}}{K_d^F} + \text{DCC}_{\text{ext}}^F \cdot \frac{1}{K_d^F} \right]$
Amphibian	7 & 8	$F = \left[ \text{DCC}_{\text{int}} \cdot \frac{\text{CR}}{K_d^F} + \text{DCC}_{\text{ext}}^F \cdot \frac{1}{K_d^F} \right]$

CR = Concentration ratio (Bq kg<sup>-1</sup> fresh weight per Bq l<sup>-1</sup> or Bq kg<sup>-1</sup>); K<sub>d</sub> = distribution coefficient (l kg<sup>-1</sup>); DCC = dose Conversion coefficient (μGy h<sup>-1</sup> per Bq kg<sup>-1</sup>); subscript “int” = internal; subscript “ext” = external. DCC’s are always provided for a volumetric source (i.e. we do not use a planar source).



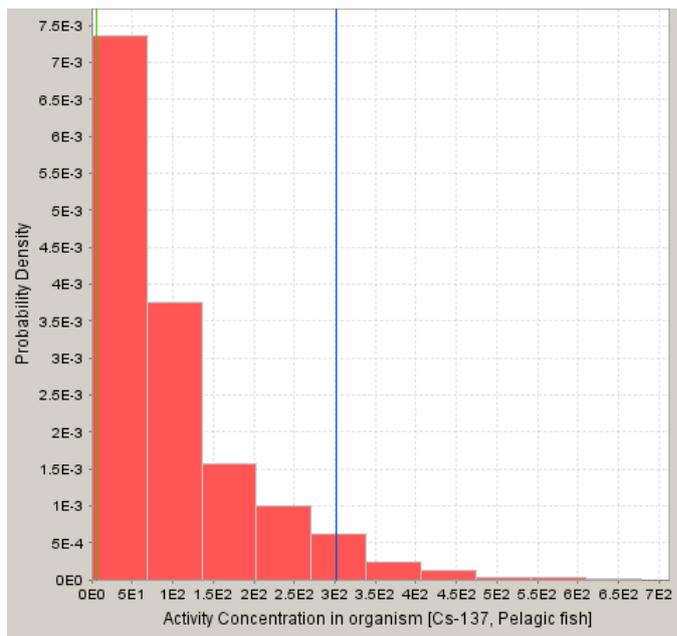
**Figure 6** Example of the use of probabilistic calculations in the derivation of EMCLs

The values derived using this methodology are presented in the section 10.19 EMCL Tabulated values.

## 10.8 Probability Distributions

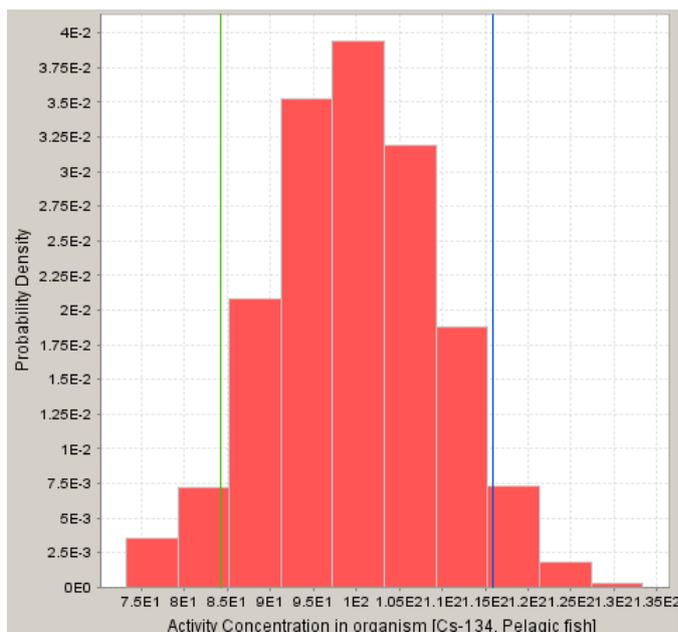
The ERICA Tool supports the most common pdf types, i.e. uniform, loguniform, exponential, normal, lognormal, triangular and logtriangular. The properties of these distribution types are well documented in the literature (see for example IAEA [1989] and Evans *et al.* [2000]). The following list provides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

- Exponential (enter mean, lower cut off and upper cut off values)



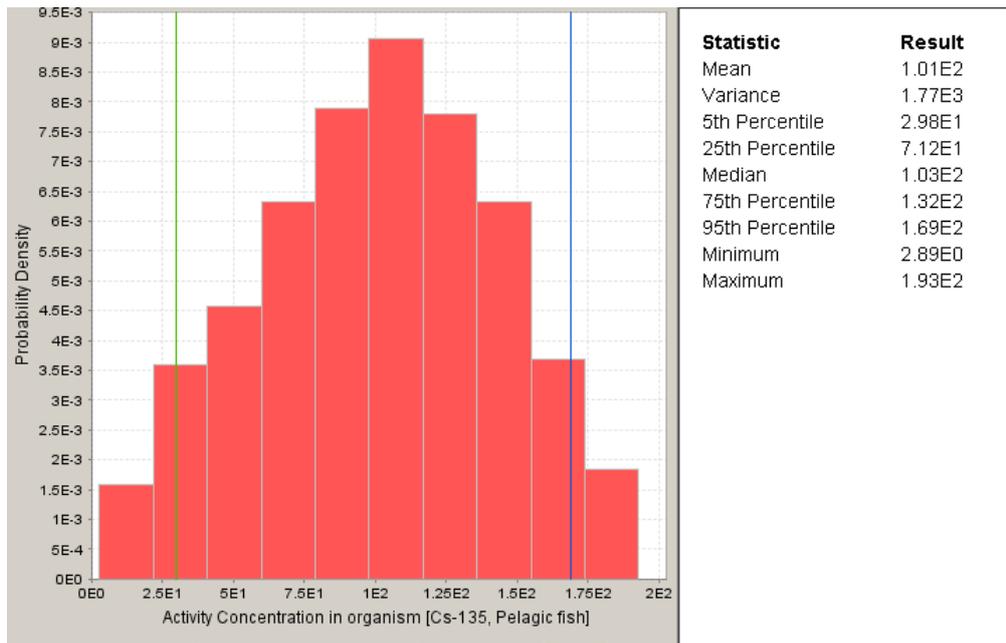
Statistic	Result
Mean	9.92E1
Variance	9.42E3
5th Percentile	5.82E0
25th Percentile	2.87E1
Median	6.79E1
75th Percentile	1.34E2
95th Percentile	3.02E2
Minimum	4.67E-2
Maximum	6.78E2

- Normal (enter mean, standard deviation, lower cut off and upper cut off values)

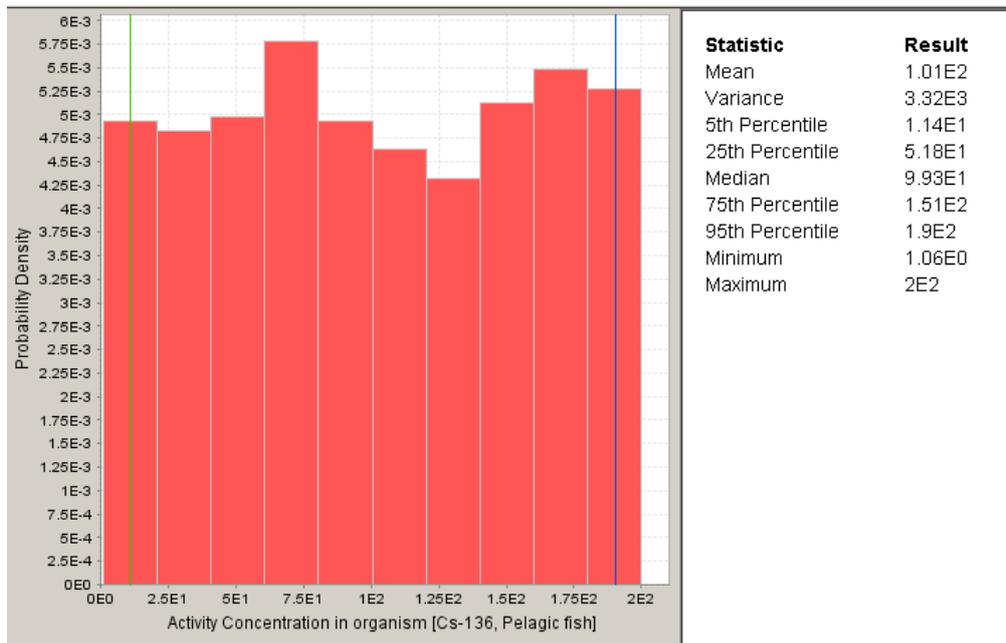


Statistic	Result
Mean	9.98E1
Variance	9.56E1
5th Percentile	8.42E1
25th Percentile	9.3E1
Median	9.99E1
75th Percentile	1.07E2
95th Percentile	1.16E2
Minimum	7.32E1
Maximum	1.33E2

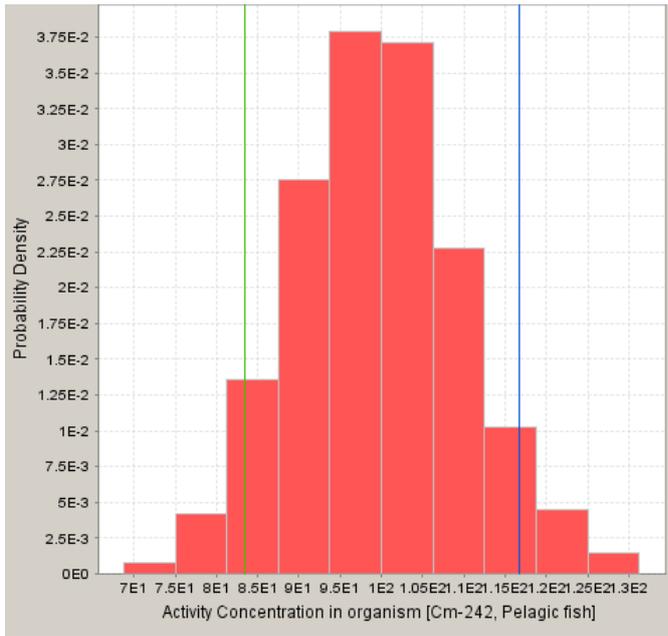
- Triangular (enter minimum, maximum and mode values)



- Uniform (enter minimum and maximum values)

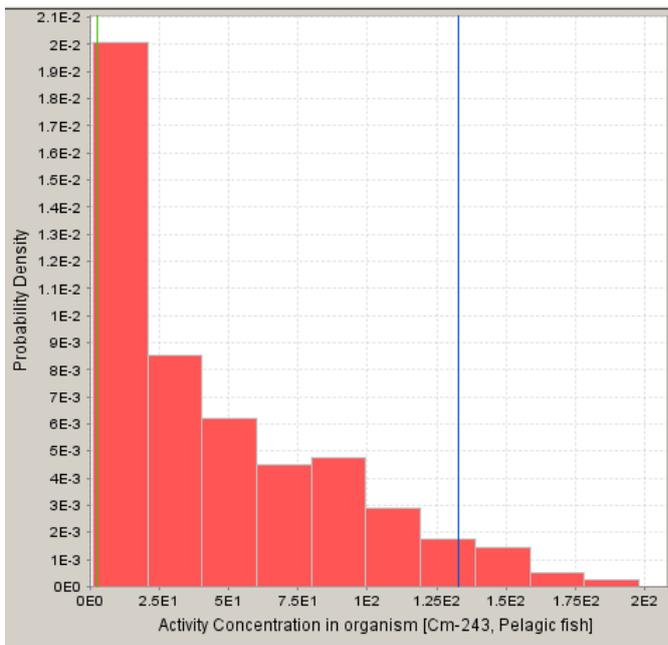


- Lognormal (enter mean, standard deviation, lower cut off and upper cut off values)



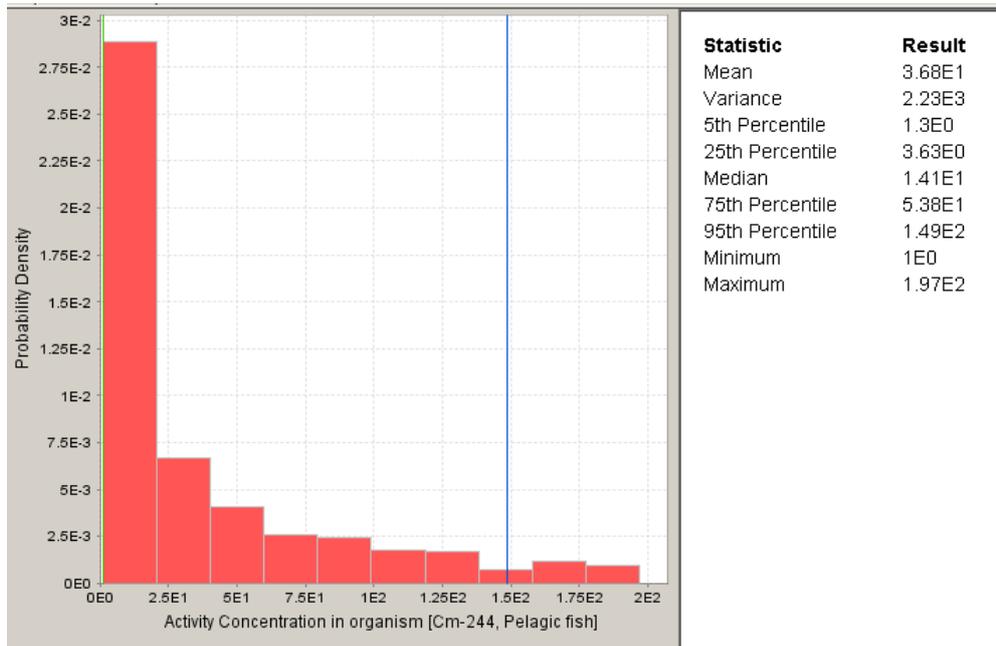
Statistic	Result
Mean	9.95E1
Variance	1.02E2
5th Percentile	8.34E1
25th Percentile	9.27E1
Median	9.91E1
75th Percentile	1.06E2
95th Percentile	1.17E2
Minimum	6.87E1
Maximum	1.31E2

