Technical Report

TR-10-08

Long term radiological effects on plants and animals of a deep geological repository

SR-Site Biosphere

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December 2010

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Summary

This study is part of the safety assessment of the planned repository for spent nuclear fuel in Forsmark, called SR-Site. The purpose of the report is to clarify whether the environment is protected against harmful effects of ionizing radiation after a possible future release of radioactive matter from the planned repository. According to the Swedish Radiation Safety Authority (SSM), biological diversity and sustainable use of biological resources must be protected, and the evaluation should pay special attention to threatened and endemic species as well as economically and culturally valuable species.

The report shows the approach to, and results of, calculations of dose rates to organisms other than man. The calculations are based on modelled activity concentrations from a potential future radioactive release, provided by a separate modelling project. Calculations were performed with the ERICA Tool, a software programme developed by an EU research project. In the ERICA Tool, dose rates for site-specific organisms (*i.e.*, occurring at the site) were calculated using input data such as size dimensions and masses of organisms, ecosystems and habitats, concentration ratios for the studied elements (*i.e.* the ratio of accumulated element concentration in the body compared with the element concentration in the surrounding environment) and maximum activity concentrations of radionuclides from the modelled future release. The results are provided in terms of final dose rates for each studied organism.

In accordance with rationales of the International Commission of Radiological Protection (ICRP) and the ERICA project, *Representative* (site-specific) *Organisms* from the planned site of the future repository were studied. Ideally, the organisms selected would meet the criteria defined by both SSM (species worth protecting) and by ICRP and ERICA (so-called *Reference Organisms*). Since activity concentrations for a number of radionuclides were missing for some of the studied organisms, a set of *Average Organisms* were constructed in order to reduce data gaps, simply by compiling data from related species.

Functional key species and economically important species are well represented in the site data. However, red-listed (threatened) species have not been studied, since activity concentrations were, for obvious reasons, unavailable. Instead, dose rates for red-listed species were calculated by using data from similar not red-listed species or Reference Organisms.

The data on radionuclide release used in the evaluation emanate from a scenario with canister corrosion and advective conditions, called “the central corrosion case” in SR-Site.

In the ERICA Tool, a screening dose-rate value of 10 μGy h^{-1} is applied. Calculated dose rates that are below this value are thought to result in a minimal risk of damage to the individual or population through reduced reproduction capacity or increased mortality. In the study, dose rates were calculated for all organisms or organisms groups and none of them exceeded the screening dose-rate value. Calculated dose rates were also below the lowest band of “derived consideration levels” that has been proposed by ICRP.

In addition, background dose rates to organisms were calculated in order to evaluate whether the total dose rates from natural background radiation and the assumed future release combined would yield values above the screening dose rate. Many of the background dose-rate calculations were based on limited data (the activity concentrations were often below the detection limit). All combined dose rates remained below the screening level of 10 μGy h^{-1}.

This study gives no reason to assume that any of the species would be harmfully affected by the increased radiation exposure caused by a possible future release from the planned repository for spent nuclear fuel at Forsmark.

Sammanfattning

Den här studien är en del av säkerhetsanalysen (SR-site) för det planerade slutförvaret av kärnavfall i Forsmark. Syftet med rapporten är att klargöra om miljön kommer att vara skyddad mot skadliga effekter av joniserande strålning efter ett möjligt framtida utsläpp av radioaktivt material från slutförvaret. Enligt Strålskyddsmyndighetens (SSM) direktiv skall biologisk mångfald och bevarandet av biologiska resurser skyddas. Dessutom skall särskild vikt läggas vid hotade och endemiska arter samt arter som anses vara av ekonomiskt och kulturellt värde.

I rapporten redovisas resultaten av och tillvägagångssättet för beräkningar av dosrater till organismer andra än människa. Beräkningarna baseras på modellererade aktivitetskoncentrationer efter ett möjligt framtida radioaktivt utsläpp. Beräkningarna gjordes med hjälp av mjukvaruprogrammet ERICA Tool, ett verktyg som utvecklats i ett EU-forskningsprojekt. I ERICA Tool har dosrater för områdesspecifika organismer som förekommer på platsen beräknats utifrån primärdata såsom storlek, vikt, ekosystem med habitatindelning, koncentrationsrater för studerade element (dvs koncentration av ackumulerade element i organismen per koncentration av element i omgivningen) samt maximala aktivitetskoncentrationer från det modellerade utsläppet. Resultaten redovisas som slutliga dosrater för varje studerad organism.

I enlighet med den internationella strålskyddskommissionen (ICRP) och ERICA-projektets principer studerades *representativa organismer* (platsspecifika) från den planerade slutförvarsplatsen. Idealfallet vore att dessa dels sammanfaller med SSM:s särskilt skyddsvärda organismer och dels inkluderar de *referensorganismer* som föreslagits av ICRP och ERICA, samt att fullständiga radionukliddata funnes för de representativa organismerna. Emellertid saknades i många fall aktivitetskoncentrationer för en mängd nuklider. För att åtminstone i någon mån reducera mängden saknade data konstruerades ett antal ”*genomsnittsorganismer* (average organisms)” genom sammanslagning av data från närbesläktade arter bland de representativa organismerna.

Ekonomiskt och kulturellt betydelsefulla arter är väl representerade i platsdata. Däremot saknas av naturliga skäl nukliddata från rödlistade (hotade) arter. För att ändå kunna beräkna dosrater för dessa har data använts från liknande icke rödlistade representativa organismer, eller från referensorganismer.

De utsläppsdata av radionuklider som använts vid dosratberäkningarna härrör från ett scenario där en kapsel förmodas korrodera under advektiva förhållanden, och benämns som ”the central corrosion case” i SR-site.

I ERICA Tool tillämpas en ”screening-dosrat” på 10 μGy h^{-1}. Uppmätta eller beräknade dosrater under detta värde bedöms innebära minimal risk för skador av betydelse för individens eller populationens reproduktionsförmåga och mortalitet. I studien har dosrater beräknats för samtliga organismer eller organismgrupper och ingen av dessa hamnade över screening-dosraten. De beräknade dosraterna ligger även under det lägsta av de band av ”härledda bedömningsnivåer (derived consideration levels)” som föreslagits av ICRP.

Dessutom har bakgrundsdoser för organismer beräknats för att få en uppfattning om det totala dosratbidraget från naturlig bakgrundsstrålning *och* från de framtida utsläppsdosraterna skulle hamna över screening-dosraten. Många av dosratberäkningarna för bakgrundsstrålning baseras dock på få tillförlitliga värden (aktivitetskoncetrationerna var i många fall under detektionsgränsen). Alla kombinerade dosrater höll sig under screeningdosraten på 10 μGy h^{-1}.

Den här studien ger ingen anledning att anta att någon av arterna skulle ta skada av den ökade strålexponeringen vid ett eventuellt framtida utsläpp från det planerade slutförvaret för använt kärnbränsle.

Contents

1 Introduction

Radioactive waste from nuclear power plants in Sweden is managed by the Swedish Nuclear Fuel and Waste Management Co, SKB. It is planned that spent nuclear fuel from the power plants will be placed in a geological repository according to the KBS-3 method /SKB 2007/. Between 2002 and 2007, SKB performed site investigations at two different sites along the eastern coast of southern Sweden: Forsmark in the municipality of Östhammar and Laxemar-Simpevarp in the municipality of Oskarshamn (Figure 1-1), with the intention of finding a suitable place for the repository. Data from the site investigations were used to produce a comprehensive, multi-disciplinary site description for each of the sites. The resulting site descriptions were reported in /SKB 2008/ (Forsmark) and /SKB 2009/ (Laxemar). Based on available knowledge from the site descriptions and from preliminary safety assessments of the planned repository, SKB decided in June 2009 to choose Forsmark as the site for the repository.

