Application of Non-Human Biota Assessment Methodologies to the Assessment of Potential Impacts from a Nuclear Waste Repository

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ABSTRACT

The protection of the environment from the effects of ionising radiation has become increasingly more topical over the last few years as the intentions enshrined in international principles and agreements have become more binding through national and international law. For example, the Directive on impact of certain projects on the environment (EIA Directive 85/337/EEC) [CEC, 1985], amended in 1997 [CEC, 1997], places a mandatory requirement on all EU Member States to conduct environmental impact assessments for a range of project having potential impact on the environment, including radioactive waste disposal. Such assessments must consider humans, fauna and flora, the abiotic environment (soil, water, air), material assets and cultural heritage as well as the interactions between these factors.

In Finland, Posiva Oy are responsible for the overall repository programme for spent nuclear fuel and, as such, are conducting the Safety Case Assessment for a proposed geological repository for nuclear waste. Within the European legislation framework, the Finnish regulatory body requires that the repository safety case assessment should include not only human radiological safety, but also an assessment of the potential impact upon populations of non-human biota. Specifically, the Safety Case should demonstrate that there will be:

- no decline in the biodiversity of currently living populations;
- no significant detriment to populations of fauna and flora; and,
- no detrimental effects on individuals of domestic animals and rare plants and animals.

At present, there are no internationally agreed criteria that explicitly address protection of the environment from ionising radiation. However, over recent years a number of assessment methodologies have been developed including, at a European level, the Framework for the Assessment of Environmental impacT (FASSET) and Environmental Risks from Ionising Contaminants (ERICA). The International Committee on Radiation Protection (ICRP) have also proposed an approach to allow for assessments of potential impacts on non-human species, in its report in 2003. This approach is based on the development and use of a small set of reference animals and plants, with their associated dose models and data sets. Such approaches are broadly applicable to the Posiva Safety Case. However, the specific biota of concern and the current climatic conditions within Finland present an additional challenge to the assessment.

The assessment methods most applicable to the Posiva Safety Case have therefore been reviewed in consideration of the regulatory requirements for the assessment and recommendations made on a suitable assessment approach. This has been applied within a test case and adaptations to the overall assessment method have been made to enable both population and individual impacts to be assessed where necessary.

The test case has been undertaken to demonstrate the application of the recommended methodology, but also to identify data gaps, uncertainties and other specific issues associated with the application of an assessment method within the regulatory context.

INTRODUCTION

At present, there are no internationally agreed criteria that explicitly address protection of the environment from ionising radiation. Traditionally, the system of radiological protection has focused on the protection of man. National and international policies and legislation, related to radiological protection, are generally based on the recommendations of an international advisory body, the International Commission on Radiological Protection (ICRP) which, until recently did not deal explicitly with environmental protection. For example, in its 1990 recommendations, ICRP stated that ‘*The Commission believes that the standards of environmental control needed to protect man to the degree currently thought desirable will ensure that other species are not put at risk*’ [Ref.. 1].

However, in recent years, there has been an increasing emphasis on environmental protection issues, fuelled by an increasing number of international and national legal instruments that deal with various aspects of protection of the environment – ranging from general requirements to minimise pollution or to maintain biodiversity and ensure sustainable development, to more specific requirements on the preservation and conservation of particular species or habitats. For example, the Directive on impact of certain projects on the environment (EIA Directive 85/337/EEC), amended in 1997, places a mandatory requirement on all EU Member States to conduct environmental impact assessments for a range of projects having potential impact on the environment, including radioactive waste disposal. Such assessments must consider humans, fauna and flora, the abiotic environment (soil, water, air), material assets and cultural heritage as well as the interactions between these factors. These types of requirements have led to the development of assessment methods to explicitly evaluate the potential impact of pollutants, including radioactive substances, on non-human species.

Due to the variability of ecosystems and the diversity of biota, such methods require a large degree of simplification and are therefore generic in nature, often being developed for the assessment of the impacts of routine discharges to the environment. However, as countries move towards the geological disposal of long-lived radioactive waste, the applicability of these methodologies to such scenarios is being tested.

In Finland, Posiva Oy is responsible for the overall repository programme for spent nuclear fuel and in December 2000 the Finnish Government issued a decision in principle in favour of a geological repository at Olkiluoto in southwest Finland. The repository will be at a depth 400-500m with disposal due to commence in 2020. In preparation for the final disposal of nuclear waste, Posiva are conducting a Safety Case Assessment (SCA) for the proposed Olkiluoto repository. The SCA is broad ranging, encompassing aspects such as canister and repository design, evolution of the site and repository, and the transport of radionuclides from the near-field to the biosphere.