- Logtriangular (enter minimum, maximum and mode values)



Statistic	Result
Mean	4.66E1
Variance	1.8E3
5th Percentile	2.97E0
25th Percentile	1.16E1
Median	3.19E1
75th Percentile	7.31E1
95th Percentile	1.33E2
Minimum	1.14E0
Maximum	1.98E2

- Loguniform (enter minimum and maximum values)



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

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

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

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

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

## 10.9 Menu items and toolbar buttons

When you open the ERICA assessment tool you are prompted to select the 'New project' option either under the FILE menu or from the toolbar to start an assessment. In addition to the 'New option' there are several other menu items under FILE. These perform the following functions:

- **FILE: New Project:** You are prompted to provide a name for the assessment and then to click ok. This creates the new assessment with the given name and the assessment will appear on the right hand side of the screen in the browser window. From here you can start entering information into the assessment. You can also press the NEW button in the toolbar.
- **FILE: Open:** this allows you to open an existing saved assessment for review, editing or completion. A standard windows dialog box will appear after selecting open and you can select the relevant filename (with the extension "\*.eca") in the dialog box. After opening the assessment name will appear in the browser window to the right of the screen. You can also press the OPEN button in the toolbar.
- **FILE: Save:** this allows you to save the currently selected assessment. You can also press the SAVE button. If this is the first time that the assessment has been saved then a standard windows save file dialog box will appear which will allow you to enter the filename and to select the directory on your computer or network where you would like to store the file. Note an asterisk is displayed beside the project name if the project has been changed since it was last opened or saved. *Please note that there is no autosave function within the tool and therefore you must remember to save your project at regular intervals.*
- **FILE: Save as:** this allows you to save the currently selected assessment but with a new filename. Note an asterisk is displayed beside the project name if the project has been changed since it was last opened or saved.
- **FILE: Close Project:** this allows you to close the currently selected assessment – if you have made changes to the currently selected assessment you will be prompted to save your changes. Note an asterisk is displayed beside the project name if the project has been changed since it was last opened or saved. *Please note that there is no autosave function within the tool and therefore you must remember to save your project before closing the file.*
- **FILE: Exit:** this allows you to completely close the ERICA assessment tool and will close all open assessments. If you have made changes to any of the open assessments you will be prompted to save your changes before the tool exits.

When you have created or opened an assessment the options on the ASSESSMENT menu become available. These are:

- **ASSESSMENT: Details:** this option provides a shortcut to the assessment details screen of the currently selected assessment and tier where you can enter basic information for your assessment.
- **ASSESSMENT: Stakeholders:** this option provides a shortcut to the stakeholders screen of the currently selected assessment and tier.
- **ASSESSMENT: Context:** this option provides a shortcut to the assessment context screen of the currently selected assessment and tier where you can select the ecosystem, organisms and radionuclides for your assessment.
- **ASSESSMENT: Radioecology:** this option provides a shortcut to the radioecology details screen of the currently selected assessment and tier where you can enter information on concentration ratios (Kds) and distribution coefficients (CRs).

- **ASSESSMENT: Occupancy:** this option provides a shortcut to the occupancy details screen of the currently selected assessment and tier where you can enter information on occupancy factors for each reference organism and modify the default radiation weighting factors.
- **ASSESSMENT: Inputs:** this option provides a shortcut to the inputs screen of the currently selected assessment and tier where you can enter your media and/or organism concentration.
- **ASSESSMENT: Results:** this option provides a shortcut to the results screen of the currently selected assessment and tier.
- **ASSESSMENT: Show Report:** this option displays the report window. The report window contains details of all the inputs and outputs for a particular assessment and can be saved and exported for use in other software packages.

You can also short cut access to the different screens by double clicking on the appropriate screen name in the browser window to the right hand side of the screen. Here you can click on the + symbol next to the name of the assessment which you would like to review or amend. This will open up the list of available screens that you can access (which is Tier dependent). The screen only appears on the list as well after the first time that you have accessed the screen within the assessment tool.

The DATABASE menu allows you to access the database views. These are:

- **DATABASE: Parameters database:** this option allows you to access parameters databases which underpin the ERICA assessment tool. So for example you can view the concentration ratio information that is contained within the ERICA tool along with the default EMCLs that have been calculated based on the  $10 \mu\text{Gy} \cdot \text{h}^{-1}$  screening value that is the default within ERICA Tiers 1 and 2 and the radioecological and occupancy factor information etc. The underpinning databases are protected to ensure that the default information is always available however it is possible to create your own databases by editing the default data values which can then be used in your current assessment and then in future ones too. After selecting this option you will see the database window with the Parameters tab selected. Full details of this are given below (Section 10.10).
- **DATABASE: Radionuclides:** this option displays the radionuclides view with the full list of radionuclides included in the ERICA assessment tool.
- **DATABASE: Organisms:** this option displays the organisms view with the full list of reference organisms included in the ERICA assessment tool

The final options list is for HELP option on the menu bar. Within this HELP menu are the following options:

- **HELP: Welcome:** this option brings the user back to the welcome screen with background information to ERICA assessment tool.
- **HELP: Help contents:** this option displays the help contents.
- **HELP: Print contents:** this option opens a printable version of the help documentation.
- **HELP: Glossary:** this option provides a link to the glossary produced within the ERICA project which provides a brief definition and description of key words that are used throughout the ERICA assessment tool and in the supporting documentation.
- **HELP: About:** this option provides information about tool version and license.

- **HELP: Release notes:** this option displays the release and updates notes.
- **HELP: Update:** this option checks for updates.
- **HELP: Contacts:** this option provides information and email addresses for reporting bugs, problems or issues with the ERICA assessment tool. The following email address can be used to report issues with the tool: [dev\\_ERICA@facilia.se](mailto:dev_ERICA@facilia.se)

Please note that if you wish to perform a search in the help for particular words or phrases, it is advisable to download and open the available pdf file and thereafter use the standard “Find” function of your PDF viewer.

### ***10.10 Database window***

When you access the databases using the DATABASE menu then you are presented with a window which three tabs on the top, one for ‘Parameters’, ‘Radionuclides’ and ‘Organisms’. The content of these are described below.

#### *Parameters*

This tab contains a list of all the parameters that have been calculated for the different radionuclides and reference organisms. It contains for example the list of concentration ratios for all three ecosystems and the distribution coefficients for the aquatic ecosystems. It also contains all the dose conversion coefficients that have been produced for the reference organisms. You can select the parameter you wish to view by selecting from the parameter window in the top left hand window of the screen and by following the tree of parameters. The parameters are linked into common groups such as dosimetry, radioecology, occupancy etc. Once you have located the parameter you wish to view you can see the details of individual numbers in the window to the top right hand side of the screen. Towards the bottom of the screen you will see the list of all the parameters that can be viewed within the section. It is here that you can also select and edit the individual parameters and thus create a user-defined database. This is done by double clicking in the cell you wish to edit and, using the delete or backspace key, make the necessary changes to the values.

#### *Radionuclides*

This tab provides the full list of radionuclides included in the ERICA assessment tool. Here you can also add new isotopes using the Add Isotope Wizard. This option allows you to derive Dose conversion coefficients for any radioisotope included within the electronic version of ICRP-38. You can start the Add Isotope Wizard by pressing the button “Add” directly beneath the list of default ERICA radionuclides.

#### *Organisms*

This tab provides the full list of reference organisms included in the ERICA assessment tool. Here you can also add new organism geometries using the add organism wizard and you can also edit your own user defined organism geometries here and also remove the organism geometries that have been created by a user of the ERICA assessment tool. Note that you can not edit or remove the ERICA default reference organisms.

## 10.11 Reference Organisms

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

This can be directly compared with the ICRP's definition for Reference animals and plants:

**A Reference Animal or Plant (RAP)** is a hypothetical entity, with assumed basic characteristics of a specific type of animal or plant, as described to the generality of the taxonomic level of the Family, with precisely 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 ERICA approach differs slightly in the sense that that ICRP's selected organisms

- are described specifically at the taxonomic level of the family and
- (will) have precisely defined anatomical, physiological and life-history properties.

Nonetheless, it should be noted that there is broad consistency between the reference organism approach adopted by FASSET/ERICA and the RAPs defined by the ICRP. More importantly, the methodology developed within ERICA will be applicable for the ICRP RAPs, i.e. will allow assessments to be conducted for the ICRP RAP's.

### Evolution of the reference organism list

The reference organism approach provides a means of reducing the assessment to manageable proportions and may allow logical links/associations between sets of data attributed to different organism types to be established. In this way some insight into the potential environmental impacts of ionising radiation may be derived for components of the environment for which data are poor or absent. The reference organism approach has been advocated in a number of earlier publications (Pentreath, 1999; Pentreath & Woodhead, 2000; Strand *et al.* 2000) where it has been argued that (see Pentreath, 1999) an attempt should not be made to model everything but that models should be selected based on an appreciation of the actual and potential data that are likely to become available, and pre-existing information concerning the effects of geometry, the behaviour of radionuclides in the environment and the behaviour of the organisms.

Pentreath & Woodhead (2001) suggested that a pragmatic selection of reference organisms should consider numerous criteria including, *inter alia*, amount of radiobiological information that is already available on them, including data on probable radiation effects and their amenability to future research. Within FASSET the scope of selection criteria was limited to a smaller number of points and included:

- ecological sensitivity, i.e., the potential of the organism, through feeding habits and habitat occupancy, to be exposed to significant dose rates from radionuclides in their environment that derive from a variety of release scenarios,
- intrinsic sensitivity of the organism to chronic low-level irradiation for the biological endpoints of significance at the relevant level of biological organisation; and,
- ecological significance, i.e., the organism's importance to the maintenance of the community or ecosystem. The potential requirement for generic representatives of each trophic level in the marine, freshwater and terrestrial environments will need to be considered.

The selection process, from an exposure pathways perspective, is documented in a Deliverable Report (D1) for the FASSET Project (Strand et al., 2001). Analyses were based on a consideration of the biogeochemical behaviour (primarily transfer and biological uptake) of 20 radionuclides (see below) within 4 terrestrial (i.e. Forest, semi-natural, agricultural and wetlands) and 3 aquatic (i.e. marine, freshwater and brackish) ecosystems. The component ecosystems were selected to be typical for Europe.

Within the ERICA project the original list of reference organisms has been reduced considerably by amalgamating the terrestrial ecosystems into a single representative semi-natural ecosystem and by removing the brackish ecosystem which arguably constitutes a sub-set of the marine system. Furthermore, the original FASSET reference organism has been replaced by related ICRP RAPs where the similarity justifies this procedure. The final list of reference organisms as considered by ERICA is shown in Table 19.

#### Attributes associated with reference organisms

For utilisation within the impact assessment process, each reference organism has been assigned default attributes relating to radioecology and dosimetry, these being:

- Equilibrium concentration ratios (these data can be accessed using the *Show database* function in the assessment tool).
- Default occupancy factors – at Tiers 1 and 2 the location within the habitat has been selected to maximise the dose-rates
- Default ellipsoidal geometries (with the 3 primary axes defined) allowing dose-conversion factors to be defined.

The basic dosimetric information for ERICA reference organisms is provided below (Table 19).

**Table 19: List of reference organisms and basic dosimetric information**

ERICA Reference organisms	Geometry defined by <sup>(a)</sup>	mass (kg)	ksi	chi
<i>Terrestrial</i>				
Amphibian	ICRP Frog	3.14E-02	0.375	0.313
Annelid	ICRP Earthworm	5.24E-03	0.100	0.100
Arthropod - detritivorous	FASSET Woodlouse	1.70E-04	0.353	0.176
Bird	ICRP Duck	1.26E+00	0.333	0.267
Flying insects	ICRP Bee	5.89E-04	0.375	0.375
Grasses & Herbs	ICRP Wild grass	2.62E-03	0.200	0.200
Lichen & bryophytes	ERICA Bryophyte	1.70E-04	0.057	0.057
Mammal - large	ICRP Deer	2.45E+02	0.462	0.462
Mammal - small-burrowing	ICRP Rat	3.14E-01	0.300	0.250
Mollusc - gastropod	ERICA Snail	1.40E-03	0.817	0.493
Reptile	ERICA Snake	7.44E-01	0.030	0.030
Shrub	ICRP Wild grass	2.62E-03	0.200	0.200
Tree	ICRP Pine Tree	4.71E+02	0.030	0.030
<i>Marine</i>				
Benthic fish	ICRP Flat fish	1.31E+00	0.625	0.063
Bird	(Wading) bird. ICRP Duck	1.26E+00	0.333	0.267
Crustacean	ERICA Phytoplankton	7.54E-01	0.600	0.300
Macroalgae	ICRP Brown seaweed	6.52E-01	1.00	0.010
Mammal	FASSET Mammal	1.82E+02	0.244	0.244
Mollusc - bivalve	FASSET Benthic mollusc	1.64E-02	0.500	0.500
Pelagic fish	FASSET Pelagic fish	5.65E-01	0.200	0.200
Phytoplankton	ERICA Phytoplankton	1.00E-06	1.000	1.000
Polychaete worm	FASSET Worm (benthic)	1.73E-02	0.052	0.052
Reptile	ERICA Turtle	1.39E+02	0.459	0.941
Sea anemones & True coral (Polyp)	ICRP Polyp	1.77E-03	1.000	1.000
Vascular plant	FASSET Vascular Plant	2.62E-02	0.250	0.250
Zooplankton	FASSET Zooplankton	6.14E-05	0.984	0.500

Freshwater

Amphibian	ICRP Frog	3.14E-02	0.375	0.313
Benthic fish	FASSET Benthic fish	1.47E+00	0.160	0.140
Bird	ICRP Duck	1.26E+00	0.333	0.267
Crustacean	FASSET Crustacean	1.57E-05	0.300	0.100
Insect larvae	FASSET Insect Larvae	1.77E-05	0.100	0.100
Mammal	FASSET Mammal	3.90E+00	0.455	0.455
Mollusc - bivalve	FASSET Bivalve mollusc	7.07E-02	0.450	0.300
Mollusc - gastropod	FASSET Gastropod	3.53E-03	0.500	0.500
Pelagic fish	ICRP Salmonid/Trout	1.26E+00	0.160	0.120
Phytoplankton	ERICA Phytoplankton	1.00E-06	1.000	1.000
Reptile	ERICA Reptile	1.00E+00	0.670	0.330
Vascular plant	FASSET Vascular Plant	1.05E-03	0.001	0.002
Zooplankton	FASSET Zooplankton	2.35E-06	0.700	0.800

<sup>(a)</sup> References: FASSET = Pröhl et al. (2003) ; ICRP = Ulavnovksy & Pröhl (2006) & ICRP (in press).