According to regulations issued by the then Swedish Radiation Protection Institute and the then Swedish Nuclear Power Inspectorate (now merged to a joint regulatory body, the Swedish Radiation Safety Authority), the safety assessment of disposal facilities for radioactive waste should include assessments of impacts on man and non-human biota from potential releases to the biosphere /SSM 2008a, b/.

The then Swedish Radiation Protection Institute has established quantitative criteria for radiological risks to man. Applicants seeking licenses to construct and operate radioactive waste repositories should demonstrate that these criteria are met. The regulatory criteria for protection of non-human biota however are only qualitative, i.e. there are no quantitative criteria to evaluate the significance of estimated risks to biota.

The present document is a part of the SR-Site project. The aim of this report is to summarise the assessment of the impact on non-human biota of potential radioactive releases from the high-level waste repository planned at Forsmark, in order to ensure adequate protection of the environment. The assessment comprises estimates of possible radiation dose rates, a discussion of strengths and weaknesses of these estimates, and a discussion of the significance of the possible dose rates.

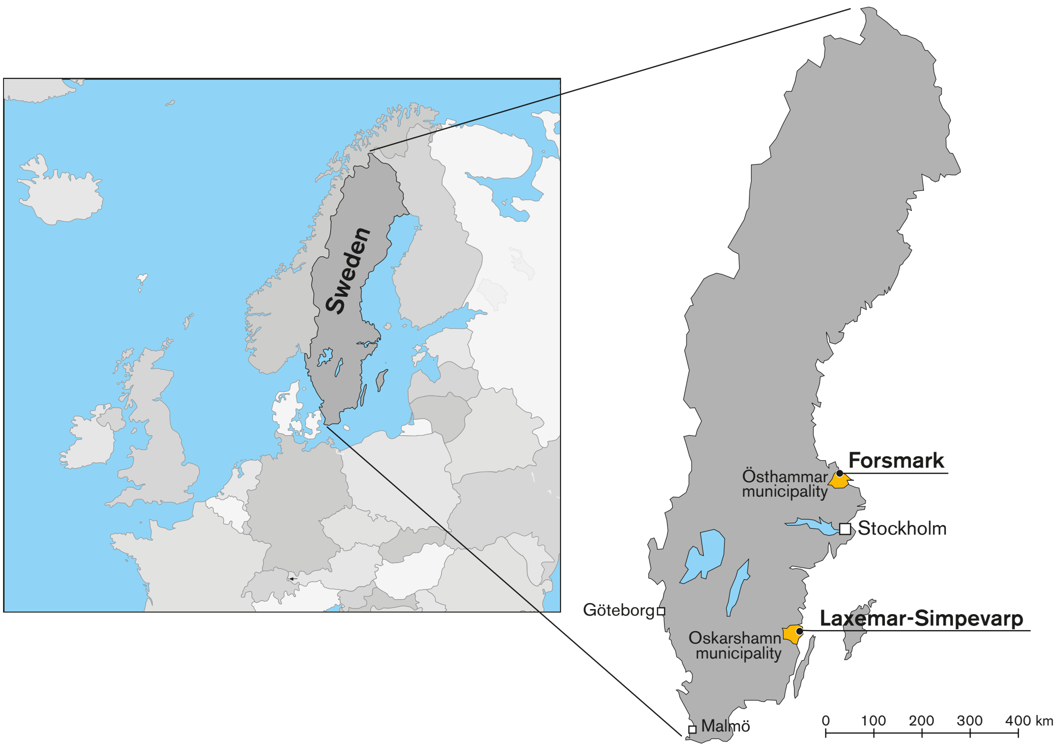


Figure 1-1. *Location of the Forsmark and Laxemar-Simpevarp sites.*

1.1 Background

Attitudes concerning the protection of animals and plants from deleterious effects of radiation have changed considerably over the last 35 years. Up until around 1970, the issue was entirely ignored. However, the 'Stockholm Declaration' of the United Nations Conference on the Human Environment /UN 1972/ established the importance of preservation and enhancement of the environment, and the International Atomic Energy Agency established a programme of assessment of the effects of ionising radiation on non-human species /IAEA 1976, 1988, 1992/.

The first radiological protection statement appears in the Recommendations of ICRP /ICRP 1977/ which made the assumption that if man is adequately protected, then other living things are also likely to be sufficiently protected. At a more general level, the /ICRP 2007/ Recommendations however include a systematic approach for radiological assessment of non-human species. This was not driven by any particular concern over environmental radiation hazards. It was meant to fill a conceptual gap in radiological protection, and to develop a protection policy in line with society's general goals for environmental protection.

However, the objectives of such a protection policy for non-human biota are not yet as clear as those of human radiological protection, which aims to prevent deterministic tissue reactions and reduce stochastic effects as much as reasonably achievable. /ICRP 2007/ suggests that the aim should be a negligible effect on the maintenance of biological diversity, the conservation of species, and the health and status of natural habitats, communities, and ecosystems. In line with this, /ICRP 2008/ notes that the biological endpoints of most relevance in individuals after radiation exposure will be those that could lead to changes in population size or structure.

/ICRP 2008/ goes on to say that some form of practical means is required to translate knowledge of the effects of radiation on different types of animals and plants into advice on management decisions and judgements that may be needed. To this end, ICRP proposes the use of a limited set of Reference Animals and Plants to serve as a basis for the understanding and interpretation of the relationships between exposure and dose, and between dose and certain categories of effect, for a few, clearly defined types of animals and plants.

Furthermore, /ICRP 2008/ notes that "dose limits" of the form used in human radiological protection would be inappropriate, but that some form of numerical guidance is required, and sets out proposed bands of "derived consideration reference levels". Within these bands, there is likely to be some chance of deleterious effects of ionising radiation to the pertinent Reference Animal or Plant that could be used to optimise protection efforts (and by inference, below these bands the risks would appear to be negligible).

In parallel with, and aligned with, these developments, a series of major research projects (EPIC, FASSET, ERICA, PROTECT) concerning these issues were funded under the European Commission Euratom Framework programmes. An overview of the entire series and detailed descriptions of each project, including links to the resulting scientific publications, are available at the erica-project.org web site. The project programme generated the ERICA Integrated Assessment approach and the ERICA Tool used in the present study (described below in Section 3.5).

The screening dose rate used in the ERICA Tool is, again, not a "dose limit". It is an instrument to assist in the separation of situations of negligible concern from those situations where it is appropriate to pause for reflection to consider whether any concern is warranted.

Thus, the ERICA screening dose rate and the ICRP derived consideration level serve much the same purposes as "benchmarks". Such benchmarks are numerical values used to guide risk assessors at various decision points in a tiered approach. They are defined as concentrations, doses, or dose rates that are assumed to be safe based on exposure – response information for a species or the ecosystem.

There appears to be some consensus around the screening values proposed by ERICA. Nevertheless, it is worth mentioning that the screening dose rate used in this study (10 μGyh^{-1}) is well below the screening dose rates used by some others, for instance the US Department of Energy /US DoE 2002/; see also /IAEA 2002/ and /UNSCEAR 1996/. USDoE suggests using a screening dose rate of: 400 μGyh^{-1} for native aquatic animals, and benchmarks of 400 and 40 μGyh^{-1} for terrestrial plants and terrestrial animals respectively. These are optional alternatives that could be use in the ERICA tool. The issue of possible alternative benchmarks is further discussed below in Section 5.3.1.

The current awareness of environmental protection issues has emerged over about a decade, and the policy advice of ICRP and the practical tools provided by the Euratom research framework programmes were generated over that time-scale. However, the present study is one of the very first cases where the policy and the tools are applied to a genuine case where the results are intended to form part of the underpinning of a license application for the siting of a repository for spent nuclear fuel.