Within the European legislation framework the Finnish regulator, the Radiation and Nuclear Safety Authority (STUK) requires that the repository SCA should include an assessment of the potential impact upon populations of non-human biota. STUK stipulate a number of requirements relating to the degree of acceptability of impacts on non-human biota. In order to ensure these stipulations would be met Enviros Consulting Ltd was contracted by Posiva to support development of a strategy for the implementation of non-human biota assessments within the SCA in consideration of the STUK regulatory requirements. The approach taken and results from a demonstration test case are presented below.

STUK REGULATORY REQUIREMENTS

STUK document YVL 8.4 [Ref. 2] sets out the regulatory requirements for the assessment of the long-term safety of disposal of spent nuclear fuel in Finland. The guidelines require that exposures to fauna and flora '*remain clearly below the levels which, on the basis of the best available scientific knowledge, would cause decline in biodiversity or other significant detriment to any living population*'. In addition, this guidance requires that rare species of plants and animals and domestic animals should not be exposed to activity concentrations that would cause detriment at the level of the individual.

It was therefore required that the SCA should demonstrate that there will be:

- no decline in the biodiversity of currently living populations;
- no significant detriment to populations of fauna and flora; and,
- no detrimental effects on individuals of domestic animals and rare plants and animals.

The guidelines require consideration to be made of the impact of the disposal of spent fuel on species of fauna and flora assuming '*the present kind of living populations*' over an assessment period of '*several thousands of years*', which has been interpreted as, in the context of the Olkiluoto site, between 2,000 and 10,000 years.

OVERVIEW OF ASSESSMENT METHODOLOGIES APPLICABLE TO OLKILUOTO

A review of available and developing methodologies was undertaken to identify methods most applicable to the Posiva SCA. Two projects together were considered to provide the most comprehensive generic biota assessment methods and associated information relevant to the Olkiluoto site – the EC FASSET (Framework for the Assessment of Environmental Impact) and EPIC (Environmental Protection from Ionizing Contaminants) programmes. The assessment methodologies underlying both of these projects, and their continuation – the ERICA (Environmental Risks from Ionizing Contaminants) programme – are broadly similar[1].

The FASSET programme focused on a wide range of organisms that were identified as representing the key trophic and functional entities within the main ecosystem types arising in Europe whereas the EPIC project focused on the environmental transfer of radioactivity in the Arctic and uptake by biota. The geographical extent of concern (the Arctic) encompasses northern Finland and it is therefore reasonable to expect the results of this project to be particularly relevant to an assessment Olkiluoto, especially considering colder climate stages. In addition, EPIC suggests that consideration is given to both average dose and doses to maximally exposed individuals, which is analogous to the method used in human assessments for the SCA. However, there are a number of data gaps inherent in the EPIC methodology. These, in particular, relate to the availability of concentration ratio (CR) and dose per unit concentration (DPUC, or DCC) factors which arise due to the limited scientific literature relating to Arctic ecosystems on which they could be derived. It was therefore considered that the EPIC methodology was too restricted to be applied alone to the Olkiluoto site. Aspects of both the FASSET and EPIC approaches were therefore applied.

Both FASSET and EPIC have a number of similarities due to the level of simplification required to assess potential impacts to what is a diverse system in terms of the environment itself and the fauna and flora that occupy each system. Both methods, like many other available or developing methodologies, have therefore often adopted a 'reference organism' approach. This entails the identification of general biota 'types' that would be expected within a generic ecosystem type such as forest, freshwater, grassland etc. Example organism 'types' would include a generic seabird or pelagic fish within a marine environment.

[1] For further details of all three projects, see www.erica-project.org.

Such organisms are represented as a simplified ellipsoid geometry for the purposes of dose calculations and generic occupancy factors applied to take account of the relative time spent within different compartments of an environment (e.g. within soil, on soil or in the air). Within the FASSET Framework, 31 'reference organism' for which parameters required for the assessment of dose have been collated.

The starting point for an assessment is the activity concentration of radionuclides in the habitat of an organism of interest. Information on the species of interest is also required. The minimum information required is:

- species name;
- dimensions on which to select a representative ellipsoid (length, width, depth); and,
- general habitat information (occupancy within different ecosystem compartments).

On the basis of this information, a representative ellipsoid can be derived and internal biota concentrations (assuming uniform distribution of radionuclides within the organism) are calculated through the application of a concentration ratio (CR) for each organism of interest. Both internal and external doses are calculated through the application of Dose Conversion Coefficients (DCC). In the case of internal doses, these are applied to activity concentrations in biota. For external doses, they are used in association with activity concentrations measured in the habitat (e.g. water, soil or sediment).