Ksi ( $\xi$ ) and chi ( $\chi$ ) are scaling parameters. If the body's major axis is orientated along the x axis, i.e.  $a = \max(a,b,c)$  and  $k_a = \max(k_a, k_b, k_c)$  the following scaling factors have been introduced:

$$\xi = \frac{k_b}{k_a} \qquad \chi = \frac{k_c}{k_a}$$

For the terrestrial ecosystem, the system becomes more complicated owing to the fact that for each reference organism only certain source-target configurations, i.e. presence of the reference organism at a specific place within its habitat, are permitted. The permitted *Occupancies* are provided in Table 20.

**Table 20 Terrestrial organisms (permitted occupancies) – crosses denote where we have a DCC**

Reference organism	In soil	On soil	In air
Annelid	x		
Arthropod - detritivorous	x	x	
Flying insects		x	x <sup>(a)</sup>
Mollusc - gastropod	x	x	
Lichen & bryophytes		x	
Grasses & Herbs		x	
Shrub		x	
Tree		x	
Mammal - small-burrowing	x	x	
Mammal - large		x	
Bird		x	x <sup>(b)</sup>
Reptile	x	x	
Amphibian	x	x	

<sup>(a)</sup> DCC calculated for on soil

<sup>(b)</sup> DCC calculated for a height of 3 m above ground level.

For all in soil geometries, the DCC is derived using a 50-cm depth uniform volume source

For all on soil geometries and the in air geometry for bird, the DCC is derived using a 10-cm depth uniform volume source.

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### ***10.12 Screening Value - Derivation of the ERICA default incremental screening dose rate value ( $10 \mu\text{Gy h}^{-1}$ )***

The ERICA Ecological Risk Assessment approach requires risk assessment benchmark values for risk characterisation within Tiers 1 and 2 to assess incremental doses. Generally, a benchmark value designates any value that is used for a comparison purpose. It becomes a screening value when it is used for screening purpose. Such values can be derived by methods that aim to ensure the protection of generic freshwater, marine and terrestrial ecosystems from detrimental effects (on structure or function). These benchmark values are:

- In Tier 1, screening values that correspond to limiting activity concentrations in media (Predicted No-Effect Concentration (PNEC, in  $\text{Bq l}^{-1}$  or  $\text{Bq kg}^{-1}$ ) obtained by back-calculation from the dose rate screening values used in Tier 2;
- In Tier 2, dose rate screening values that correspond to a Predicted No-Effect Dose-Rate (PNEDR, in  $\mu\text{Gy h}^{-1}$ ) chronic scenarios respectively;

The object of protection within the ERICA Integrated Approach is that generic ecosystems (freshwater, marine and terrestrial) should be protected from effects on structure and function under chronic exposure to radionuclides. The proposed  $10 \mu\text{Gy h}^{-1}$  incremental screening dose rate has been derived from examination of data on effects of ionising radiation in non-human biota collated in the FREDERICA effects database (see also Chapter 7). This database includes data from the original FASSET Radiation Effects Database (FRED), covering the period 1945-2001, plus data from new references up to the end of the ERICA project (early 2007). FREDERICA also contains the output from experiments conducted within the ERICA project and field data from the former Soviet Union.

The  $10 \mu\text{Gy h}^{-1}$  incremental screening dose rate is the result of an analysis of the chronic exposure data from amongst the more than 26,000 data entries in the original FRED database. The analyses conducted follows EC recommendations for the estimation of Predicted No-Effect Concentrations (PNEC) for chemicals [EC, 2003]. A three-step methodology was used:

- First, a coherent data sub-set was extracted from each experiment, covering endpoints related to mortality, morbidity and reproduction.
- Second, a systematic mathematical treatment was applied to reconstruct dose rate-effect relationships and to estimate critical toxicity endpoints. For chronic exposure, the critical toxicity endpoint is the estimated EDR10 (in  $\mu\text{Gy h}^{-1}$ ) or the Effect Dose Rate giving rise to a 10% change in observed effect.

- The third step of the method consists in using these estimated critical toxicity data to derive a Predicted No-Effect Dose Rate (PNEDR) using the Species Sensitivity Distribution method (SSD) [EC, 2003].

The SSD method was used to estimate the dose rates below which 95% of species in the aquatic/terrestrial ecosystem should be protected: the HDR<sub>5</sub>, Hazardous Dose Rate giving a 10% effect to 5% of species being estimated. After analyses of the data for different ecosystems separately there was no statistical justification to attempt to derive ecosystem specific screening dose rates and all data were analysed together as a generic ecosystem. The final dose screening values (PNEDR) for application in Tiers 1 and 2, are then obtained by applying a safety factor of between 1 and 5 to allow for remaining extrapolation uncertainties (*e.g.* the irradiation pathway that could lead to a dominant internal dose by  $\alpha$  or  $\beta$  emitters).

The method can be summarised as follows:

$$PNEDR = \frac{HDR_5}{SF} \text{ when the SSD method is applied.}$$

### Screening values recommended for Tiers 1 and 2

ERICA has proposed the screening values to be used in the first two Tiers of the tiered approach for ecological risk characterisation that can be applied across the range of activities that use radioactive substances. These proposals are based on the following reasoning:

*Object of protection.* Generic ecosystems (freshwater, marine and terrestrial) should be protected from effects on structure and function under accidental (acute exposure) or chronic releases of radionuclides.

*Specific methods.* Species Sensitivity Distributions (SSD) built on ecotoxicity data obtained from the mathematical processing of the effects data within the FRED, and averaging per umbrella effect for each species (geometric mean per umbrella effect for each species, species weighted in the distribution, no weight per taxonomic group). The cut-off value is fixed at 95% of species to be protected (as recommended in EC [2003]) and the likely distribution is used for the derivation of the  $HD(R)_5$  with the associated confidence intervals (95% CI).

Ecotoxicity data were grouped according to ecosystem: freshwater (FW), marine (SW), and terrestrial (TER), and per exposure regime (acute or chronic). For acute exposures, there was a statistical difference between the sensitivity of species from the marine ecosystem and species from freshwater. Thus, species from aquatic ecosystems were not merged to construct a SSD. On the contrary, there was no difference between freshwater and terrestrial species sensitivity, thus allowing construction of a common SSD for a generic continental ecosystem (FW+TER). For chronic exposures, there was no difference between the radiosensitivity of species from marine and freshwater ecosystems. The two sets were then grouped into a unique aquatic ecosystem. The difference between aquatic species and terrestrial species sensitivity was not statistically different. This finding allowed the construction of a unique SSD for generic ecosystems (SW+FW+TER) chronically exposed to external  $\gamma$  irradiation.

*ERICA incremental dose rate screening values for Tiers 1 and 2.*

For chronic exposure situations, the  $HDR_5$  and associated 95% confidence interval are as follows:

- generic ecosystems (terrestrial, freshwater and marine): 81.8  $\mu\text{Gy h}^{-1}$  [23.8; 336].

To derive the screening value, a SF of 5 is applied, giving the value rounded down and expressed with one significant digit. This resulted in:

- Chronic exposure screening value - 10  $\mu\text{Gy h}^{-1}$  for all ecosystems.

At the ecosystem level, the no-effect values lie in the dose range giving rise to minor cytogenetic effects or minor effects on morbidity in vertebrates. These effects are not expected to be directly relevant at higher organisational levels, such as the structure and functioning of ecosystems.

### ***10.13 Spatial data sets***

At its simplest level an assessor may wish to input the maximum measured or modelled activity concentration in the media of interest (soil, water etc) in Tier 1 to be conservative. However, in some cases, an assessment may be required for a contaminated area with clearly defined spatial boundaries or with a well-defined mixing zone for aquatic discharges. In these cases, spatial averaging may be desirable if not a prerequisite for calculations at Tiers 1 and 2. In other cases, selection of sampling sites beyond a mixing zone to mitigate, e.g. the influence of short time-scale spatial and temporal fluctuations in contaminant levels may be required. The key point here is that the assessor needs to explain the reasoning behind their decisions on which activity concentration values should be entered into the assessment tool and which form the basis for subsequent calculations of dose rates to different species.

Note that if there is more than one source of radionuclide discharge, it is recommended that the radionuclide concentration for each of the discharges be calculated separately. The cumulative radionuclide concentration at location  $x$  may then be obtained by summing the results for the individual radionuclides. The following text describes this in more detail:

#### **10.13.1 An assessment of multiple sources discharging into a river catchment and impacting one site downstream**

Because the assessment is focused on one site, the key information that is required is the input activity concentrations for the radionuclides discharged into the river that arrive at the site of interest.

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

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

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

At Tier 3 you will need to use an assessment specific transport model to determine the activity concentrations of radionuclides arriving at the site of interest from multiple sources. These values can be used as the input to the assessment tool either as the contribution from each individual source or in combination.

### 10.13.2 Dealing with mobile organisms inhabiting adjacent but differently contaminated areas

There may be situations which require assessment where an organism is known to spend time in different areas within a spatially heterogeneously contaminated area. For example there may be three adjacent areas within an organism's home range with low, average and high soil contamination and the organism may be known to spend its time equally in these three ecosystems (e.g. 33% of the time in each area). In these circumstances your input activity concentrations (based on the soil activity concentration) can be determined in a number of ways as follows:

- if you are tier 1 and aiming to be conservative, you could assume that the organism spends 100% time in the area of high soil contamination and therefore enter that activity concentration in to the Tool;
- if you wish to use a more realistic soil input activity concentration you could determine a spatially weighted average by multiplying each activity concentration by the fraction of time spent in that area and combining to produce an input value;
- depending upon the complexity of the situation you might wish to use more sophisticated approaches such as a GIS to generate a spatially weighted activity concentration as an input value.

### 10.14 SRS-19 Models

The IAEA SRS-19 models have been adapted within the assessment tool to determine the radionuclide concentration(s) of interest at sites based on the dispersion components of the SRS-19 models as input concentration values for the assessment. These are for use in Tiers 1 and 2 as the SRS-19 models used to estimate the dispersion of radionuclides in the atmosphere and in aquatic systems were designed to minimise the possibility that the calculated results will underestimate real doses by more than a factor of 10. These models are not available in Tier 3. The dispersion models are appropriate to estimate average concentrations in water or air due to continuous releases to water or air from single radionuclide sources when it is reasonable to assume that an equilibrium or quasi-equilibrium has been established with respect to the released radionuclides and the relevant components of the environment. As with any model, the results will have an associated uncertainty. The key uncertainties and assumptions are therefore highlighted in help sections of the individual models.

It should be noted that there may be occasions where the assessor decides to determine the dose to a sessile organism or organisms that are located close to or within the outfall pipe. In these circumstances it will not be necessary to use the dispersion models as the assessor should use the activity concentration measured in the outfall or pipe. Whether you use the activity concentration at the point of discharge, a dispersion model value or some other input concentration value the key point is that this should be defined and justified within the problem formulation stage.

The individual transport models provided have been coded from the IAEA SRS-19 report on Generic Models for Use in Assessing the Impact of Discharges of Radioactive Substances to the Environment (full reference details provided below). This report is available by following this link:

[www-pub.iaea.org/MTCD/publications/PDF/Pub1103\\_scr.pdf](http://www-pub.iaea.org/MTCD/publications/PDF/Pub1103_scr.pdf)

The following transport models are available:

- Small lake (<400 km<sup>2</sup>);
- Large lake (>=400 km<sup>2</sup>);
- Estuarine;

- River;
- Coastal;
- Air.

It should be noted that in the case where an assessor is interested in a sessile organism that is identified at the point of discharge, then the use of these dispersion models is of limited value because you would simply take the outfall/pipe activity concentration. The choice here will need to be defined within the problem formulation stage and should be justified whichever way the information is used.

*Reference:* Generic Models for Use in Assessing the Impact of Discharges of Radioactive Substances to the Environment. Safety Reports Series 19. STI/PUB/1102 216pp.; 21 figures; 2001, ISBN 92-0-100501-6, English. 51.00 Euro. Date of Issue: 28 September 2001. Safety Reports Series No. 19. Copyright 2003-2004, International Atomic Energy Agency, PO Box 100, Wagramer Strasse 5, A-1400 Vienna, Austria.