2 This report

2.1 SR-Site safety assessment

This report is a part of the safety assessment SR-Site. The SR-Site project is a sub-project of the Spent fuel project, and the main SR-Site report /SKB 2011/ will support the application to build a final repository for spent nuclear fuel. SR-Site is focused on three major fields of investigations; the performance of the repository, the geosphere, and the biosphere. This report belongs to the biosphere part of SR-Site, which is synthesised in /SKB 2010/.

A detailed description of the overall work plan and methodology for SR-Site Biosphere and the linkage to the main SR-Site project is given in /SKB 2010/. The report structure in SR-Site Biosphere, (with this report outlined in orange) is presented in Figure 2-1.

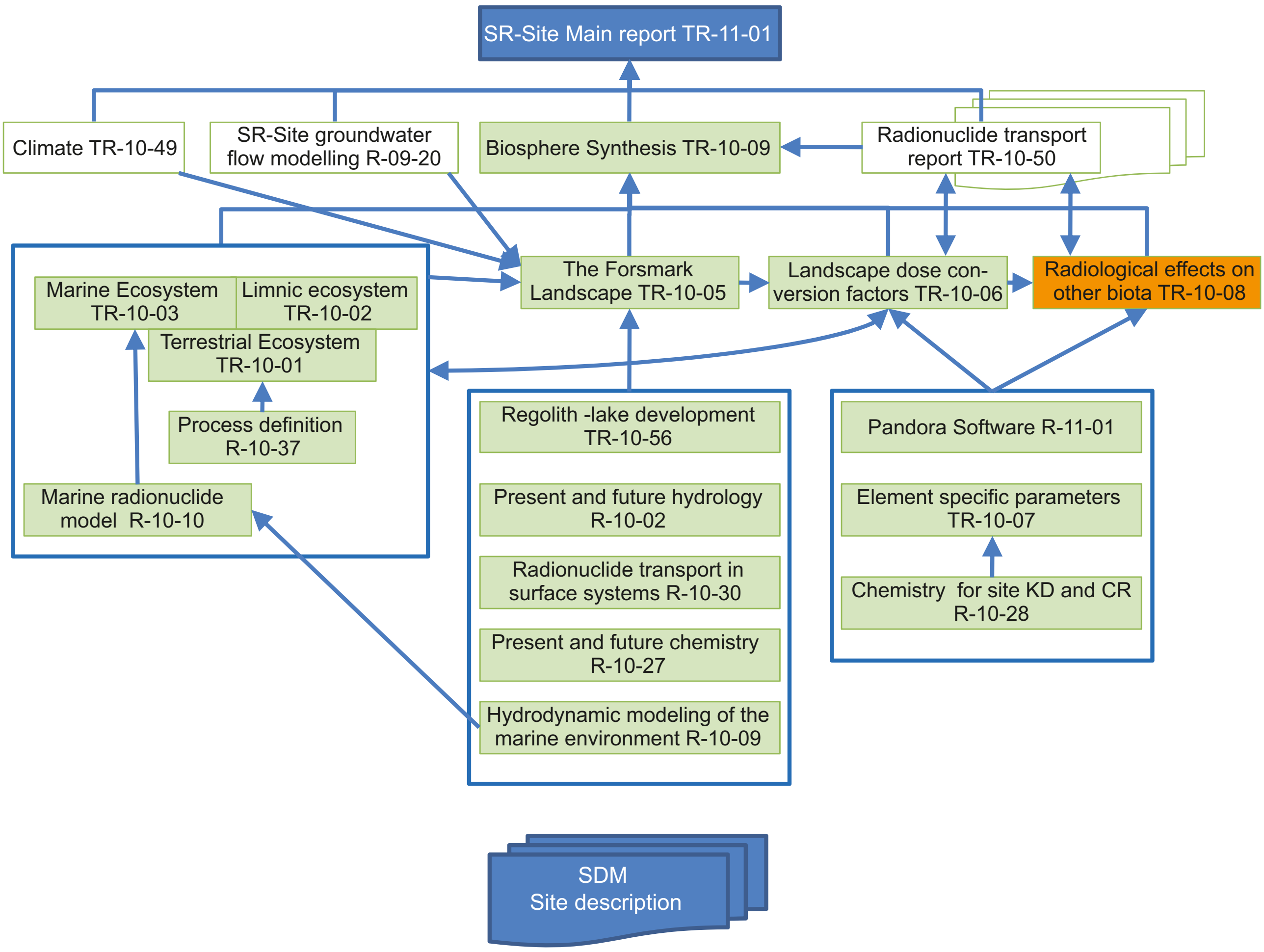


Figure 2-1. The hierarchy of reports produced in the SR-Site Biosphere project. This report (marked red) and its dependencies on information from biosphere reports and other reports within SR-Site.

2.2 General aim and structure of this report

The aim of this report is to assess the impact on non-human biota of potential radioactive releases from the high-level waste repository planned at Forsmark, in order to ensure adequate protection of the environment.

The assessment takes account of the following factors:

At first, two locations were considered (Forsmark and Laxemar). Since SKB has decided to locate the repository at Forsmark, the main analysis refers to this site only. Some data concerning Laxemar are provided in the Appendix, since they may be useful as supplementary information where little or no direct data are available from Forsmark.

Initially, two main release scenarios ("the central corrosion case" and "growing pinhole") were considered. The main analysis focuses on the central corrosion case only, since preliminary assessments show that this release scenario has the biggest impact.

Radiation dose rates are estimated using the ERICA software Tool, described in Section 3.2 of this report.

Results are assessed in the light of regulations and requirements of the Swedish Radiation Safety Authority concerning protection of the environment /SSM 2008b/.

The overall structure of the report is as follows:

Chapter 1 gives an introduction and backround to assessing dose rates to non-human biota.

Chapter 2 describes this report in context of the SR-Site project and provide the aim and structure of the present report.

Chapter 3 describes the methods used to handle input data (activity concentrations, choice of species considered, concentration factors, etc) by the ERICA Tool.

Chapter 4 summarises the resulting output data analysed by the ERICA Tool.

Chapter 5 is a summary and a discussion of the results.

Chapter 6 lists the references.

Appendix A comprise input and output data with more detailed information from the assessments, and some supplementary data.

2.3 Definitions

Some important terms and concepts used in this report are presented and defined in Table 2-1.

Table 2-1. Definitions of important terms and concepts used in the report.

Abbreviation/Term	Explanation/Comment
Benchmark	Benchmarks are numerical values used to guide risk assessors at various decision points in a tiered approach. They are defined as concentrations, doses, or dose rates that are assumed to be safe based on exposure – response information for a species or ecosystem.
Biosphere object	Environmental compartment.
CR	Concentration ratio, i.e. the radionuclide activity concentration in biota whole body (Bq kg^{-1} fresh weight) divided by the radionuclide activity concentration in their surroundings (soil: Bq kg^{-1} dw; air: Bq m^{-3}; water: Bq l^{-1}).
DCC	Dose conversion coefficient, i.e. absorbed dose rate (µGy h^{-1}) per unit activity in organism (Bq kg^{-1} fw) or medium (Bq kg^{-1} *or* Bq l^{-1}).
dw	Dry weight.
ERICA	“Environmental Risk from Ionising Contaminants: Assessment and Management”; an Euratom-funded research project.
ERICA Tool	A software programme for assessment of environmental risks, devised within ERICA.
FASSET	“Framework for the Assessment of Environmental Impact”, an Euratom-funded research project.
FREDERICA	A comprehensive radiation effects database compiled in the FASSET and ERICA projects, available at www.frederica-online.org.
fw	Fresh weight.
ICRP	The International Commission on Radiological Protection.
Average Organisms*	Related organisms compiled into one ‘average’ organism in order to fill certain data gaps.
Reference Organisms	A series of entities that provide a basis for the estimation of radiation dose rates to a range of organisms which are typical, or representative, of a contaminates environment. These estimates, in turn, provide a basis for assessing the likelihood and degree of radiation effects.
Representative species	A selection of species found at the investigation sites for which activity concentration measurements are available.
RQ	Risk Quotient; predicted environmental dose rate divided by a benchmark dose rate assumed to be environmentally “safe” (the details of the calculation differ between Tiers in the ERICA Tool).
SKB	The Swedish Nuclear Fuel and Waste Management Co.
SSM	Strålsäkerhetsmyndigheten, the Swedish Radiation Safety Authority.
Tier (ERICA)	Three assessment stages in the ERICA Tool where satisfying certain criteria in Tier 1 or 2 indicates that effects on biota are negligible and allows the user to exit the assessment process, while if effects are not shown in a lower Tier to be negligible, the assessment continues to the next Tier.