The exposure of both flora and fauna is expressed as an absorbed dose rate (Gy/hour). However, the absorbed dose of differing radiations can produce differing degrees of effect in the same biological endpoint. Weighting factors are therefore applied to account for the difference in effect between low- and high-LET radiations. In the case of alpha radiation, a weighting factor of 10 is generally applied to weighted DPUC factors and for tritium a weighting factor of 3 is applied. There is uncertainty associated with the use of these factors, with the possible range of weighting factors for alpha radiation being said to be between 5 and 20 [Ref. 3].

In relation to the regulatory requirements set by STUK for the SCA, the application of the default data in FASSET and ERICA was considered to be applicable to the assessment of effects on generic 'reference creatures', in the context of the populations of fauna and flora and biodiversity criteria. However, this approach was considered too generic to apply to an assessment of effects on individuals of rare or sensitive species. As a consequence, the 'maximally exposed individual' concept of EPIC was applied and more specific effects data or individual-related dose rate comparators were applied to take account of potentially enhanced sensitivities.

ENVIRONMENT AROUND OLKILUOTO – CURRENT AND FUTURE PREDICTIONS

Landscape

Olkiluoto Island is located to the southwest of the Finnish mainland. The island is currently surrounded by the brackish Baltic Sea. The island is characterized with shallow bays, and interwoven forests, rocky outcrops, nutrient-rich mires, meadows and reed colonies in near-shore areas [Ref. 4]. The climate is such that the island can be covered in snow and ice for around 4 months per year [Ref. 4].

As part of its development of a SCA, Posiva has undertaken assessments of the likely environmental changes on the island and its immediate vicinity over the period of the next 10 thousand years. Of particular relevance is the continuing process of postglacial land uplift in this area, such that, over time, marine and coastal areas are progressively being converted into wetland, forest and agricultural areas. This is likely to result in a reduction in salinity of the area over time as the catchment area increases through land uplift, resulting in a greater freshwater input to the coastal area. The changing nature of the area will clearly affect the biota present in a given location and would have a potential to impact on the transfer of any radionuclides released into the immediate environment.

Predictions of future landscape have been made by Posiva on the basis of seabed topography and sediment mapping. Seabed topography has enabled predictions of the location of lakes and rivers to be made and the sediment maps allow future soil types and hence vegetation types to be predicted [Ref. 5]. The future land and vegetation-type predictions have been made for various time-steps including the step of 5850 year after present (AP), used in this assessment to present the far future including all relevant ecosystem types. Overall it is predicted that, over the period of the next few thousand years, agricultural land will be established and concentrated around rivers and possibly wetland areas formed as a result of land up-lift. Since the STUK requirement was for an assessment of potential impacts on fauna and flora over a period of 'several thousand years' the latter time step prediction (Fig. 1) was used as the basis for the development of a test case scenario.

Fig. 1. Landscape prediction of the area around Olkiluoto at 5850 years AP.

Biota

As indicated above, STUK effectively places general requirements on the protection of populations and biodiversity and more specific requirements on the protection of rare and/or sensitive species and domestic animals. For the purposes of this assessment, a range of species was identified to be representative of those encountered in the types of ecosystem present (or likely to be present) on Olkiluoto Island on the basis of Natura 2000 site descriptions, game statistics and agricultural statistical bulletins. Local knowledge of the Olkiluoto area was also provided by Posiva. Of particular note was the importance of the Olkiluoto area as a migratory passage for Moose, a species of local public interest.

A number of generic species were also considered to be representative of the types and range of species found in the ecosystems, but which were not specifically referred to in the documents consulted. These were identified to ensure that the full range of organisms was considered, as part of the test case, and in the context of the population/diversity criterion.

TEST CASE SCENARIO

Dose rates to non-human biota were conducted using the approach outlined in FASSET, but incorporating the Arctic-specific data from EPIC where available. The overall approach taken in the test case is described below and summarized in Figure 2. Adaptations made to the methodology to account to take account of the specific criteria set by STUK are described in the subsequent section.