#### 10.14.1 SRS 19 Aquatic models – Small lake, large lake, estuarine river & coastal – general features

Radionuclides discharged into surface waters are subject to a series of physical and chemical processes that affect their transport from the source point. These processes include:

- Flow processes, such as transport (advection) and mixing processes (turbulent dispersion);
- Sediment processes, such as adsorption/desorption on suspended, shore/beach and bottom sediments, and downstream transport, deposition and resuspension of sediment, which adsorbs radionuclides;
- Other processes, including radionuclide decay and other mechanisms that will reduce concentrations in water, such as radionuclide volatilization (if any).

The processes are, in general, three dimensional and transient in nature. However, a generic assessment of annual average radionuclide concentrations from routine discharges can be made on the assumption that a number of processes are at a steady state.

Radionuclides may become adsorbed on to sediments in water, thus reducing the dissolved radionuclide concentration in the water column. However, radionuclides adsorbed on to suspended sediment may still migrate downstream, deposit river/sea bottom and then be resuspended from the bottom and become incorporated in banks and beaches. These processes are highly site-specific. Over a period time, remobilization of radionuclides associated with deposited sediments can become an additional source of exposure, the importance of which depends upon the radionuclide involved. It is possible to calculate radionuclide concentrations in sediment, corresponding to the concentration in water, by using a distribution coefficient  $K_d$  ( $L\ kg^{-1}$ ) which is how the assessment tool works.

A degree of conservatism (i.e. the tendency to overestimate actual concentrations) is necessary for such a generic approach, and in this methodology this is derived from the following conditions.

- The locations where surface waters or sediments are assumed to be utilized by hypothetical reference organisms are intentionally selected to limit the potential for underestimating actual exposures.
- Values for flow rates, current velocity and water depth are representative of the lowest annual average conditions occurring over a period of 30 years (not applicable for coastal model). Furthermore, the concentrations are provided for the centre of the line of the plume which will give the highest concentration within the plume.

- Radionuclide concentrations are calculated along the plume centreline (not applicable for small lake)
- Radionuclides are assumed to be released along the bank/shore, thus restricting any mixing which might occur.

### **Applicability**

As a result of the simplifying assumptions implicit in its derivation, this generic methodology strictly applies only if the following conditions are satisfied.

- The surface water geometry (e.g. river cross-section, shoreline) does not change greatly with distance;
- The flow characteristics (e.g. flow velocity, water depth) do not change significantly with distance or with time;
- Radionuclides in water and sediment, under the conditions of a routine, long term release, can be considered to be in equilibrium;

#### **10.14.2 SRS 19 Small Lake Transport Model**

The generic methodology used in the Safety Report for a small lake is based on a box type model. The detailed derivation of this solution and the associated assumptions is discussed in Annex VI in the SRS-19 report.

#### **Applicability of the model**

A water body is considered to be a small lake if its surface area is less than 400 km<sup>2</sup>;

Full details of the small lake transport model are described in section 4.6.2 on page 47 in the SRS 19 report and assumes that the radionuclide concentration throughout is uniform. The model requires the following basic parameters in order to be run within the ERICA assessment tool:

- Discharge rates (Bq s<sup>-1</sup>) for the selected radionuclides;
- The flow rate (m<sup>3</sup> s<sup>-1</sup>) of the river flowing into the lake;
- The lake volume (m<sup>3</sup>); and
- The expected life of the facility which is discharging the radioactivity (y).

It is possible to estimate the input flow rate (m<sup>3</sup> s<sup>-1</sup>) from the entry of a single parameter which is the estimated river width (m) that feeds the lake. You should be aware however that there the estimate function uses a conservative approach to estimating the input flow rate because it calculates the flow rate based on the estimated 30 year low annual river flow rate. Section 4.6.2 provides additional information on the parameters needed. This model does not predict the fate and behaviour of atmospherically released radionuclides, which might be deposited onto the surface of the lake. The SRS-19 report does describe a method for adding a contribution from atmosphere to the aquatic models as follows:

If there is atmospheric deposition of radionuclides on to a small lake and its watershed, the calculation of radionuclide concentrations in the lake should account for this contribution, in addition to the liquid discharge directly to the lake. To account for this contribution, it is assumed that the size of the lake watershed is 100 times the lake surface area, and that 2% of a radionuclide deposited on to the

watershed reaches the lake through runoff, surface soil erosion and groundwater seepage. Full details are given in section 4.6.2.2.

This has not been implemented in the ERICA assessment tool and so if you need to include the atmospheric component into an aquatic assessment within Tiers 1 and 2 using the SRS-19 model approach we recommend that:

- You could run the assessment twice, once to assess the aquatic ecosystem using the relevant aquatic dispersion model from SRS-19 and once to assess the terrestrial ecosystem using the air dispersion model from SRS-19 that is provided.
- You could run the atmospheric dispersion model from SRS-19 either within or outside the tool and note the input concentrations that arise. Then do the same with the relevant aquatic dispersion model and finally combine the input concentrations externally to the tool by applying the approach outlined in section 4.6.2.2 of the SRS-19 report and use the site-specific concentration values to enter the appropriate input concentrations based on a combined atmospheric and aquatic input for the aquatic ecosystem under consideration.

You also need to provide a discharge value, in  $\text{Bq s}^{-1}$ , for each radionuclide that was selected in the Assessment Context screen. These values should be typed in to the appropriate cell by clicking into the cell, entering the number and either pressing the return key, using the cursor keys to move up or down to the next cell or double clicking a different entry. Please note that it is possible to edit numbers once they have been entered but you should be aware that clicking into a cell does not necessarily replace the value already there. You must clear the contents of the cell using the delete or backspace key in order to replace the existing number.

*Back:* Click the back button to return to the previous screen to make further modifications to the input or to check on the information entered, any modifications made to either the current page before moving to the previous screen or any changes made to the previous screen are made in the tool record. This allows mistakes or omissions to be corrected at any time when using the tool.

*Next:* Click the next button once the screen has been completed to move to the Results screen. This button will only be useable if you have entered all the necessary parameter values to allow the SRS-19 model to run.

### 10.14.3 SRS 19 Large Lake Transport Model

The generic methodology used in the Safety Report for a large lake is based on a box type model and assumes that the radionuclide concentration throughout is uniform. The detailed derivation of this solution and the associated assumptions is discussed in Annex VI in the SRS-19 report.

#### **Applicability of the model**

Large lakes are those that have a water surface area of at least  $400 \text{ km}^2$ .

The large lake transport model is described in full in section 4.6.3 on page 49 in the SRS 19 report. The main difference between the small and large lake model is that large lakes are those with a large residence time and with lake flows dominated by wind induced currents. The radionuclide transport in these large lakes is controlled mainly by wind induced flow, stratification and seasonal turnover, and scale dependent mixing, similar to the situation in coastal waters. However, even in a large lake complete mixing over the entire lake can be achieved in a relatively short period of time (much less than one year) owing to a very large dispersion coefficient that changes with distance and seasonal turnover. However, near the release point complete mixing is unlikely to occur. The model requires the following basic parameters in order to be run within the ERICA assessment tool:

- Discharge rates ( $\text{Bq s}^{-1}$ ) for the selected radionuclides;

- The water depth (m) at the radionuclide discharge effluent outfall;
- The distance between the release point in the lake and the shore (m);
- The longitudinal distance (along the lake current direction) from the release point to a potential receptor location (m);
- The lake current velocity ( $\text{m s}^{-1}$ ) (the assessment tool uses  $0.1 \text{ m s}^{-1}$  as a default value);
- The location of the receptor point (being either on the shoreline or in the lake).

Section 4.6.3 provides additional information on the parameters needed. This model does not predict the fate and behaviour of atmospherically released radionuclides, which might be deposited onto the surface of the lake.

You also need to provide a discharge value, in  $\text{Bq s}^{-1}$ , for each radionuclide that was selected in the Assessment Context screen. These values should be typed in to the appropriate cell by clicking into the cell, entering the number and either pressing the return key, using the cursor keys to move up or down to the next cell or double clicking a different entry. Please note that it is possible to edit numbers once they have been entered but you should be aware that clicking into a cell does not necessarily replace the value already there. You must clear the contents of the cell using the delete or backspace key in order to replace the existing number.

*Back:* Click the back button to return to the previous screen to make further modifications to the input or to check on the information entered, any modifications made to either the current page before moving to the previous screen or any changes made to the previous screen are made in the tool record. This allows mistakes or omissions to be corrected at any time when using the tool.

*Next:* Click the next button once the screen has been completed to move to the Results screen. This button will only be useable if you have entered all the necessary parameter values to allow the SRS-19 model to run.

#### 10.14.4 SRS 19 Estuarine Transport Model

The generic methodology used in the Safety Report for estuaries is based on analytical solutions to advection–diffusion equations describing radionuclide transport in surface waters with steady state uniform flow conditions. The detailed derivation of this solution and the associated assumptions is discussed in Annex VI in the report.

Radionuclide concentrations in water (and sediment) may be calculated for specific locations where non-human species might be present. These locations (at a specified distance  $x$  m from the point of discharge) are selected to represent the nearest point where the non-human species will be utilising the water that is conceivable during the projected lifetime of an operating facility. The methodology also includes simple processes to estimate default dispersion coefficients, river flow conditions and the coastal current, if site-specific values are unavailable. This information is described in section 4.4 within the SRS-19 report.

#### **Applicability of the model**

The Estuarine transport model is described in full in section 4.4 on page 39 in the SRS 19 report. An estuary is a water body that is connected at one end to a river and at the other end to the sea. An estuary velocity reverses with the tide, and an estuary can contain fresh or saline water, although it is generally less saline than that of the sea. For the purposes of this generic methodology a radioactive discharge is assumed to occur from one of the estuary banks. The radionuclide concentration at the banks may be assessed using a methodology that is very similar to that for rivers, but with some

adjustments to account for tidal effects. The model requires the following basic parameters in order to be run:

- Discharge rates ( $\text{Bq s}^{-1}$ ) for the selected radionuclides;
- Estuarine depth (m);
- Estuarine width (m);
- Flow rate ( $\text{m}^3 \text{s}^{-1}$ );
- Tidal period (s) (the assessment tool uses  $4.5 \times 10^4$  s as a default value, which is for two tides per day (i.e. semidiurnal); if there is only one tide per day then the input value should be  $9 \times 10^4$ );
- Ebb velocity ( $\text{m s}^{-1}$ ) (the assessment tool uses  $0.5 \text{ m s}^{-1}$  as a default value);
- Flood velocity ( $\text{m s}^{-1}$ ) (the assessment tool uses  $0.5 \text{ m s}^{-1}$  as a default value);
- Longitudinal distance from the release point to a potential receptor location (m);
- Location of the receptor (same or opposite side of river bank as discharge point, and upstream or downstream from the discharge point).

It is also possible to estimate the flow rate ( $\text{m}^3 \text{s}^{-1}$ ) parameter by clicking the estimate button and entering a value of river width (m). You should be aware however that there the estimate function uses a conservative approach to estimating the input flow rate because it calculates the flow rate based on the estimated 30 year low annual river flow rate. Section 4.4 provides additional information the parameters needed. This model does not predict the fate and behaviour of atmospherically released radionuclides, which might be deposited onto the surface of the lake.

You also need to provide a discharge value, in  $\text{Bq s}^{-1}$ , for each radionuclide that was selected in the Assessment Context screen. These values should be typed in to the appropriate cell by clicking into the cell, entering the number and either pressing the return key, using the cursor keys to move up or down to the next cell or double clicking a different entry. Please note that it is possible to edit numbers once they have been entered but you should be aware that clicking into a cell does not necessarily replace the value already there. You must clear the contents of the cell using the delete or backspace key in order to replace the existing number.

*Back:* Click the back button to return to the previous screen to make further modifications to the input or to check on the information entered, any modifications made to either the current page before moving to the previous screen or any changes made to the previous screen are made in the tool record. This allows mistakes or omissions to be corrected at any time when using the tool.

*Next:* Click the next button once the screen has been completed to move to the Results screen. This button will only be useable if you have entered all the necessary parameter values to allow the SRS-19 model to run.

#### 10.14.5 SRS 19 River Transport Model

The generic methodology used in the Safety Report for rivers is based on analytical solutions to advection–diffusion equations describing radionuclide transport in surface waters with steady state uniform flow conditions. The detailed derivation of this solution and the associated assumptions is discussed in Annex VI in the report.

Radionuclide concentrations in water (and sediment) may be calculated for specific locations where non-human species might be present. These locations (at a specified distance  $x$  m from the point of

discharge) are selected to represent the nearest point where the non-human species will be utilising the water that is conceivable during the projected lifetime of an operating facility. The methodology also includes simple processes to estimate default dispersion coefficients, river flow conditions and the coastal current, if site-specific values are unavailable. This information is described in section 4.3 within the SRS-19 report.

### **Applicability of the model**

The river transport model is described in section 4.3 on page 34 in the SRS 19 report. The following parameters are required to calculate radionuclide concentrations in a river (corresponding to the lowest annual river flow rates expected in a 30 year period):

- Discharge rates ( $\text{Bq s}^{-1}$ ) for the selected radionuclides;
- River width (m);
- River depth (m);
- Flow rate ( $\text{m}^3 \text{s}^{-1}$ );
- Longitudinal distance from the release point to a potential receptor location (m);
- Location of the receptor (same or opposite side of the river bank as discharge point).

It is also possible to estimate the flow rate ( $\text{m}^3 \text{s}^{-1}$ ), river width (m) and depth (m) parameters by clicking the estimate button and entering a value for the river width (m). Note that using this approach will overwrite any values that you have already entered for these three parameters. You should be aware however that there the estimate function uses a conservative approach to estimating the input flow rate because it calculates the flow rate based on the estimated 30 year low annual river flow rate. Section 4.3 provides additional information the parameters needed. This model does not predict the fate and behaviour of atmospherically released radionuclides, which might be deposited onto the surface of the lake.