*See Section 2.2.4 for details.

3 Methods

The environmental impact was assessed by evaluating the potential effects of a radionuclide release on individual specimens of a range of important and/or sensitive species. The rationale for this approach is the assumption that if there are no detrimental effects on the level of individuals, then negative consequences on the population or ecosystem levels should be most unlikely. This assumption may not be universally valid, though. For instance, long term effects of low-dose radiation may affect growth rates in populations of, e.g. planktons. A slight reduction of the zoo- or phytoplankton fecundity has been seen, and it has been claimed that this may over a long period of time create unexpected effects on the population /Wilson et al. 2010/.

The general assessment methodology used is described in Section 3.1. Section 3.2 enumerates the radionuclides considered. It also provides values of the activity concentrations in environmental media obtained as output from the "radionuclide model" for the release scenarios considered. Section 3.3 describes the ecosystems and Section 3.4 discusses the organisms that were studied. Section 3.5 explains the use of the ERICA Tool and the dose-rate assessments obtained. Section 3.6 discusses exposure pathways. Section 3.7 describes the calculation of dose conversion coefficients, while Section 3.8 explains the choice of concentration ratios.

3.1 Methodology for assessment of impact on non-human biota

The overall approach for assessment of the impact of radionuclide releases on non-human biota is illustrated in Figure 3-1. Radionuclide releases to the biosphere according to the advection/corrosion base case (where an eroded buffer exposes a canister to advection of corrodants and hence to enhanced corrosion rates and ultimately to canister failure) were used as input to a radionuclide model /Avila et al. 2010/ where radionuclide activity concentrations in environmental media in discharge areas in the Forsmark landscape were simulated for temperate conditions.

The resulting activity concentrations in water, in sediments in freshwater and marine ecosystems, and in peat and air in wetland ecosystems, were used as input to the ERICA software Tool /Brown et al. 2008/ in order to obtain activity concentrations in different types of biota, and ultimately absorbed dose rates. The ERICA Tool estimates external dose rates from the activity concentration in media, and internal dose rates from activity concentrations in biota if available, otherwise from activity concentrations in media, using concentration ratios.

The numerical endpoint of the impact assessment was the total absorbed dose rate from each radionuclide considered in the *assessment* to different types of biota. Finally, the sum of the dose rates was evaluated against a screening dose rate corresponding to the lowest dose rate that can potentially lead to detrimental effects on individual organisms (i.e. a no-effects dose rate).

3.2 Radionuclides considered in the assessments

The list of radionuclides considered in the assessments is presented in Table 3-1. This list comprises all radionuclides that are included in the SR-Site safety assessment, with the exception of Ac-227, Pa-231, and Pd-107. For these three nuclides, neither site nor literature data were available with respect to biological uptake (i.e. CR), precluding a meaningful analysis. Most of the 37 radionuclides (of 24 elements) considered are present by default in the ERICA Tool, but some isotopes, shown in italics in Table 3-1, were added to the ERICA database.

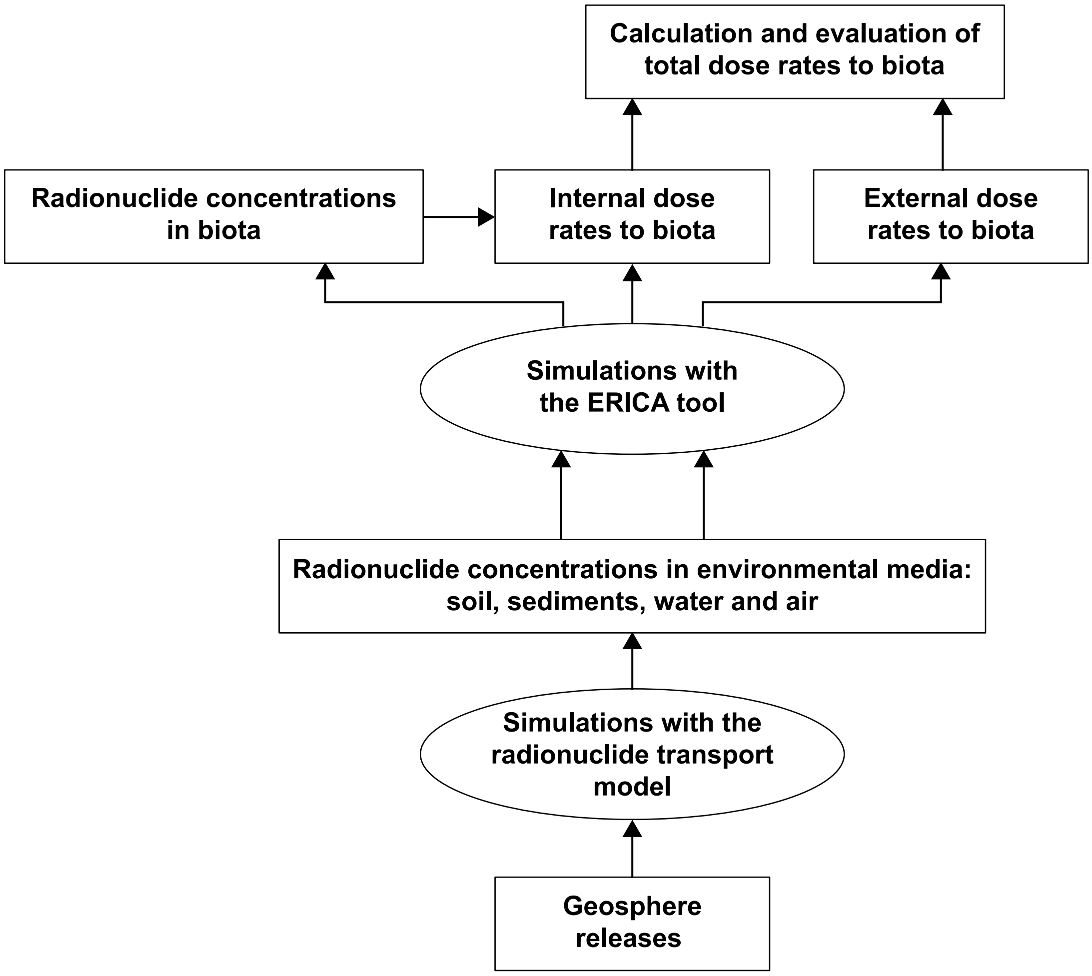


Figure 3-1. *Assessment of the impact of radionuclide releases on non-human biota. The process starts by obtaining radionuclide concentrations. These are used as input data to the ERICA Tool and the resulting dose rates to biota are evaluated. Steps performed in this report are indicated in bold. The preceding steps, indicated in italics, are described in /SKB 2011/ (geosphere release) and /Avila et al. 2010/ (radionuclide model of the biosphere).*

Table 3-1. Elements and radionuclides considered in the assessments. Entries in italics are elements/ radionuclides that were added to the default database of the ERICA Tool.