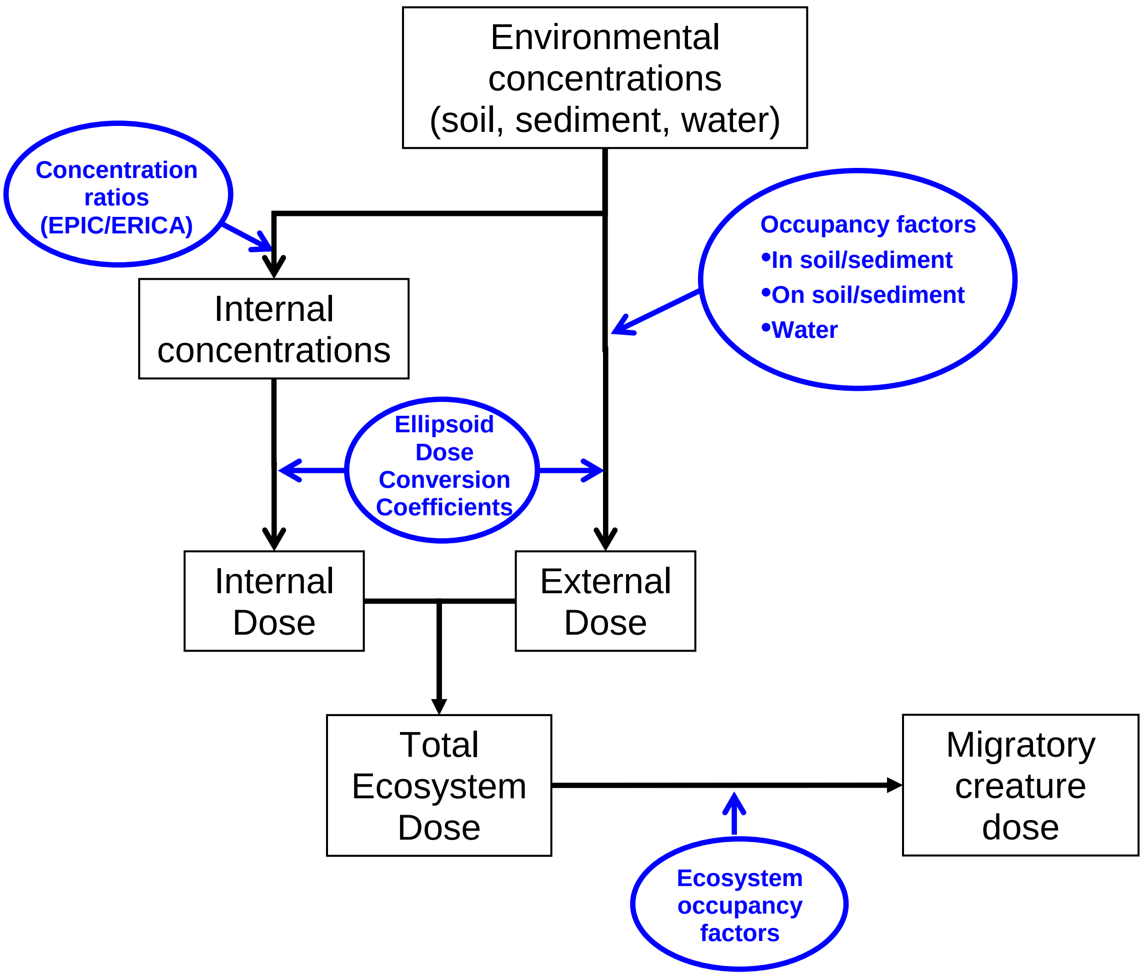

Fig. 2. Approach to the assessment of dose to non-human biota

Radionuclides considered

The following radionuclides were considered in the test case[2]: Cl-36, Ni-59, Se-79, Tc-99, I-129, Cs-135, Ra-226, Th-230, U-234, U-238, Np-237, and Pu-239.

Activity concentrations in ecosystem compartments

For illustrative purposes the assessment was based primarily on a single time period (10,000 years AP). A test case scenario was identified in consultation with Posiva on the basis of the predicted landscape at

[2] C-14 was initially included in the test case scenario. However, due to the inconsistency between the format of modelled data (soil/water concentrations) and that required as input for the assessment (air concentrations), this could not be further incorporated within the assessment.

5850 years AP (illustrated above), assuming current ecosystem types and biota populations. On this basis, the following ecosystems were identified:

- brackish waters;
- freshwaters (lakes and rivers);
- mires;
- grassland/agricultural areas; and,
- mixed forests.

The approach applied to represent the flow of radionuclides into and through these ecosystems is demonstrated in Figure 3.