You also need to provide a discharge value, in  $\text{Bq s}^{-1}$ , for each radionuclide that was selected in the Assessment Context screen. These values should be typed in to the appropriate cell by clicking into the cell, entering the number and either pressing the return key, using the cursor keys to move up or down to the next cell or double clicking a different entry. Please note that it is possible to edit numbers once they have been entered but you should be aware that clicking into a cell does not necessarily replace the value already there. You must clear the contents of the cell using the delete or backspace key in order to replace the existing number.

*Back:* Click the back button to return to the previous screen to make further modifications to the input or to check on the information entered, any modifications made to either the current page before moving to the previous screen or any changes made to the previous screen are made in the tool record. This allows mistakes or omissions to be corrected at any time when using the tool.

*Next:* Click the next button once the screen has been completed to move to the Results screen. This button will only be useable if you have entered all the necessary parameter values to allow the SRS-19 model to run.

#### **10.1.4.6 SRS 19 Coastal Transport Model**

The generic methodology used in the Safety Report for coastal systems is based on analytical solutions to advection–diffusion equations describing radionuclide transport in surface waters with steady state uniform flow conditions. The detailed derivation of this solution and the associated assumptions is discussed in Annex VI in the report.

Radionuclide concentrations in water (and sediment) may be calculated for specific locations where non-human species might be present. These locations (at a specified distance  $x$  m from the point of discharge) are selected to represent the nearest point where the non-human species will be utilising the water that is conceivable during the projected lifetime of an operating facility. The methodology also includes simple processes to estimate default dispersion coefficients, river flow conditions and the coastal current, if site-specific values are unavailable. This information is described in section 4.5 within the SRS-19 report.

### Applicability of the model

- This model is only applicable if the longitudinal distance  $x$  (the distance from the release point to a potential receptor location along the coastal current direction) is more than  $7D$  with  $D$  being the water depth and when the transversal distance  $y$  does not differ much from  $y_0$  which is the distance between the release point and the beach ( $(|y-y_0|/x) \ll 3.7$ ).
- Note also that this model is best suited to predicting radionuclide activity concentrations for distances of up to 10's of km from the discharge point. At greater distances ( $>100$  km) the predictions become less reliable and this model should be used with caution for distances greater than 100 km. For distances  $> 100$  km we advise using a purpose built dispersion model.

The coastal transport model is described in section 4.5 on page 44 in the SRS 19 report. The following parameters are required to calculate radionuclide concentrations in a coastal system:

- Discharge rates (Bq s<sup>-1</sup>) for the selected radionuclides;
- Water depth (m). The water depth at the radionuclide discharge effluent outfall;
- Longitudinal distance between the release point and the shore (m);
- Distance between the release point and receptor (m). Longitudinal distance (along the coastal current direction) from the release point to a potential receptor location;
- Coastal current (m s<sup>-1</sup>) (the assessment tool uses 0.1 m s<sup>-1</sup> as a default);
- Location of the receptor (along the shoreline or in the sea).

Section 4.5 provides additional information the parameters needed. This model does not predict the fate and behaviour of atmospherically released radionuclides, which might be deposited onto the surface of the lake.

You also need to provide a discharge value, in Bq s<sup>-1</sup>, for each radionuclide that was selected in the Assessment Context screen. These values should be typed in to the appropriate cell by clicking into the cell, entering the number and either pressing the return key, using the cursor keys to move up or down to the next cell or double clicking a different entry. Please note that it is possible to edit numbers once they have been entered but you should be aware that clicking into a cell does not necessarily replace the value already there. You must clear the contents of the cell using the delete or backspace key in order to replace the existing number.

*Back:* Click the back button to return to the previous screen to make further modifications to the input or to check on the information entered, any modifications made to either the current page before moving to the previous screen or any changes made to the previous screen are made in the tool record. This allows mistakes or omissions to be corrected at any time when using the tool.

*Next:* Click the next button once the screen has been completed to move to the Results screen. This button will only be useable if you have entered all the necessary parameter values to allow the SRS-19 model to run.

#### 10.14.7 SRS 19 Air Transport Model

After release to the atmosphere, radionuclides undergo downwind transport (advection) and mixing processes (turbulent diffusion). Radioactive material will also be removed from the atmosphere by both wet and dry deposition on to the ground, and by radioactive decay. A simple generic atmospheric dispersion model that allows for the above processes and for the effects of any buildings in the vicinity of the release has been implemented into the ERICA assessment tool. Full details are provided in section 3 and in Annex I of the SRS-19 report.

A Gaussian plume model is applied here to assess the dispersion of long term atmospheric releases; this model is widely accepted for use in radiological assessment activities. The model is considered appropriate for representing the dispersion of either continuous or long term intermittent releases within a distance of a few kilometres of the source. The methods described here briefly and in full in section 3 of the SRS-19 report should not be used to calculate radionuclide concentrations in air resulting from short term releases (e.g. short duration, accidental releases). The Gaussian plume model is sensitive to the relationship between the height at which the effluent is released (m) and the height of the buildings that affect airflow near the release point (m). The presence of buildings and other structures, such as cooling towers, will disturb the flow of air resulting in three main zones of flow around a building which are:

- The upwind displacement zone, where the approaching air is deflected around the building.
- The relatively isolated cavity zone immediately on the leeward side of the building.
- The highly disturbed wake zone further downwind from the building. The wake zone may extend downwind for some distance (the exact distance depends upon the source configuration and meteorological conditions).

The building from which the release occurs is generally assumed to be the one that most influences the resulting plume dispersion. However, this is not always the case. If the release point is on a building in the immediate vicinity of a much larger building, the larger building is likely to exert more influence on plume dispersion than the smaller one from which the release originated.

The generic approach described above has been designed to require a minimum input of data by the user. The ERICA assessment tool requires the following parameters to model the atmospheric dispersion:

- Discharge rates ( $\text{Bq s}^{-1}$ ) for the selected radionuclides;
- The release height (m);
- Distance to the receptor (m);
- Wind speed ( $\text{m s}^{-1}$ ) (the assessment tool uses  $2 \text{ m s}^{-1}$  as a default value);
- Fraction of time (unitless) (the assessment tool uses 0.25 as a default value);
- Dry deposition coefficient ( $\text{m d}^{-1}$ ) (the assessment tool uses  $500 \text{ m d}^{-1}$  as a default value);
- Wet deposition coefficient ( $\text{m d}^{-1}$ ) (the assessment tool uses  $500 \text{ m d}^{-1}$  as a default value);
- Surface soil density ( $\text{kg m}^{-2}$ );
- Duration of discharge (year).

You also have the option to include nearby buildings in the assessment by answering yes or no by selecting the appropriate radial button. If you select yes then you will also be prompted to enter:

- The building height (m);
- Surface area of the buildings (m<sup>2</sup>).

You also need to provide a discharge value, in Bq s<sup>-1</sup>, for each radionuclide that was selected in the Assessment Context screen. These values should be typed in to the appropriate cell by clicking into the cell, entering the number and either pressing the return key, using the cursor keys to move up or down to the next cell or double clicking a different entry. Please note that it is possible to edit numbers once they have been entered but you should be aware that clicking into a cell does not necessarily replace the value already there. You must clear the contents of the cell using the delete or backspace key in order to replace the existing number.

You are cautioned that these parameters should be determined as accurately as possible. The value of the height of the buildings used for example should ideally include both the physical height of the release point and any additional height resulting from the rise of the effluent plume owing to thermal or mechanical effects. However, neglecting plume rise will tend to result in an over-prediction of downwind air concentrations and, therefore, is appropriate for a generic assessment.

The building surface area used should be that of the building most influencing the air flow around the source. For most releases this will be the building from which the release occurs. If the release point is surrounded by other buildings and similar structures, such as cooling towers, a building other than the one associated with the release may need to be used.

The downwind distance to the receptor used in the screening calculations should be the location of the nearest point of interest for dose calculation purposes. This location may be different for different pathways of exposure and should be considered and addressed in the problem formulation description. This may result in multiple air concentrations being required for a single facility assessment.

### **Applicability and limitations of the models**

- It should be noted that the Gaussian plume model is not generally applicable at  $x > 20$  km. As a result, it is recommended that any receptors of concern that are beyond 20 km from the release point should be considered to be at  $x = 20$  km for generic assessment purposes;
- The uncertainty associated with the application of a Gaussian plume model for continuous releases from a single source is about a factor of 4 or 10 for a flat and complex terrain respectively;
- Gaussian plume models are primarily used for to locations within a distance of a few kilometres of the source. At distances less than 2.5 times the square root of the frontal area of the building, the model provides generally conservative results, whereas for distances of about 2.5 the square root of the front area, the model tends to underpredict the real concentrations for wind speeds above 5 m s<sup>-1</sup>. However, for the purpose of the assessment tool, the exact simulation of the influence of the building is relatively unimportant.

*Back:* Click the back button to return to the previous screen to make further modifications to the input or to check on the information entered, any modifications made to either the current page before moving to the previous screen or any changes made to the previous screen are made in the tool record. This allows mistakes or omissions to be corrected at any time when using the tool.

*Next:* Click the next button once the screen has been completed to move to the Results screen. This button will only be useable if you have entered all the necessary parameter values to allow the SRS-19 model to run.

### ***10.15 Temporal data sets***

At its simplest level an assessor may wish to input the maximum measured or modelled activity concentration in the media of interest (soil, water etc) in Tier 1 to be conservative. However, in some cases, an assessment may be required for a contaminated area with clearly defined spatial boundaries or with a well-defined mixing zone for aquatic discharges. In these cases, temporal averaging may be desirable if not a prerequisite for calculations at Tiers 1 and 2. In other cases, the influence of short time-scale temporal fluctuations in contaminant levels may need to be assessed here it is important to understand what the assessment is attempting to evaluate and this needs to be described within the problem formulation. The key point here is that the assessor needs to explain the reasoning behind their decisions on which activity concentration values should be entered into the assessment tool and which form the basis for subsequent calculations of dose rates to different species. It is worth considering running the tool a number of times using different time integrated input activity concentrations if it is well known that there are big differences in say the activity concentrations observed in water over a short time period (hours to a few days) compared with an data averaged annually. This may happen if a site is releasing pulsed discharges of radioactivity. In these cases the activity concentrations may be much higher than the annually averaged release but being pulsed they may be more rapidly dispersed into the environment and there may be less time for the activity to be taken up by organisms. Another problem to be considered is the lifespan of some of the organisms that may be exposed to the radioactivity. For example some algae species may have a life span of 2-3 days and therefore they might be reproducing during the time of the maximum peak of the discharge. In these cases, high doses might be predicted to them and you will need to consider issues such as the radiosensitivity of the species in order to determine the likely significance of any impacts caused by exposure to radiation. These issues will need to be considered within the problem formulation.

Note that if there is more than one source of radionuclide discharge, it is recommended that the radionuclide concentration for each of the discharges be calculated separately. The cumulative radionuclide concentration at location  $x$  may then be obtained by summing the results for the individual radionuclides.

### ***10.16 Uncertainty Factors***

The objective of Tier 2 is to identify situations where there is a very low probability, for example 1 or 5%, that the dose to any selected reference organism exceeds the adopted screening dose rate.

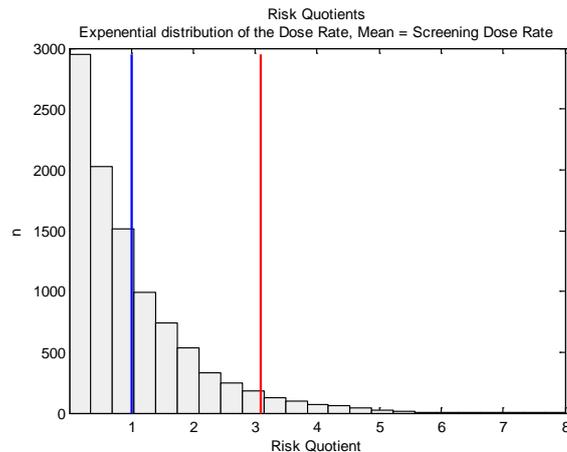
The screening test in Tier 2 is designed in the following way:

- An expected value of the RQ is calculated using expected values for the input data and the parameters.
- The 95<sup>th</sup> or 99<sup>th</sup> percentile of the RQ are estimated by multiplying the expected value of the RQ by an uncertainty factor (UF). The uncertainty factor is defined as the ratio between the 95<sup>th</sup>, 99<sup>th</sup> or any other percentile (above the expected value) and the expected value of the probability distribution of the dose rate (and RQ). To estimate the UF it is assumed that the dose rate and the RQ follow exponential distributions with means equal to the estimated expected values. In this case the UFs corresponding to the 95<sup>th</sup> and 99<sup>th</sup> percentiles are equal to 3 and 5 respectively.

The UFs also maintain conservatism between Tiers 1 and 2. With the same input values and default settings, then the results for Tiers 1 and 2 should approximate to one another because essentially the user has not thought in more detail about the problem they are facing and has not amended the problem formulation accordingly.