Element	Radionuclide	Element	Radionuclide
Ag	*Ag-108m*	Pb	Pb-210
Am	Am-241, *Am-243*	Po	Po-210
C	C-14	Pu	Pu-239, Pu-240, *Pu-242*
Ca	*Ca-41*	Ra	Ra-226
Cl	Cl-36	Se	Se-79
Cm	Cm-244, *Cm-245*, *Cm-246*	*Sm*	*Sm-151*
Cs	Cs-135, Cs-137	*Sn*	*Sn-126*
Ho	*Ho-166m*	Sr	Sr-90
I	I-129	Tc	Tc-99
Nb	Nb-94	Th	*Th-229*, Th-230, Th-232
Ni	Ni-59, Ni-63	U	*U-233*, U-234, U-235, *U-236*, U-238
Np	Np-237	Zr	*Zr-93*

3.2.1 Activity concentrations in environmental media

The basic assumption of the present assessment is that some degree of failure of the barriers at the repository will lead to a release of radionuclides. The activity concentrations in environmental media that would result from such a release constitute a primary input to the ERICA Tool.

Such input data were obtained by taking, for each radionuclide assessed, the maximum far-field release for the central corrosion case during the simulation period of 1 million years and applying it as a constant release rate to the Forsmark biosphere of Forsmark /Avila et al. 2010/. The radionuclide model of Avila et al. was used to run the biosphere simulations through the temperate period of an interglacial (~20,000 years) for all biosphere objects in the Forsmark landscape.

This resulted in time series of radionuclide concentrations in different environmental media for each biosphere object in the Forsmark landscape. For each radionuclide, maximum values over the simulation period of the activity concentrations in wetland (considered to be equal to soil in the ERICA tool), air (for C-14), water (freshwater and marine), and sediments were obtained for each landscape object.

These maximum activity concentrations in all relevant environmental media, across all landscape objects, and among maximum values over time, are shown in Table 3-2. They were used as input values for calculations of dose rates to biota within the ERICA Tool.

3.3 Ecosystems considered

Three ecosystems are defined in the ERICA tool. These are: terrestrial, freshwater, and marine ecosystems. In this work, data with activity concentrations originate from more specified ecosystems at the investigation site, defined as: wetland, watercourses, lakes, and sea (with its brackish water). These "new" categories of ecosystems were assigned to the ERICA ecosystems as follows:

- Wetland = the ERICA terrestrial ecosystem.
- Watercourses and lakes = the ERICA freshwater ecosystem.
- Sea = the ERICA marine ecosystem (which is probably adequate also for brackish water; cf. /Takata et al. 2010/).

Agricultural ecosystems were not considered in the analysis. This was because in the biposphere assessment future contaminated agricultural land in Forsmark will originate from drained wetland, and this land is expected to be productive (and thus provide a stable environment) for 100 years or less /Lindborg 2010/. Thus, the species associated with this land would either be introduced by humans (crop or livestock), or invade from adjacent agricultural land and consequently being part of large and stable biological populations. The terrestrial, limnic and marine ecosystemsin Forsmark are thoroughly described in /Löfgren 2010/, /Andersson 2010/ and /Aquilonius 2010/.

The ecosystems are further categorised in the ERICA tool with a total of 10 habitats. These are described in more detail in Section 3.7.4.

3.4 Organisms considered in the assessments

In order to prevent or reduce the frequency of deleterious radiation effects in the environment to a level where it would have a negligible impact on the maintenance of biological diversity, the conservation of species, or the health and status of natural habitats, communities, and ecosystems, it is necessary to relate exposure to dose, dose to effect, and effect to consequences /ICRP 2008/.

To permit such analyses, the ERICA Tool uses a small, well-defined basic reference set of data, the *Reference Organisms*. These are described in Section 3.4.1. According to /Beresford et al. 2007/, the selection of Reference Organisms included in the ERICA Tool makes it possible to address all protected species within Europe. Nevertheless, to increase the confidence in the analysis, a number of common species currently found in Forsmark were also included in the assessment. These species are referred to as *Representative Species*.

The Reference Organisms are likely to include several of the Representative Species that are more site-specific, but with usually less complete data sets. The representative species from the site of the planned repository, Forsmark, are described in Section 3.4.2 and some additional data from Laxemar are described in the Appendix. In line with regulatory requirements, a number of particularly "vulnerable or important" species were also considered; these are described in Section 3.4.3.

For many of the site-specific Representative Species, site data with respect to morphology and concentration ratios (CR, see Section 3.8) were available and were used in the assessments. For some of the site-specific Representative Species, available data were based on a few samples only or were incomplete. In order to achieve at least some limited improvement, "*Average Organisms*" were created by compiling data from related organisms. These Average Organisms are described in Section 3.4.4.

3.4.1 Reference Organisms

The ERICA Tool contains a set of *Reference Organisms* for which default values are provided for all parameters needed for dose rate calculations. These were chosen in the FASSET project, a forerunner of ERICA described in /Larsson 2004/, and in close contact with ICRP /ICRP 2007, 2008/. /Beresford et al. 2007/, define the ERICA Reference Organisms as:

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

The ERICA Reference Organisms are similar in concept to the Reference Animals and Plants of ICRP, defined as:

"*hypothetical entit[ies], with the assumed basic biological characteristics of a particular type of animal or plant, as described to the generality of the taxonomic level of family, with defined anatomical, physiological, and life-history properties, that can be used for the purposes of relating exposure to dose, and dose to effects, for that type of living organism*" /ICRP 2007/.

In the ERICA Tool the Reference Organisms have been grouped into three general ecosystem categories, namely terrestrial, freshwater and marine ecosystems. The Reference Organisms provided for each ecosystem cover a predefined range of weights, but it is possible to use the ERICA Tool for organisms whose weights are outside the pre-defined ranges using extrapolation methods.

A selection of Reference Organisms that are most likely to be seen at the site was considered in the assessments presented in this report (Table 3-3). Some Reference Organisms from the ERICA list were excluded, e.g. sea anemones and marine turtles which do not occur at the Forsmark site. The reference organism "bird egg" was excluded since most organisms in this study are measured as adults. There is one exception though: freshwater insect larvae. Commonly they spend most of their lifetime in water before reproduction takes part in the air. There is of course a wide variety of lifestyles within the Order of insects.

Table 3-2. Maximum values, over time and across all "biosphere objects", of activity concentrations in: soil (Bq/kg dw and Bq/m³ for C-14), freshwater, and marine (Bq/l) sediments (Bq/kg dw) predicted with the radionuclide model for the central corrosion case at Forsmark. For sediments, maximum values are given, selected from either the upper or the lower level of the concentrations in sediment layers, above quaternary deposits.