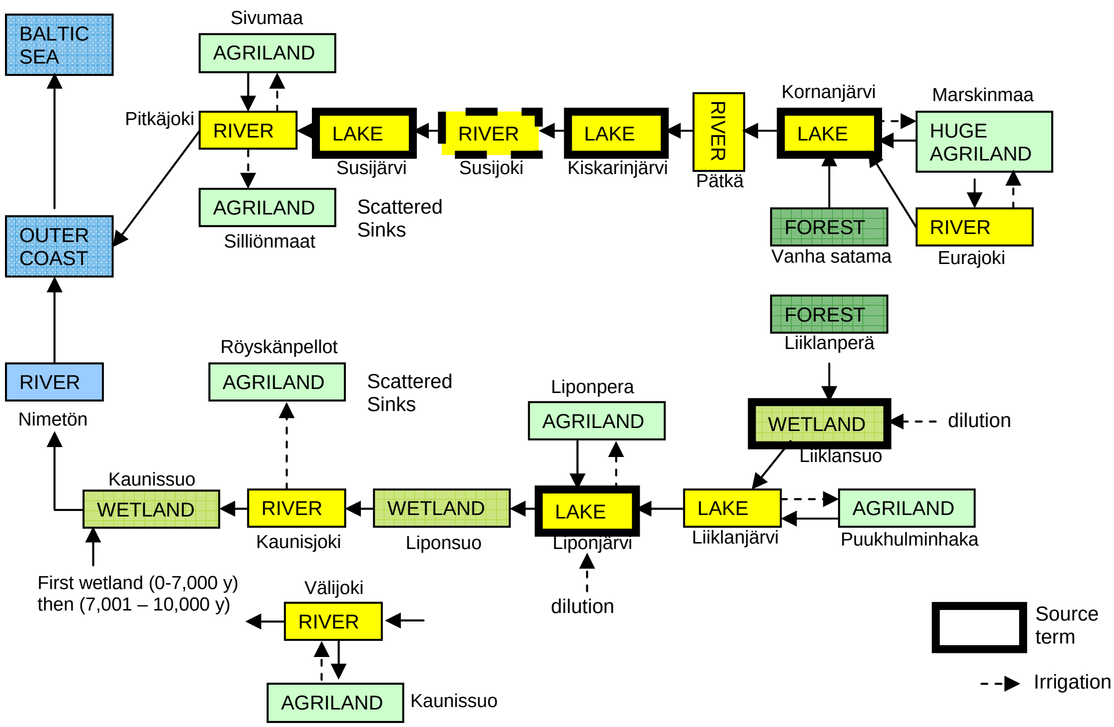

Fig. 3. Radionuclide release points and ecosystem flow

Data were provided by Posiva for a release of 1 Bq/y into the whole landscape and activity concentrations in soil, sediment and water were predicted by Facilia AB using the compartmental models [Refs 6, 7, 8]) in the PANDORA environment [Ref. 9], in each ecosystem on the basis of a direct release into each of the boxes outlined in bold in Figure 3. Predicted activity concentrations based on a 1 Bq/y release to the biosphere were subsequently multiplied by the source term at 10,000 years, based on a dissolving canister scenario.

Reference creatures

A range of species for consideration in the test case was selected from those identified during the review of biota for the Olkiluoto area on the basis of the following criteria:

- Generic biota were selected that are representative of fauna likely to be present in the generic ecosystems outlined above and generic 'reference creatures' (e.g. small herbivorous mammal) allocated. The types of species for which these reference creatures may be considered to be representative were identified.

- A sub-set of the rare/protected and domestic biota was selected for demonstration purposes. These were selected on the basis that they provide a means of demonstrating specific aspects of the assessment methodology, for example:
  - Occupancy within ecosystem compartments likely to result in increased dose;
  - Ability to demonstrate assessment at the level of the individual compared to population; and/or,
  - Migration between ecosystems.

Generic biota and rare/protected species and domestic animals identified for the Olkiluoto area were categorised according to the types of ecosystem (Tables I and II, respectively). For the purposes of the assessment, generic biota were termed ‘reference creatures’ and rare/protected and domestic biota were termed ‘interest species’.

Occupancy factors were assigned for biota within each ecosystem to account for the amount of time spent in different ecosystem compartments (soil, sediment, water, above ground) assuming 100% occupancy within the ecosystem as a whole.

Table I. Reference Creatures by Ecosystems.