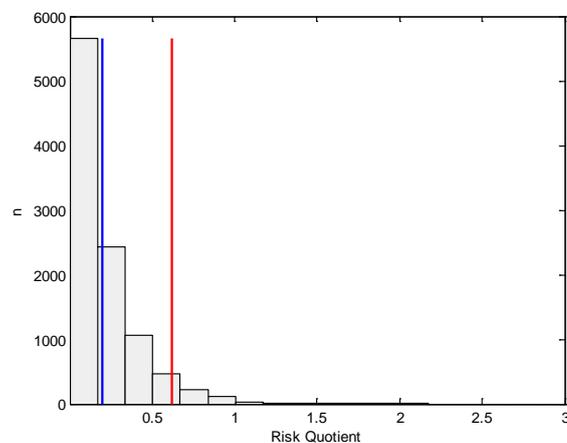
Figure 7 shows the probability distribution of the RQ obtained from a Monte Carlo simulation, assuming that the estimated dose-rate follows an exponential distribution with a mean value of 10  $\mu\text{Gy h}^{-1}$ , equal to the ERICA screening value. The blue vertical line represents the expected value, in this

case equal to 1, whereas the red line corresponds to the 95<sup>th</sup> percentile. The ratio between the 95<sup>th</sup> percentile and the expected value, i.e. the UF, is equal to 3 for this and any exponential distribution.



**Figure 7** Probability distribution of the Risk Quotients obtained for the case when the dose rate follows an exponential distribution with a mean value equal to the screening dose rate. The vertical red and blue lines correspond to the 95<sup>th</sup> percentile and expected value of the RQ respectively.

Under these assumptions and selecting a UF = 3, if the estimated expected value multiplied by the UF is equal to or lower than one, then the probability that the RQ exceeds 1 is equal to or lower than 5%. This is the same as saying that the probability of the estimated dose rate exceeding the screening dose rate is equal to or lower than 5%. An example of such a situation is presented in Figure 8 which shows the distribution of RQs that is obtained if it is assumed that the dose rate follows an exponential distribution with a mean of 2  $\mu\text{Gy h}^{-1}$  and again using the incremental screening dose rate of 10  $\mu\text{Gy h}^{-1}$ . The 95<sup>th</sup> percentile of the RQ equals 0.6 in this case.



**Figure 8** Probability distribution of the Risk Quotients obtained for the case when the dose rate follows an exponential distribution with a mean value equal to 2  $\mu\text{Gy h}^{-1}$  and assuming an incremental screening dose rate of 10  $\mu\text{Gy h}^{-1}$ . The vertical red and blue lines correspond to the 95<sup>th</sup> percentile and expected value of the RQ respectively. It can be concluded that the probability that the dose rate is above 1 is below the accepted level, in this case 5%.

The tool also allows the assessor to provide their own UF value. The user-defined UF may be substantially lower than the default settings, for example, when many site-specific data are available there may be some justification for refining the value. Such calculations require knowledge of the distribution of the RQ and propagation of the uncertainties in the dose calculations. In most cases, the RQ will be log-normally distributed and a simple equation for the UF, as a function of the coefficient of variation of the RQ can be obtained. The coefficients of variation can be estimated from the

standard deviation of the input data and parameter values, either analytically or by Monte Carlo simulations. This should be considered as an advanced user option.

It should be noted that the EMCL is derived through the application of “real” PDFs in many cases e.g. where data are numerous a log-normal distribution for the CR is applied in the calculation. The EMCL corresponds to the limiting organism. If we select the same radionuclide and limiting organism at Tier 2 and use the same input data (note that normally “expected values” for input data are required at Tier 2 but that maximum values might be stipulated in the problem formulation) then the RQs at Tiers 1 and 2 do not necessarily match. This is because the 95<sup>th</sup> percentile (of the RQ) derived from applying a UF at Tier 2 assumes an exponential distribution using an expected value as mean whereas the 95<sup>th</sup> percentile derived at Tier 1 will not take the form of an exponential but instead reflects a combination of various distributions. It should be emphasised that the UF is an approximation for allowing uncertainty in the dose-rate estimation at Tier 2 to be addressed.

## ***10.17 Uncertainty in the assessment tool - dosimetry***

### **10.17.1 Internal exposure due to non-homogeneous distributions of radionuclides**

Dose conversion coefficients (DCC) to assess absorbed dose rates in reference organisms due to internal and external exposure to gamma and beta emitters have been calculated and published assuming three dimensional ellipsoids with different dimensions and some representative irradiation geometries (Taranenko et al. 2004, Vives i Batle et al. 2004, Ulanovsky and Pröhl 2006).

Although the differences found in the absorbed fractions depending on the energy made necessary the calculation of DCCs for reference organisms of various sizes and shapes, the huge number of possible situations made also necessary to assume some simplifications concerning both the geometric models and the radionuclide distributions. In particular, homogeneous distribution of emitters has been assumed in all the cases, to calculate DCCs for monoenergetic photons and electrons in the range 10 keV – 5 MeV. Thus, the absorbed dose rate in a given organism for a given radionuclide is:

$$\dot{D}_{body} = DCC^{internal} \times A_{M,body} + DCC^{external} \times A_{M,outside}$$

Where:

$A_{M,body}$ ,  $A_{M,outside}$  are the activity concentrations in the body and the surrounding medium, respectively.

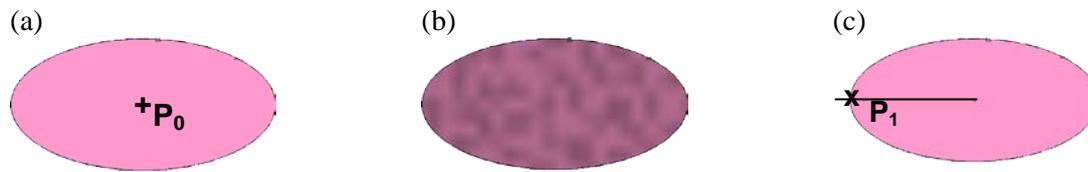
Because the assumed homogeneity may not be valid for many radionuclides, two general situations have been analyzed more in detail: (i) the calculation of whole body doses for non-homogeneous distributions of incorporated radionuclides (and the uncertainty associated to the use of a homogeneous distribution to calculate whole body doses); (ii) the calculation of organ / whole body dose rates due to accumulation of radionuclides in a critical organ.

Rather than provide new sets of numbers, the purpose is to calculate the uncertainty associated to the possible non-homogeneous distribution within the body as well as to indicate some simple methods to estimate organ doses, based on the relationship between whole body and organ doses. Obviously, the uncertainty thus calculated does not take into account the simplistic nature of the reference organisms compared with the actual animals and plants.

### **10.17.2 Uncertainties in the calculated whole body DCC for internal exposure associated to inhomogeneous distribution of internal emitters**

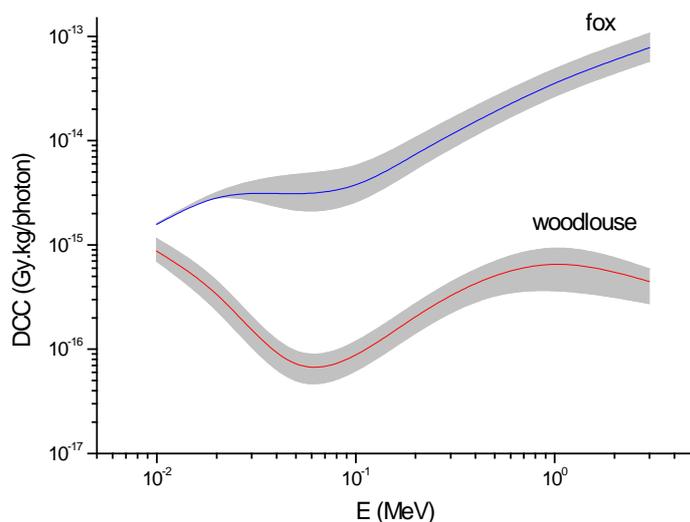
New DCCs for the reference organisms (Taranenko et al. 2004) have been calculated considering a monoenergetic point source located either in the centre of the ellipsoid and in the farthest point (closer to

the surface), emitting photons (energy in the range 10 keV – 3 MeV) or electrons (energies in the range 10 keV – 5 MeV).

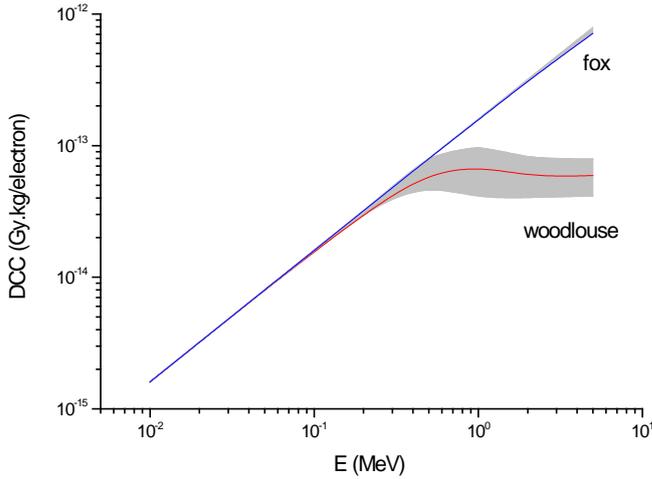


**Figure 9** Schematic representation of the three considered cases: central point source (maximum absorbed fraction), homogeneous distribution, and eccentric point source (minimum absorbed fraction)

For geometrical reasons (see Figure 9), it is clear that central point source (a) and eccentric point source (c), among all the possible source distributions, give respectively the maximum and minimum absorbed fraction. This is the situation depicted in Figures 10 for photons and Figure 11 for electrons. The upper and lower borders of the shaded regions correspond to the central and eccentric point sources, respectively. Continuous line has been calculated assuming a homogeneous distribution.



**Figure 10** Energy dependence of photon DCC for the reference organisms ‘woodlouse’ and ‘fox’ considering the three distributions depicted in Figure 9



**Figure 11 Energy dependence of electrons DCC for the reference organisms ‘woodlouse’ and ‘fox’ considering the three distributions depicted in Figure 9**

Therefore and considering a rectangular probability distribution of possible DCCs values between minimum and maximum values, the associated standard uncertainty for the homogeneous distribution values is (ISO 1995, Kacker et al. 2002):

$$u(DCC_{homogeneous}^{int\,ernal}) = \frac{(DCC_{central\,point}^{int\,ernal} - DCC_{eccentric\,point}^{int\,ernal})}{2\sqrt{3}}$$

Then, whole body doses due to internal exposure could be calculated using the DCC value for homogeneous distributions with this uncertainty, i.e.:

$$\dot{D}_{body}^{int\,ernal} = [DCC_{homogeneous}^{int\,ernal} \pm u(DCC_{homogeneous}^{int\,ernal})] \times A_{M,body}$$

The standard uncertainties for DCCs of selected reference organisms (Taranenko et al. 2004), calculated assuming a rectangular distribution between the values of DCC obtained for central and eccentric point sources is listed in Tables 21 and 22. For photons, uncertainty does not change too much with E and it is lower than 20-25% for the considered reference organisms (woodlouse mass: 0.17 g, fox mass: 6.6 kg). For electrons and due to its finite range in tissue equivalent material, uncertainty depends very much of the organisms size and energy and it is negligible below a given threshold (approximately 0.5 MeV for woodlouse and 5 MeV for fox). Uncertainty is always lower for bigger (and more massive) organisms.

**Table 21** Standard uncertainty for the photon DCC of selected reference organisms, calculated assuming a rectangular distribution between the values of DCC obtained for a central and an eccentric point source gamma emitters (photons)

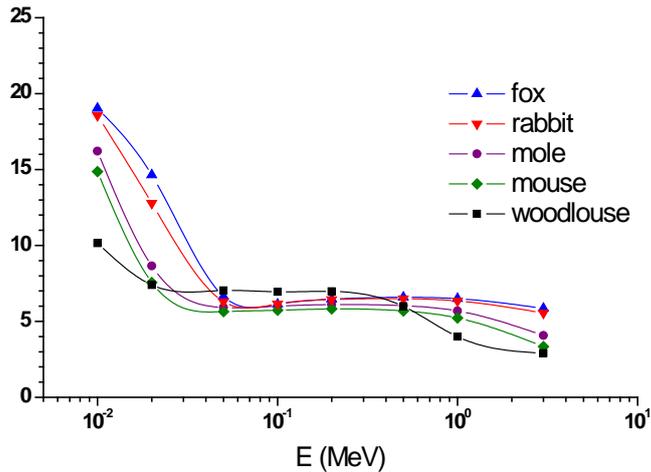
photon E (MeV)	standard uncertainty				
	woodlouse	mouse	mole	rabbit	fox
0.010	14.0%	2.6%	1.9%	0.7%	0.4%
0.020	18.2%	16.4%	14.9%	6.5%	3.6%
0.050	18.3%	19.3%	20.5%	22.3%	21.5%
0.100	18.1%	18.2%	19.2%	21.5%	22.1%
0.200	18.2%	17.6%	18.2%	19.3%	19.4%
0.500	21.0%	17.4%	17.8%	17.9%	17.5%
1.000	25.1%	18.2%	18.3%	17.5%	16.9%
3.000	21.0%	22.1%	22.2%	18.6%	17.3%

**Table 22** Standard uncertainty for the DCC of selected reference organisms, calculated assuming a rectangular distribution between the values of DCC obtained for a central and an eccentric point sources. beta emitters (electrons)

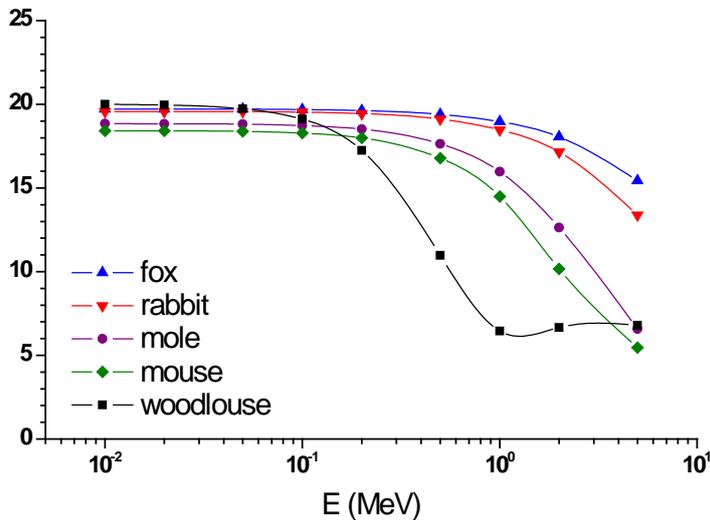
electron E (MeV)	standard uncertainty				
	woodlouse	mouse	mole	rabbit	fox
0.010	0.0%	0.1%	0.0%	0.0%	0.0%
0.020	0.1%	0.0%	0.0%	0.0%	0.0%
0.050	0.3%	0.1%	0.1%	0.1%	0.1%
0.100	0.7%	0.1%	0.1%	0.0%	0.0%
0.200	2.3%	0.2%	0.1%	0.0%	0.0%
0.500	15.5%	1.0%	0.7%	0.2%	0.1%
1.000	23.1%	2.8%	2.0%	0.7%	0.5%
2.000	19.8%	11.4%	5.1%	1.6%	1.1%
5.000	18.1%	21.0%	21.1%	4.4%	2.9%

### 10.17.3 Estimation of organ dose due to the accumulation of radionuclide in a critical organ

For low energy emitters (i.e. ‘short range’ electrons and ‘low mean free path’ photons), a significant dose gradient can be found surrounding the source. Therefore and although the uncertainty in the whole body DCC can be very small (whole body dose does not actually depend on the point where the emitter is located), organ dose can be very high compared with whole body dose if the emitter is located in a given organ. This situation is illustrated in Figures 12 and 13, where organ / whole body dose ratios are presented for selected reference organisms, considering a cantered spherical organ, 5% total mass.