Activity concentration after a release according to the the central corrosion case						
	Terrestrial		Freshwater		Marine	
Nuclides	Soil	Air	Water	Sediment	Water	Sediment
Ag-108m	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Am-241	2.2E–12	1.1E–19	1.1E–16	3.7E–11	8.4E–19	1.3E–12
Am-243	7.6E–10	3.8E–17	7.7E–14	1.9E–08	2.6E–16	2.5E–10
C-14	4.7E–10	1.4E–13	2.8E–11	9.5E–09	6.4E–12	4.1E–09
Ca-41	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Cl-36	1.9E–06	9.5E–14	2.0E–08	1.5E–06	1.1E–09	2.3E–06
Cm-244	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Cm-245	7.1E–11	3.5E–18	1.7E–15	9.7E–10	4.3E–18	1.5E–11
Cm-246	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Cs-135	8.2E–04	4.1E–11	7.5E–09	1.8E–03	7.3E–11	2.1E–05
Cs-137	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Ho-166m	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
I-129	8.7E–04	4.4E–11	4.9E–07	3.8E–02	1.1E–08	9.3E–04
Nb-94	8.4E–03	4.2E–10	2.7E–08	2.6E–02	5.0E–10	4.1E–04
Ni-59	8.7E–01	4.3E–08	8.1E–05	1.2E+01	7.4E–07	1.6E–01
Ni-63	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Np-237	6.2E–03	3.1E–10	2.9E–06	2.5E–01	6.7E–08	5.2E–03
Pa-231	8.2E–05	4.1E–12	1.2E–08	1.0E–03	2.8E–11	1.4E–05
Pb-210	2.9E–03	1.4E–10	1.6E–08	8.5E–02	4.3E–10	1.2E–03
Pd-107	3.0E–03	1.5E–10	1.3E–07	3.6E–04	1.4E–09	3.5E–05
Po-210	2.9E–03	1.4E–10	1.6E–07	8.6E–02	5.2E–11	1.3E–03
Pu-239	1.6E–04	7.9E–12	5.3E–08	2.1E–03	1.3E–10	4.3E–05
Pu-240	2.7E–09	1.4E–16	1.1E–12	6.7E–08	4.1E–15	1.4E–09
Pu-242	5.9E–04	2.9E–11	2.0E–07	4.5E–03	2.8E–10	9.3E–05
Ra-226	2.8E–03	1.4E–10	2.7E–07	7.5E–02	7.2E–09	1.2E–03
Se-79	1.2E–04	5.9E–12	6.1E–08	3.0E–03	1.6E–09	9.7E–05
Sm-151	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Sn-126	1.3E–04	6.7E–12	4.5E–09	1.1E–03	5.2E–11	1.2E–05
Sr-90	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Tc-99	1.9E–04	9.7E–12	3.6E–06	1.5E–03	1.5E–07	6.7E–04
Th-229	1.0E–03	5.0E–11	5.7E–09	5.1E–03	9.5E–12	1.7E–04
Th-230	2.4E–06	1.2E–13	1.1E–11	2.9E–06	4.2E–15	6.8E–08
Th-232	1.8E–11	9.1E–19	1.1E–16	3.1E–11	2.3E–20	3.8E–13
U-233	1.4E–03	6.8E–11	6.5E–08	1.5E–02	1.1E–09	1.7E–04
U-234	8.6E–06	4.3E–13	4.0E–10	4.6E–05	3.0E–12	5.1E–07
U-235	5.7E–07	2.9E–14	2.7E–11	2.9E–06	1.9E–13	3.2E–08
U-236	9.4E–06	4.7E–13	4.4E–10	4.9E–05	3.2E–12	5.5E–07
U-238	6.1E–06	3.1E–13	2.9E–10	3.2E–05	2.1E–12	3.6E–07
Zr-93	1.5E–01	7.4E–09	7.5E–06	1.2E+00	1.1E–08	2.7E–02

Table 3-3. Reference Organisms from the ERICA Tool used in this study and broadly comparable organism as defined by ICRP and FASSET. (F) = freshwater, (M) = Marine and (T) = terrestrial.

Reference organism	Comments
Amphibian (T)	ICRP frog
Benthic fish (M)	ICRP flat fish
Benthic mollusc (M)	FASSET benthic mollusc
Bird (F)	ICRP duck
Bird (M)	ICRP duck
Bird (T)	ICRP duck
Bivalve mollusc (F)	FASSET bivalve mollusc
Crustacean (F)	FASSET crustacean
Crustacean (M)	ICRP crab
Detritivorous invertebrate (T)	FASSET woodlouse
Flying insect (T)	ICRP bee
Gastropod (T)	ICRP snail
Gastropod (F)	FASSET gastropod
Grasses and herbs (T)	ICRP wild grass
Insect larvae (F)	FASSET insect larvae
Large mammal (T)	ICRP deer
Lichen and bryophytes (T)	ICRP bryophyte
Macroalgae (M)	ICRP brown seaweed
Mammal (F)	FASSET mammal
Mammal (M)	FASSET mammal
Pelagic fish (F)	ICRP salmonid/trout
Pelagic fish (M)	FASSET pelagic fish
Phytoplankton (F)	FASSET phytoplankton
Phytoplankton (M)	FASSET phytoplankton
Polychaete worm (M)	FASSET benthic worm
Reptile (T)	FASSET snake
Shrub (T)	Not defined
Small mammal (T)	ICRP rat
Soil invertebrate (T)	ICRP earthworm
Tree (T)	ICRP pine tree
Vascular plant (F)	FASSET vascular plant
Vascular plant (M)	FASSET vascular plant
Zooplankton (F)	FASSET zooplankton
Zooplankton (M)	FASSET zooplankton

3.4.2 Representative Species from the site

According to /Beresford et al. 2007/, the selection of Reference Organisms included in the ERICA Tool makes it possible to address all protected species within Europe. Nevertheless, it was considered important to include, in addition to those Reference Organisms, assessments for representative species commonly found at the studied sites to increase the confidence in the analysis (Table 3-4). The Representative Species are common and/or "keystone" species in the ecosystems at Forsmark. A keystone species has a disproportionate effect on the environment relative to its biomass, affects many other organisms in an ecosystem, and helps to determine the types and numbers of various other species in a community. These species include both plants and animals.

The identification of Representative Species were based on site investigation data and knowledge about the ecosystems at the site, described in the ecosystem reports /Andersson (ed) 2010, Aquilonius (ed) 2010, Löfgren (ed) 2010/. The selection of the representative species were in general based on information gained in the detailed site investigations /e.g. Andrén 2004, Borgiel 2004, Engdahl and Ericsson 2004, Green 2005, Heibo and Karås 2005, Lindborg 2006, Truvé and Cederlund 2005/, on the abundance and function of the species in the ecosystems. Although the list of representative species is not exhaustive in terms of species found at Forsmark, the selection was deemed representative for the current aquatic and terrestrial ecosystems at the site.

Table 3-4. Representative Species from Forsmark considered in the assessments. The right column report the number of samples available from each species used for the calculation of CR (Section 3.8).