Marine	**Freshwater**	**Wetland**	**Grassland/ Agriculture**	**Forest**
Phytoplankton Zooplankton Macro-algae Worm Benthic mollusc Benthic crustacean Pelagic fish Benthic fish Wading Bird Aquatic Mammal (seal)	Phytoplankton Zooplankton Vascular plant Insect larvae Benthic mollusc Benthic crustacean Pelagic fish Benthic fish Duck	Grass Vascular plant Worm Bird egg Bird Small herbivorous mammal Carnivorous mammal	Grass / herb Shrub Fruit tree Worm Burrowing mammal Large herbivorous mammal Bird Bird egg Carnivorous mammal	Grass / herb Shrub Tree Worm Burrowing herbivorous mammal Large herbivorous mammal

Table II. Interest Species by Ecosystems.

Marine	Freshwater	Wetland	Grassland/ Agriculture	Forest
Otter Greylag goose Atlantic Salmon	Otter Freshwater pearl mussel Atlantic Salmon	Bear Elk Otter Greylag goose	Sheep Cow Root crop Grain crop Wolf Elk Greylag goose Bank Swallow Mountain hare	Wolf Bear Elk Mountain hare

Reference geometries and dose conversion coefficients

Non-human biota dose calculations are conducted on the basis of a simplified geometry representative of the dimensions of the main body of the organism (i.e. extremities such as legs, wings etc are not included). Each reference creature and interest species was therefore assigned an appropriate ellipsoid geometry.

Geometry-specific dose conversion coefficients (DCC) for both internal and external exposure to each radionuclide were then assigned. In the case of internally incorporated radionuclides, it is assumed that radionuclides are uniformly distributed in the application of dose conversion factors. Internal DCCs represent the ratio between the average concentration of a radionuclide in a reference creature and the dose rate to that organism. External DCCs are the ratio between the average concentration of a radionuclide in an environmental compartment (soil, sediment, water) of a reference ecosystem and the dose rate to a reference creature.

Data were gathered on creature dimensions and the most applicable geometry from both the EPIC and FASSET/ERICA databases and these were applied, taking account of the position of the organism in relation to soil where possible. In the case of some organisms, for example bear and elk, no suitable geometries were available. A prototype tool developed through ERICA was therefore applied to derive a suitable geometry and applicable dose conversion factors for these interest species.

Model application

To permit the calculation of dose, a series of spreadsheets was developed containing all of the identified parameter values and equations for the calculation of dose rate (μGy/h). Formulae in FASSET [2003] provided the basis for dose rate calculations. Both internal and external dose rates were calculated on the basis of these formulae and summed to calculate overall dose to each reference creature and interest species.

External absorbed dose rate is calculated taking into account the proportion of time that a creature spends in different compartments of the reference ecosystem. Environmental concentrations in soil, sediment and/or water were provided by Facilia from the PANDORA simulation as the basis for these calculations.

Internal activity concentrations for reference creatures were calculated through the application of concentration ratios (CR) assuming uniform conditions (i.e. no account it taken of potential accumulation of radionuclides within individual tissues).

Weighting factors were applied to take account of the differing biological effectiveness of different types of ionising radiation. A factor of 20 has been applied to alpha radiation, 3 to low energy beta and 1 to gamma/high energy beta.

ADAPTATIONS TO THE ASSESSMENT METHODOLOGY

Differentiation between generic creatures and interest species

The generic FASSET/ERICA and EPIC approaches have been developed as a means of assessing potential impacts at the level of the population. In this respect, average CR values are normally applied. However, STUK place requirements on Posiva to assess impacts at the level of the individual for rare/protected and domestic species. To take account of these criteria, maximum CR values and the use of maximum occupancy within those ecosystem compartments likely to result in increased dose (for example, hibernation/burrowing within soil) were applied. Possible enhanced sensitivities of such species were, in effect, taken into account by the application of individual related dose rate comparators.

Climate considerations

Occupancy factors were adapted in order to take account of the extreme climatic conditions (ice coverage for up to 4 months per year, whilst maintaining maximizing assumptions. For example, in the case of an organism that hibernates during the winter period, occupancy within soil was maximized. However, for those biota that remain active throughout the year, no account was taken of the potential barrier between organism and soil during ice coverage.

Migration

As noted previously, the Olkiluoto area is a migration route for Moose. It was therefore a requirement of Posiva that the test case take account of the relative contribution to dose arising during the migratory of fauna. Therefore, where reference organisms occupy multiple reference ecosystems, scaling factors for their relative occupancy in each system were determined and applied subsequent to dose calculations for each reference ecosystem to calculate overall 'migratory' doses.

INDICATIVE RESULTS

The predicted dose rates are many orders of magnitude below those at which biological effects might be expected to occur, in individuals or populations, and below those generally encountered in nature. As such, they are orders of magnitude below the proposed screening values being developed as part of the ERICA project (indicative of potential effects on individuals) and in the UNSCEAR/IAEA values that are related to the potential for effects in the populations.