**Figure 12** Energy dependence of organ / body dose ratio for a cantered spherical organ representing 5% total mass of the reference organism (photons)



**Figure 13** Energy dependence of organ / body dose ratio for a cantered spherical organ representing 5% total mass of the reference organism (electrons)

In general, the organ dose rate due to a given activity concentration in the organ,  $A_{M,organ}$ , is:

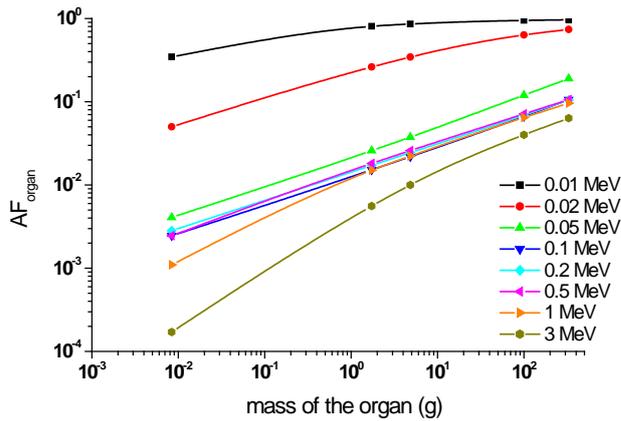
$$\dot{D}_{organ} = E \times AF_{organ}(E, m_{organ}) \times A_{M,organ}$$

Where

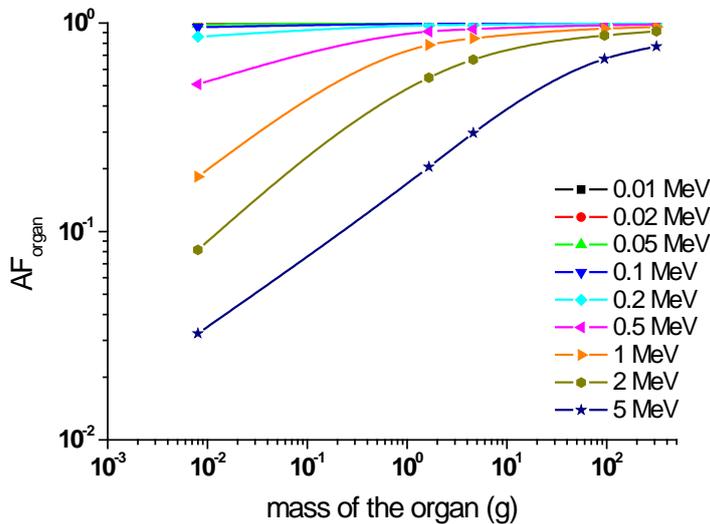
$AF_{organ}$  is the absorbed fraction in the organ. Then, when  $AF \approx 1$  (e.g. for electrons with  $E < 0.5$  MeV), it results:

$$\dot{D}_{organ} \approx \dot{D}_{body} \times \frac{m_{body}}{m_{organ}}$$

For a general case and due to the many possible cases, a conservative estimation can be obtained using the absorbed fraction,  $AF_{organ}(E, m_{organ})$ , calculated assuming a spherical organ in an effectively infinite media. As it can be seen in Figures 14 and 15,  $AF_{organ}(E, m_{organ})$  is a smooth function of  $E$  and  $m_{organ}$ , thus interpolation methods could be applied.



**Figure 14** Energy and mass dependence of the absorbed fraction  $AF_{organ}(E, m_{organ})$  for monoenergetic photons in a homogeneously contaminated organ, assuming spherical shape within an effectively infinite volume



**Figure 15** Energy and mass dependence of the absorbed fraction  $AF_{organ}(E, m_{organ})$  for monoenergetic electrons in a homogeneously contaminated organ, assuming spherical shape within an effectively infinite volume

For alpha radiation and taking into account its short range in water and soft tissue, it can be assumed that  $AF \approx 1$ . Then, the absorbed dose rate due to an activity density  $A_M$  (in Bq/kg) of a given alpha emitter is:

$$\dot{D} = A_M \sum_{\alpha} E_{\alpha} y_{\alpha}$$

Where

$E_{\alpha}$  and  $y_{\alpha}$  are respectively the emission energy and emission yield for the radionuclide and the summation is extended to all the emission energies. For those organisms of size smaller than range, more specific calculations at microdosimetric level may be of interest (see, for example, C.J. Tung et al. 2004).

#### 10.17.4 Concluding remarks

Whole body dose rates in reference organisms due to internal exposure can be calculated using the DCCs for homogeneous distribution and the average whole activity concentration:

$$\dot{D}_{body}^{int\ ernat} = \left[ DCC_{homogeneous}^{int\ ernat} \pm u(DCC_{homogeneous}^{int\ ernat}) \right] \times A_{M, body}$$

For photons, the uncertainty due to a possible non-homogeneous radionuclide distribution is lower than 20-25%, in the considered cases. For electrons, uncertainty is negligible below a threshold energy, depending on the size of the organisms.

When the radionuclide is concentrated in a given organ, organ dose rate can be higher than whole body dose rate. In a general case:

$$\dot{D}_{organ} = E \times AF_{organ}(E, m_{organ}) \times A_{M, organ}$$

Where

$AF_{organ}$  is a smooth function of the energy and the mass of the organ. If the absorbed fraction in the organ is close to one, then a simple relationship can be used:

$$\frac{\dot{D}_{organ}}{\dot{D}_{body}} \approx \frac{m_{body}}{m_{organ}}$$

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#### 10.18 Useful websites for life history data

Website	Topics covered
<a href="http://www.arkive.org/species/">http://www.arkive.org/species/</a>	Globally endangered and protected mammals, birds, reptiles, amphibians, fish, invertebrates, plants and fungi
<a href="http://www.bbc.co.uk/nature/animals/">http://www.bbc.co.uk/nature/animals/</a>	Worldwide animals, plants, habitats and sea life (inc. corals)
<a href="http://www.rspb.org.uk/birds/guide/index.asp">http://www.rspb.org.uk/birds/guide/index.asp</a>	Guide to birds in the UK
<a href="http://www.birdlife.org/datazone/species/index.html">http://www.birdlife.org/datazone/species/index.html</a>	Worldwide bird population estimates
<a href="http://www.iucnredlist.org/">http://www.iucnredlist.org/</a>	2006 IUCN red list of threatened species

### 10.19 EMCL Tabulated values

Table 23: EMCL values for **soil** (Bq kg<sup>-1</sup> d.w.) or for S, H, C, P (Bq m<sup>-3</sup> in air) in a generic **terrestrial ecosystem** based on the ERICA Screening dose rate of 10 µGy h<sup>-1</sup>.

<b>Radionuclide</b>	<b>EMCL Bq kg<sup>-1</sup> d.w.</b>	<b>Limiting organism</b>
H-3	2.64E+03	Bird
C-14	8.40E+01	Mammal - small-burrowing
P-32	6.33E+00	Mammal - large
P-33	5.52E+01	Amphibian
S-35	7.63E+02	Grasses & Herbs
Cl-36	1.20E+03	Grasses & Herbs
Ca-45	7.58E+03	Reptile
Cr-51	6.29E+05	Annelid
Mn-54	2.21E+04	Arthropod - detritivorous
Co-57	1.59E+05	Mammal - small-burrowing
Co-58	1.85E+04	Mammal - small-burrowing
Ni-59	1.24E+06	Lichen & Bryophytes
Co-60	7.30E+03	Amphibian
Ni-63	8.77E+05	Lichen & Bryophytes
Zn-65	6.67E+03	Mammal - large
Se-75	3.47E+04	Annelid
Se-79	5.29E+04	Annelid
Sr-89	3.28E+03	Lichen & Bryophytes
Sr-90	2.03E+03	Lichen & Bryophytes
Nb-94	1.15E+04	Annelid
Nb-95	2.38E+04	Annelid
Zr-95	2.43E+04	Amphibian
Tc-99	4.61E+03	Grasses & Herbs
Ru-103	7.30E+03	Lichen & Bryophytes
Ru-106	2.24E+03	Lichen & Bryophytes
Cd-109	1.53E+04	Arthropod - detritivorous
Ag-110m	5.65E+03	Mammal - large
Sb-124	1.03E+04	Annelid
I-125	2.11E+05	Mammal - large
Sb-125	4.41E+04	Annelid
I-129	1.59E+05	Mammal - large
Te-129m	5.35E+03	Annelid
I-131	3.14E+04	Mammal - small-burrowing
I-132	6.49E+03	Amphibian
Te-132	3.02E+03	Annelid
I-133	1.73E+04	Mammal - small-burrowing
Cs-134	1.22E+03	Mammal - large
Cs-135	1.97E+04	Mammal - large
Cs-136	9.43E+02	Mammal - large
Cs-137	2.28E+03	Mammal - large
Ba-140	2.87E+02	Bird

La-140	6.06E+03	Amphibian
Ce-141	3.56E+05	Annelid
Ce-144	1.04E+05	Bird
Eu-152	1.72E+04	Annelid
Eu-154	1.55E+04	Amphibian
Ir-192	1.99E+04	Amphibian
Pb-210	6.25E+03	Lichen & Bryophytes
Po-210	4.44E+01	Lichen & Bryophytes
Ra-226	2.77E+01	Lichen & Bryophytes
Th-227	2.11E+02	Lichen & Bryophytes
Ra-228	1.28E+04	Lichen & Bryophytes
Th-228	3.86E+01	Lichen & Bryophytes
Th-230	2.66E+02	Lichen & Bryophytes
Pa-231	9.62E+01	Lichen & Bryophytes
Th-231	6.29E+04	Lichen & Bryophytes
Th-232	3.11E+02	Lichen & Bryophytes
Th-234	2.80E+04	Lichen & Bryophytes
U-234	1.17E+02	Lichen & Bryophytes
U-235	1.26E+02	Lichen & Bryophytes
Np-237	1.00E+02	Lichen & Bryophytes
Pu-238	7.52E+02	Lichen & Bryophytes
U-238	1.33E+02	Lichen & Bryophytes
Pu-239	8.00E+02	Lichen & Bryophytes
Pu-240	8.00E+02	Lichen & Bryophytes
Am-241	8.62E+01	Lichen & Bryophytes
Pu-241	2.94E+06	Lichen & Bryophytes
Cm-242	7.58E+01	Lichen & Bryophytes
Cm-243	8.00E+01	Lichen & Bryophytes
Cm-244	8.00E+01	Lichen & Bryophytes
Cf-252	7.81E+01	Lichen & Bryophytes

Table 24: EMCL values for **water** ( $\text{Bq l}^{-1}$ ) in a generic **freshwater ecosystem** based on the ERICA Screening dose rate of  $10 \mu\text{Gy h}^{-1}$ .