Related organism in ERICA	Representative Species from the Forsmark site			No. of samples
	English name	Swedish name	Scientific name	
Terrestrial				
Grasses and herbs	Small cow-wheat	Skogskovall	*Melampyrum sylvaticum*	1
Grasses and herbs	Stone bramble	Stenbär	*Rubus saxatilis*	2
Lichen/bryophytes	Funnel chanterelle	Trattkantarell	*Cantharellus tubaeformis*	1
Lichen/bryophytes	Glittering wood-moss	Husmossa	*Hylocomium splendens*	1
Lichen/bryophytes	Granulated bolete	Grynsopp	*Suillus granulatus*	1
Lichen/bryophytes	Moss	Mossa	*Bryophyta sp*	1
Lichen/bryophytes	Porcini	Stensopp	*Boletus edulis*	1
Lichen/bryophytes	Saffron milk cap	Blodriska	*Lactarius deterrimus*	1
Lichen/bryophytes	Scaly hedgehog	Fjällig taggsvamp	*Sarcodon imbricatus*	1
Lichen/bryophytes	Shaggy moss	Kranshakmossa	*Rhytidiadelphus triquetrus*	1
Lichen/bryophytes	Velvet bolete	Sandsopp	*Suillus variegatus*	1
Lichen/bryophytes	–	Anisspindling	*Cortinarius odorifer*	1
Lichen/bryophytes	–	Aprikosspindling	*Cortinarius armeniacus*	1
Lichen/bryophytes	–	Brännagelskivling	*Collybia peronata*	1
Lichen/bryophytes	–	Rökslöjskivling	*Hypholoma capnoides*	1
Lichen/bryophytes	–	Skogsriska	*Lactarius trivialis*	1
Lichen/bryophytes	–	Svavelriska	*Lactarius scrobiculatus*	1
Lichen/bryophytes	–	–	*Cortinarius sp.*	1
Mammal, large	Moose	Älg	*Alces alces*	5
Mammal, large	Red fox	Rödräv	*Vulpes vulpes*	1
Mammal, small	Bank vole	Ängssork	*Myodes glareolus*	3
Mammal, small	Common shrew	Vanlig näbbmus	*Sorex araneus*	1
Mammal, small	Water vole	Vattensork	*Arvicola terrestris*	7
Mammal, small	Y-necked mouse	Större skogsmus	*Apodemus flavicollis*	2
Shrub	Bilberry	Blåbär	*Vaccinium myrtillus*	2
Tree	Norwegian spruce	Gran	*Picea abies*	3
Freshwater				
Bivalve mollusc	Duck mussel	Allmän dammussla	*Anodonta anatina*	3
Pelagic fish	Pike	Gädda	*Esox lucius*	4
Pelagic fish	Roach	Mört	*Rutilus rutilus*	2
Pelagic fish	Ruffe	Gärs	*Gymnocephalus cernuus*	1
Pelagic fish	Tench	Sutare	*Tinca tinca*	9
Vascular plant	Chara	Kransalg	*Characeae sp*	4
Marine				
Benthic mollusc	Baltic macoma	Östersjömussla	*Macoma baltica*	3
Benthic mollusc	Lagoon cockle	Hjärtmussla	*Cerastoderma glaucum*	2
Benthic mollusc	River nerite	Östersjöbåtsnäcka	*Theodoxus fluviatilis*	2
Crustacean	Idothea	Havsgråsugga	*Idotea baltica*	2
Macroalgae	Bladder wrack	Blåstång	*Fucus vesiculosus*	3
Macroalgae	Brown algae	Trådslick	*Pilayella littoralis*	3
Pelagic fish	Roach	Mört	*Rutilus rutilus*	3
Pelagic fish	Ruffe	Gärs	*Gymnocephalus cernuus*	3
Pelagic fish	Smelt	Nors	*Osmerus eperlanus*	3
Phytoplankton	Microphytes	Mikrofyter	–	2
Phytoplankton	Phytoplankton	Fytoplankton	–	3
Vascular plant	Fennel pondweed	Borstnate	*Potamogeton pectinatus*	3
Zooplankton	Zooplankton	Zooplankton	–	1

3.4.3 Particularly vulnerable or important species

According to regulations issued by the Swedish Radiation Safety Authority /SSM 2008b/, species that are "red-listed" (threatened or particularly vulnerable), functional key species, and economically important species need special attention.

With reference to the assessment of protection of the environment, the guidance part of the regulations points out that:

"*The organisms considered in the analysis of environmental impact should be chosen in view of their importance in the ecosystems, but taking account also of the importance of protecting them in view of other biological, economical, or conservation of nature criteria.*

Other biological criteria include, e.g. a distinctive genetic character and isolation (such as endemic species known today). Economic criteria refer to the significance of the organisms for various trades (such as hunting and fishing). Conservation of nature criteria include whether the organisms are protected according to current legislation or local regulations. Other aspects, such as cultural history, should also be taken into account when such organisms are identified.

An evaluation of the effects of ionising radiation in selected organisms, due to radioactive substances that may have been released from a final repository, may be performed based on the general guidance provided by the International Commission on Radiological Protection /ICRP 2003/. The relevance of the knowledge and databases used concerning the distribution of radioactive substances in ecosystems and the effects of radiation on different organisms should be assessed and described." (Translated from Swedish by the author).

"Red-listed" species are considered to be threatened or particularly vulnerable according to the criteria put forward by the International Union for Conservation of Nature and Natural Resources. In Sweden the "red-listed species" are identified by the Swedish Species Information Centre by direction of the Swedish Environmental Protection Agency /Gärdenfors 2010/.

Here, "functional key species" denotes great importance for the functioning of the ecosystems considered and "species of particular economic importance" are (or potentially can be) used by man for various purposes (e.g. food, clothes, manufacturing material). The identification of functional key species and species of particular economic importance are based on knowledge about the ecosystems and species at the site, comprehensively described in /Andersson (ed) 2010, Aquilonius (ed) 2010, Löfgren (ed) 2010/.

Tables 3-5a–e list red-listed species, key functional species, and economically important species representing the Forsmark site. Red-listed species were taken primarily from the site investigation, but also additional red-listed species were taken from the County of Uppsala County to represent Forsmark, covering other functional groups of red-listed species not so far investigated (e.g. butterflies) or not yet found in Forsmark. The Tables 3-5a–e include scientific and, where available, English names. For species with no English name, the Swedish name is given. Where possible, the closest related Reference Organism is also listed alongside the selected Forsmark species for comparison. Table 3-5a comprises terrestrial "red-listed" species in Uppsala County, Table 3-5b shows freshwater "red-listed" species in Uppsala County, and Table 3-5c marine "red-listed" species in Uppsala County. Table 3-5d lists "key functional and dominant species", and Table 3-5e species of particular economic importance, all at the Forsmark site.

Table 3-5a. "Red-listed" terrestrial organisms found in the Forsmark area with Swedish and scientific names, and as far as possible, related/corresponding ERICA Reference Organisms and Representative Species from the site.

Related ERICA Reference Organism	Swedish names	Scientific names	Related Representative Species from the site
Amphibian	Gölgroda	*Rana lessonae*	–
Bird	Brushane	*Philomachus pugnax*	–
Bird	Gräshoppsångare	*Locustella naevia*	–
Bird	Jorduggla	*Asio flammeus*	–
Bird	Rördrom	*Botaurus stellaris*	–
Bird	Småfläckig sumphöna	*Porzana porzana*	–
Flying insects	Dvärgflickslända	*Nehalennia speciosa*	–
Flying insects	Guldgräshoppa	*Chrysochraon dispar*	–
Flying insects		*Singa nitidula*	–
Flying insects	Träsksammetslöpare	*Chlaenius sulcicollis*	–
Flying insects	Väddnätfjäril	*Euphydryas aurinia*	–
Gastropoda	Kalkkärrsgrynsnäcka	*Vertigo geyeri*	–
Grasses & Herbs	Gulyxne	*Liparis loeselii*	Average plant
Grasses & Herbs	Loppstarr	*Carex pulicaris*	Average plant
Lichen & bryophytes	Bokfjädermossa	*Neckera pumila*	Average bryophyte
Lichen & bryophytes	Käppkrokmossa	*Hamatocaulis vernicosus*	Average bryophyte
Lichen & bryophytes	Timmerskapania	*Scapania apiculata*	Average bryophyte
Lichen & bryophytes	Västlig njurlav	*Nephroma laevigatum*	Average bryophyte
Mammal	Fransfladdermus	*Myotis nattereri*	Average rodent
Mammal	Lo	*Lynx lynx*	–
–	Blackticka	*Junghuhunia collabens*	–

Table 3-5b. "Red-listed" freshwater organisms found in Uppsala County (see text) with Swedish and scientific names, and as far as possible, related/corresponding ERICA Reference Organisms and Representative Species from the site.