A number of limitations were inherent within the assessment. These primarily relate to data gaps associated with concentration ratios and dose conversion coefficients for the reference creatures and interest species that were considered. It is, however, not anticipated that these would significantly affect the conclusions on the overall significance of the predicted dose rates, due to the magnitude of the data.

The highest dose rates were calculated for the forest ecosystem with a protected plant being the most exposed creature [Fig. 4a]. Biota within the wetland ecosystem were predicted to receive the lowest exposure. For other ecosystems, the following biota were predicted to receive the greatest exposure:

- Marine – salmon (2×10^{-32} μGy/h)
- Freshwater – vascular plant (1.3×10^{-33} μGy/h)
- Agricultural/grassland – protected plant (5.5×10^{-34} μGy/h)
- Wetland – bird egg (1.3×10^{-37} μGy/h)

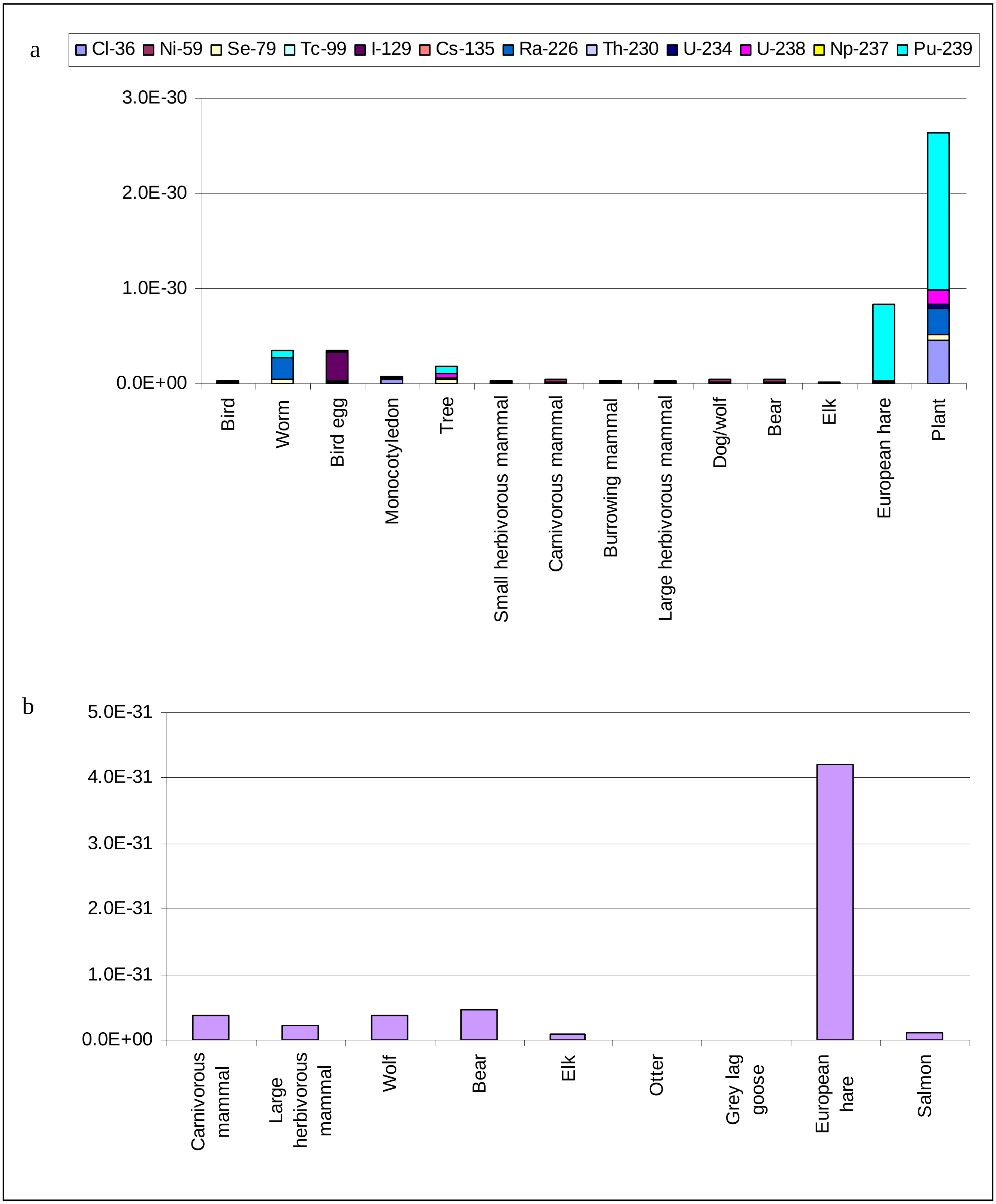

Fig. 4. Predicted dose rates to (a) forest biota and (b) migratory biota

In the case of migratory creatures [Fig. 4b], dose rates to the most exposed migratory biota (European hare) are around 4×10^{-31} µGy/h. These values are lower than those that would be predicted by their occupancy in the forest system alone (of around 1×10^{-30} µGy/h).