<b>Radionuclide</b>	<b>EMCL <math>\text{Bq l}^{-1}</math></b>	<b>Limiting organism</b>
H-3	3.94E+05	Mammal
C-14	4.76E-01	Benthic fish
P-32	2.19E-02	Reptile
P-33	1.91E-01	Reptile
S-35	2.65E+02	Insect larvae
Cl-36	3.27E+01	Benthic fish
Ca-45	4.95E+01	Pelagic fish
Cr-51	5.49E+00	Insect larvae
Mn-54	9.09E-02	Insect larvae
Co-57	3.30E-01	Insect larvae
Co-58	4.20E-02	Insect larvae

Ni-59	6.41E+01	Insect larvae
Co-60	1.68E-02	Insect larvae
Ni-63	2.27E+02	Insect larvae
Zn-65	2.94E+00	Reptile
Se-75	4.37E+00	Insect larvae
Se-79	2.43E+01	Mollusc - bivalve
Sr-89	6.58E-01	Mammal
Sr-90	3.39E-01	Mammal
Nb-94	4.88E+00	Mammal
Nb-95	1.18E+01	Mammal
Zr-95	2.30E+00	Insect larvae
Tc-99	6.17E+02	Reptile
Ru-103	3.89E-01	Insect larvae
Ru-106	1.33E-01	Insect larvae
Cd-109	2.75E-01	Insect larvae
Ag-110m	1.71E-02	Insect larvae
Sb-124	1.78E-01	Insect larvae
I-125	1.19E+00	Insect larvae
Sb-125	8.20E-01	Insect larvae
I-129	1.91E+00	Insect larvae
Te-129m	1.90E+00	Insect larvae
I-131	1.19E-01	Insect larvae
I-132	1.91E-02	Insect larvae
Te-132	2.85E-01	Insect larvae
I-133	6.10E-02	Insect larvae
Cs-134	2.05E-02	Insect larvae
Cs-135	8.70E+00	Insect larvae
Cs-136	1.45E-02	Insect larvae
Cs-137	5.10E-02	Insect larvae
Ba-140	3.09E-01	Insect larvae
La-140	5.35E-03	Insect larvae
Ce-141	1.35E-01	Insect larvae
Ce-144	1.29E-02	Insect larvae
Eu-152	2.94E+00	Mammal
Eu-154	1.93E+00	Mammal
Ir-192	1.99E-02	Insect larvae
Pb-210	1.12E+00	Insect larvae
Po-210	1.45E-03	Insect larvae
Ra-226	9.09E-04	Insect larvae
Th-227	6.90E-04	Vascular plant
Ra-228	2.50E-01	Insect larvae
Th-228	1.03E-04	Vascular plant
Th-230	9.52E-04	Vascular plant
Pa-231	7.94E-03	Mollusc - gastropod
Th-231	1.79E-02	Insect larvae
Th-232	1.12E-03	Vascular plant

Th-234	8.70E-04	Insect larvae
U-234	2.53E-01	Vascular plant
U-235	2.72E-01	Vascular plant
Np-237	4.57E-01	Mollusc - bivalve
Pu-238	1.59E-02	Mollusc - gastropod
U-238	2.96E-01	Vascular plant
Pu-239	1.70E-02	Mollusc - gastropod
Pu-240	1.69E-02	Mollusc - gastropod
Am-241	9.62E-03	Mollusc - gastropod
Pu-241	6.25E+01	Mollusc - gastropod
Cm-242	1.96E-02	Phytoplankton
Cm-243	2.06E-02	Phytoplankton
Cm-244	2.07E-02	Phytoplankton
Cf-252	9.35E-03	Mollusc - gastropod

Table 25: EMCL values for **sediment** ( $\text{Bq kg}^{-1} \text{ d.w.}$ ) in a generic **freshwater ecosystem** based on the ERICA Screening dose rate of  $10 \mu\text{Gy h}^{-1}$ .

<b>Radionuclide</b>	<b>EMCL <math>\text{Bq kg}^{-1} \text{ d.w.}</math></b>	<b>Limiting organism</b>
H-3	6.02E+04	Vascular plant
C-14	8.62E-01	Benthic fish
P-32	1.80E-01	Benthic fish
P-33	1.56E+00	Benthic fish
S-35	3.92E+05	Reptile
Cl-36	2.66E+00	Pelagic fish
Ca-45	1.35E+04	Pelagic fish
Cr-51	3.56E+05	Insect larvae
Mn-54	2.06E+04	Insect larvae
Co-57	1.22E+05	Insect larvae
Co-58	1.76E+04	Insect larvae
Ni-59	1.08E+06	Insect larvae
Co-60	7.04E+03	Insect larvae
Ni-63	8.13E+05	Insect larvae
Zn-65	6.25E+02	Reptile
Se-75	5.52E+03	Mammal
Se-79	5.92E+03	Zooplankton
Sr-89	5.13E+02	Mammal
Sr-90	2.65E+02	Mammal
Nb-94	7.69E+01	Mammal
Nb-95	1.86E+02	Mammal
Zr-95	1.93E+04	Insect larvae
Tc-99	8.47E+02	Pelagic fish
Ru-103	3.56E+04	Insect larvae
Ru-106	1.22E+04	Insect larvae
Cd-109	3.95E+04	Mollusc - bivalve

Ag-110m	6.10E+03	Insect larvae
Sb-124	4.81E+03	Reptile
I-125	5.56E+04	Mammal
Sb-125	1.72E+04	Reptile
I-129	3.94E+04	Reptile
Te-129m	1.96E+03	Bird
I-131	1.31E+04	Reptile
I-132	3.70E+03	Reptile
Te-132	1.09E+03	Mammal
I-133	6.80E+03	Reptile
Cs-134	9.90E+03	Insect larvae
Cs-135	1.09E+05	Amphibian
Cs-136	7.19E+03	Insect larvae
Cs-137	1.75E+04	Reptile
Ba-140	8.62E+02	Bird
La-140	6.54E+03	Insect larvae
Ce-141	1.65E+05	Insect larvae
Ce-144	1.63E+04	Insect larvae
Eu-152	1.03E+03	Mammal
Eu-154	6.80E+02	Mammal
Ir-192	7.14E+02	Benthic fish
Pb-210	5.00E+03	Mollusc - bivalve
Po-210	1.70E+00	Insect larvae
Ra-226	2.80E+00	Insect larvae
Th-227	8.20E+00	Vascular plant
Ra-228	1.19E+03	Mollusc - bivalve
Th-228	1.48E+00	Vascular plant
Th-230	1.03E+01	Vascular plant
Pa-231	4.81E+01	Mollusc - bivalve
Th-231	2.53E+03	Vascular plant
Th-232	1.20E+01	Vascular plant
Th-234	1.16E+03	Vascular plant
U-234	1.23E+01	Mollusc - gastropod
U-235	1.34E+01	Mollusc - gastropod
Np-237	1.28E-01	Mollusc - bivalve
Pu-238	6.06E+02	Phytoplankton
U-238	1.44E+01	Mollusc - gastropod
Pu-239	6.45E+02	Phytoplankton
Pu-240	6.45E+02	Phytoplankton
Am-241	2.07E+02	Mollusc - bivalve
Pu-241	2.37E+06	Phytoplankton
Cm-242	4.93E-01	Phytoplankton
Cm-243	5.18E-01	Phytoplankton
Cm-244	5.18E-01	Phytoplankton
Cf-252	2.07E+02	Mollusc - gastropod

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Table 26: EMCL values for **water** (Bq l<sup>-1</sup>) in a generic **marine ecosystem** based on the ERICA Screening dose rate of 10 µGy h<sup>-1</sup>.

<b>Radionuclide</b>	<b>EMCL Bq l<sup>-1</sup></b>	<b>Limiting organism</b>
H-3	3.94E+05	Mollusc - bivalve
C-14	1.16E+01	Zooplankton
P-32	1.64E-01	Crustacean
P-33	1.42E+00	Sea anemones & True coral
S-35	3.51E+04	Sea anemones & True coral
Cl-36	3.76E+04	Vascular plant
Ca-45	3.70E+02	Bird
Cr-51	1.14E+00	Polychaete worm
Mn-54	1.05E-03	Polychaete worm
Co-57	4.74E-02	Polychaete worm
Co-58	5.88E-03	Polychaete worm
Ni-59	4.37E+01	Sea anemones & True coral
Co-60	2.30E-03	Polychaete worm
Ni-63	3.32E+01	Sea anemones & True coral
Zn-65	4.27E-02	Polychaete worm
Se-75	1.54E+00	Polychaete worm
Se-79	1.02E+01	Crustacean
Sr-89	4.98E+01	Reptile
Sr-90	2.53E+01	Reptile
Nb-94	1.41E-03	Polychaete worm
Nb-95	2.93E-03	Polychaete worm
Zr-95	1.20E-03	Polychaete worm
Tc-99	1.07E+00	Vascular plant
Ru-103	9.62E-02	Polychaete worm
Ru-106	7.35E-02	Polychaete worm
Cd-109	4.03E-01	Mollusc - bivalve
Ag-110m	6.37E-02	Polychaete worm
Sb-124	4.33E-01	Polychaete worm
I-125	1.08E+01	Polychaete worm
Sb-125	1.94E+00	Polychaete worm
I-129	6.17E+00	Polychaete worm
Te-129m	1.91E+00	Reptile
I-131	2.67E+00	Polychaete worm
I-132	1.02E+00	Polychaete worm
Te-132	5.81E-01	Polychaete worm
I-133	1.33E+00	Polychaete worm
Cs-134	2.87E-01	Polychaete worm
Cs-135	1.59E+02	Reptile
Cs-136	2.11E-01	Polychaete worm
Cs-137	7.63E-01	Polychaete worm
Ba-140	2.95E-01	Polychaete worm
La-140	2.57E-04	Polychaete worm

Ce-141	7.35E-03	Polychaete worm
Ce-144	1.66E-03	Polychaete worm
Eu-152	8.33E-04	Polychaete worm
Eu-154	7.63E-04	Polychaete worm
Ir-192	2.14E-02	Polychaete worm
Pb-210	6.41E-02	Phytoplankton
Po-210	3.79E-04	Polychaete worm
Ra-226	1.90E-02	Phytoplankton
Th-227	1.45E-04	Phytoplankton
Ra-228	8.93E-01	Polychaete worm
Th-228	2.59E-05	Phytoplankton
Th-230	1.81E-04	Phytoplankton
Pa-231	8.06E-03	Polychaete worm
Th-231	2.91E-02	Polychaete worm
Th-232	2.12E-04	Phytoplankton
Th-234	3.21E-03	Polychaete worm
U-234	1.96E-01	Polychaete worm
U-235	2.12E-01	Polychaete worm
Np-237	1.98E-01	Sea anemones & True coral
Pu-238	8.20E-04	Phytoplankton
U-238	2.29E-01	Polychaete worm
Pu-239	8.70E-04	Phytoplankton
Pu-240	8.70E-04	Phytoplankton
Am-241	5.32E-04	Phytoplankton
Pu-241	3.19E+00	Phytoplankton
Cm-242	4.22E-04	Phytoplankton
Cm-243	4.42E-04	Phytoplankton
Cm-244	4.44E-04	Phytoplankton
Cf-252	5.05E-04	Phytoplankton

Table 27: EMCL values for **sediment** (Bq kg<sup>-1</sup> d.w.) in a generic **marine ecosystem** based on the ERICA Screening dose rate of 10 µGy h<sup>-1</sup>.

<b>Radionuclide</b>	<b>EMCL Bq kg<sup>-1</sup> d.w.</b>	<b>Limiting organism</b>
H-3	1.10E+05	Phytoplankton
C-14	3.27E+03	Zooplankton
P-32	2.02E+02	Pelagic fish
P-33	1.75E+03	Pelagic fish
S-35	4.88E+03	Sea anemones & True coral
Cl-36	1.96E+02	Phytoplankton
Ca-45	6.54E+04	Phytoplankton
Cr-51	4.76E+05	Polychaete worm
Mn-54	2.13E+04	Polychaete worm
Co-57	1.30E+05	Polychaete worm
Co-58	1.78E+04	Polychaete worm

Ni-59	3.15E+05	Sea anemones & True coral
Co-60	6.99E+03	Polychaete worm
Ni-63	2.33E+05	Sea anemones & True coral
Zn-65	4.15E+03	Crustacean
Se-75	2.41E+03	Reptile
Se-79	8.47E+03	Crustacean
Sr-89	1.45E+02	Bird
Sr-90	7.46E+01	Mammal
Nb-94	1.12E+04	Polychaete worm
Nb-95	2.33E+04	Polychaete worm
Zr-95	2.38E+04	Polychaete worm
Tc-99	3.25E+01	Vascular plant
Ru-103	1.97E+04	Zooplankton
Ru-106	6.54E+03	Zooplankton
Cd-109	5.08E+03	Mollusc - bivalve
Ag-110m	4.85E+02	Reptile
Sb-124	3.24E+02	Mammal
I-125	2.92E+02	Polychaete worm
Sb-125	1.18E+03	Reptile
I-129	1.67E+02	Polychaete worm
Te-129m	3.01E+02	Reptile
I-131	6.94E+01	Mollusc - bivalve
I-132	2.70E+01	Mollusc - bivalve
Te-132	9.71E+01	Reptile
I-133	3.48E+01	Mollusc - bivalve
Cs-134	1.07E+04	Polychaete worm
Cs-135	1.99E+05	Bird
Cs-136	8.00E+03	Polychaete worm
Cs-137	2.48E+04	Reptile
Ba-140	6.02E+03	Polychaete worm
La-140	7.35E+03	Polychaete worm
Ce-141	2.19E+05	Polychaete worm
Ce-144	4.90E+04	Polychaete worm
Eu-152	1.52E+04	Polychaete worm
Eu-154	1.37E+04	Polychaete worm
Ir-192	1.35E+04	Phytoplankton
Pb-210	2.33E+03	Phytoplankton
Po-210	1.39E+03	Polychaete worm
Ra-226	1.81E+01	Phytoplankton
Th-227	1.14E+02	Phytoplankton
Ra-228	1.31E+04	Polychaete worm
Th-228	2.09E+01	Phytoplankton
Th-230	1.44E+02	Phytoplankton
Pa-231	1.54E+05	Phytoplankton
Th-231	3.65E+04	Phytoplankton
Th-232	1.68E+02	Phytoplankton

Th-234	4.26E+04	Phytoplankton
U-234	3.34E+01	Polychaete worm
U-235	3.62E+01	Polychaete worm
Np-237	2.74E+01	Reptile
Pu-238	2.45E+01	Phytoplankton
U-238	3.89E+01	Polychaete worm
Pu-239	2.61E+01	Phytoplankton
Pu-240	2.61E+01	Phytoplankton
Am-241	2.79E+02	Phytoplankton
Pu-241	9.62E+04	Phytoplankton
Cm-242	1.96E+02	Phytoplankton
Cm-243	2.06E+02	Phytoplankton
Cm-244	2.06E+02	Phytoplankton
Cf-252	2.72E+02	Phytoplankton

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