With the exception of the wetland and agricultural/grassland ecosystems, Pu-239 was predicted to be the most significant contributor to dose. In the wetland ecosystem, Cl-36 was the dominant radionuclide with regards to dose. In the agricultural/grassland ecosystem, dose rate was dominated by contributions from Pu-239, Cl-36 and I-129.

CONCLUSIONS

STUK guideline requirements place a requirement on Posiva to ensure that activity concentrations in the biosphere do not result in:

- a decline in biodiversity or other significant impact on living populations; or
- impacts on individual rare species of plant or animal, including domestic species.

Combined, the ERICA and EPIC assessment frameworks provide a methodological approach that, with some modifications, enables these criteria to be assessed. Average concentration ratios from both methodologies (with a preference for EPIC data) have been combined with DCC values to enable a generic assessment to be conducted for populations of reference creatures that are of relevance to the ecosystems around the proposed repository site.

No dose rates were calculated that would be likely to give rise to significant impacts on non-human biota – to individuals or populations. This is indicated by the dose rates being very much lower than screening levels under development, which are based on existing biological effects data primarily from information for individuals (10 µGy/h within ERICA), or the existing 'benchmarks' derived on the basis of expectation of population effects (UNSCEAR/IAEA – 40 µGy/h for terrestrial animals and 400 µGy/h for terrestrial plants and aquatic biota [Refs 10 - 12]). On the basis of these preliminary results it can therefore be concluded that the proposed Olkiluoto waste repository is of low risk to both generic populations of non-human biota and the interest species considered.

In considering populations and biodiversity, however, there are additional factors that should ideally be taken into account. The reference organism approach does not directly allow population dynamics and species/reference creature interactions to be taken into account. For example, in the marine ecosystem, the interest species 'salmon' was predicted to receive the greatest dose and the reference creature 'phytoplankton' the second greatest dose. At higher dose rates than anticipated here, there would be a potential for radiation-induced effects on phytoplankton to have an additional knock-on effect on salmon due to foodchain impacts (a reduction in phytoplankton could reduce zooplankton availability on which salmon feed) that would not be accounted for in the 'reference organism' approach adopted. However, the dose rates calculated in the present test case are all significantly below any dose rate that would be likely to cause such impacts.

The potential for heightened exposure of rare, sensitive and domestic species has been taken into account primarily through the application of maximum CR values and the use of maximum occupancy factors. Results indicate that this approach can result differences of over an order of magnitude in the dose rates calculated for example, in the marine ecosystem the interest species salmon was calculated to receive a dose rate of 2.1×10^{-32} compared to a generic pelagic fish, assessed on the basis of the same geometry and DCC values, calculated to receive a dose rate of 1.5×10^{-34}. In addition, the possibility of greater sensitivities to radiation-induced effects is taken into account by comparison with the screening individual-related levels developed as a result of the FASSET and ERICA projects as opposed to 'benchmarks'; the results of the test case are orders of magnitude below these levels.

With regard to the application of maximum CR values, it is unlikely that an interest species would maximally accumulate all radionuclides present in an ecosystem and the approach could therefore be considered overly conservative. However, considering the low environmental activity concentrations predicted during the timescale of the assessment, further detailed assessment of 'realistic' CR values for use in the assessment (which would likely reduce the calculated dose rates) is unlikely to be warranted.

For the purposes of the test case, migratory assumptions were also applied. However, results indicated that the consideration of migration served to reduce the dose rate to a given interest species in comparison to that received in the ecosystem with the highest activity concentrations. The more conservative approach would therefore be to assume 100 % occupancy in the ecosystem giving rise to the highest exposures. It was therefore concluded that the application of migration occupancy factors represents a level of sophistication that is probably not warranted considering the range of dose rates calculated. However, it was recommended that any simplifications of the methodology are based on a study of the sensitivity of results to variations in input parameters and in consideration of the approach applied for human protection purposes.

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