Related ERICA Reference Organism	Swedish names	Scientific names	Related Representative Species from the site
Amphibian	Gölgroda	*Rana lessonae*	–
Amphibian	Större vattensalamander	*Triturus cristatus*	–
Bivalve mollusc	Flat dammussla	*Pseudanodonta complanata*	Average mollusc
Bivalve mollusc	Tjockskallig målarmussla	*Unio crassus*	Average mollusc
Bivalve mollusc	Äkta målarmussla	*Unio pictorum*	Average mollusc
Bird (duck)	Brunand	*Aythya ferina*	–
Bird (duck)	Kungsfiskare	*Alcedo atthis*	–
Bird (duck)	Svarthakedopping	*Podiceps auritus*	–
Bird (duck)	Svarttärna	*Chlidonias niger*	–
Bird (duck)	Svärta	*Melanitta fusca*	–
Crustacean	Flodkräfta	*Astacus astacus*	–
Crustacean	Hällkarsräka	*Tanymastix stagnalis*	–
Crustacean	Linsräka	*Limnadia lenticularis*	–
Crustacean	Spetssköldbladfoting	*Lepidurus apus*	–
Gastropoda	Rundläppad skivsnäcka	*Anisus spirorbis*	Average mollusc
Gastropoda	Sumpkamgälsnäcka	*Valvata macrostoma*	Average mollusc
Insect larvae	–	*Bagous binodulus*	–
Insect larvae	–	*Bagous petro*	–
Insect larvae	Bredfotad rörbock	*Donacia brevitarsis*	–
Insect larvae	Brokig strömvapenfluga	*Oxycera trilineata*	–
Insect larvae	Bäckbuksimmare	*Sigara hellensii*	–
Insect larvae	–	*Cloeon schoenemundi*	–
Insect larvae	–	*Donacia dentata*	–
Insect larvae	Dvärgflickslända	*Nehalennia speciosa*	–
Insect larvae	Gulbukig jättevapenfluga	*Stratiomys chamaeleon*	–
Insect larvae	–	*Hydaticus continentalis*	–
Insect larvae	–	*Hydrochus megaphallus*	–
Insect larvae	–	*Macroplea appendiculata*	–
Mammal	Utter	*Lutra lutra*	–
Pelagic fish	Asp	*Aspius aspius*	Average fish
Pelagic fish	Lake	*Lota lota*	Average fish
Pelagic fish	Mal	*Silurus glanis*	Average fish
Pelagic fish	Vimma	*Vimba vimba*	Average fish
Pelagic fish	Ål	*Anguilla Anguilla*	Average fish
Vascular plant	Bandnate	*Potamogeton compressus*	Fennel pondweed
Vascular plant	Dvärgslinke	*Nitella confervacea*	Chara
Vascular plant	Fyrling	*Tillaea aquatica*	–
Vascular plant	Kustgrimmia	*Grimmia decipiens*	–
Vascular plant	Nordslamkrypa	*Elatine orthosperma*	–
Vascular plant	Rödlånke	*Lythrum portula*	–
Vascular plant	Sjöbryum	*Bryum knowltonii*	–
Vascular plant	Småsvalting	*Alisma wahlenbergii*	–
Vascular plant	Spretsträfse	*Chara rudis*	Chara
Vascular plant	Spädslinke	*Nitella gracilis*	Chara
Vascular plant	Stjärnslinke	*Nitellopsis obtusa*	Chara
Vascular plant	Strandbräsma	*Cardamine parviflora*	–
Vascular plant	Styvnate	*Potamogeton rutilus*	Fennel pondweed
Vascular plant	Uddnate	*Potamogeton friesii*	Fennel pondweed
Vascular plant	Uddslinke	*Nitella mucronata*	Chara
Vascular plant	Vårslinke	*Nitella capillaries*	–
Vascular plant	Ävjebrodd	*Limosella aquatic*	–
Vascular plant	Ävjepilört	*Persicaria foliosa*	–

Table 3-5c. "Red-listed" marine organisms found in the Forsmark area with Swedish and scientific names, and as far as possible, related/corresponding ERICA Reference Organisms and Representative Species from the site.

Related ERICA Reference Organism	Swedish names	Scientific names	Related Representative Species from the site
Benthic fish	Tånglake	*Zoarces viviparus*	Average fish
Benthic fish	Vimma	*Vimba vimba*	Average fish
Bird (duck)	Bergand	*Aythya marila*	–
Bird (duck)	Ejder	*Somateria mollissima*	–
Bird (duck)	Gråtrut	*Larus argentatus*	–
Bird (duck)	Svarthakedopping	*Podiceps auritus*	–
Bird (duck)	Svärta	*Melanitta fusca*	–
Bird (duck)	Tobisgrissla	*Cepphus grylle*	–
Bird (wading)	Roskarl	*Arenaria interpres*	–
Macroalgae (brown) seaweed)	Taggtofs	*Stypocaulon scoparium*	Bladder wrack
Mammal	Havsörn	*Haliaeetus albicilla*	–
Mammal	Utter	*Lutra lutra*	–
Mammal	Vikare	*Pusa hispida*	–
Pelagic fish	Lake	*Lota lota*	Average fish
Pelagic fish	Sjurygg	*Cyclopterus lumpus*	Average fish
Pelagic fish	Ål	*Anguilla anguilla*	Average fish
Vascular plant	Bandnate	*Potamogeton compressus*	Fennel pondweed
Vascular plant	Fyrling	*Tillaea aquatica*	Fennel pondweed
Vascular plant	Nordslamkrypa	*Elatine orthosperma*	Fennel pondweed
Vascular plant	Raggsträfse	*Chara horrida*	–
Vascular plant	Småsvalting	*Alisma wahlenbergii*	Fennel pondweed
Vascular plant	Uddnate	*Potamogeton friesii*	Fennel pondweed
Vascular plant	Ävjebrodd	*Limosella aquatica*	–

Table 3-5d. "Key functional and dominant" organisms found in the Forsmark area with English and scientific names, and as far as possible, related/corresponding ERICA Reference Organisms and Representative Species from the site. (F = freshwater, M= marine, T= terrestrial)

Related ERICA Reference Organism	English names	Scientific names	Related Representative Species from the site
Amphibia	Common frog (T)	*Rana temporaria*	–
Benthic mollusc	Baltic macoma (M)	*Macoma baltica*	Average mollusc/Baltic macoma
Bivalve mollusc	Duck mussel (F)	*Anotonta anatina*	Average mollusc/Duck mussel
Crustacean	Idothea (M)	*Idothea sp*	Idothea
Grasses & Herbs	Bottle sedge (T)	*Carex rostrata*	–
Grasses & Herbs	Reed (T)	*Phragmites australis*	–
Insect larvae	Midge (F)	*Tanypodinae*	–
Lichen & bryophytes	Peat moss (T)	*Sphagnum sp*	Average bryophyte
Macroalgae	Bladder wrack (M)	*Fucus vesiculosus*	Bladder wrack
Mammal	Red fox (T)	*vulpes vulpes*	Red fox
Mammal	Water vole (T)	*Arvicola terrestris*	Average rodent/Water vole
Pelagic fish	Herring (M)	*Clupea harengus*	Average fish
Pelagic fish	Perch (F, M)	*Perca fluviatilis*	Average fish
Pelagic fish	Pike (F, M)	*Esox lucius*	Average fish/Pike
Pelagic fish	Roach (F)	*Rutilus rutilus*	Average fish/Roach
Pelagic fish	Ruffe (F)	*Gymnocephalus cernua*	Average fish/Ruffe
Pelagic fish	Tench (F, M)	*Tinca tinca*	Average fish/Tench
Phytoplankton	Phytoplankton (M)	*sp*	Phytoplankton
Tree	Alder (T)	*Alnus glutinosa*	–
Tree	Norwegian spruce (T)	*Picea abies*	Norwegian spruce
Tree	Pine tree (T)	*Pinus silvestris*	–
Vascular plant	Chara (F)	*Chara spp.*	Chara
Vascular plant	Reed (F)	*Phragmites australis*	–
Zooplankton	Microphytobenthos (F)	*Various spp.*	Average phytoplankton
Zooplankton	Zooplankton (M)	*Various spp.*	Zooplankton

Table 3-5e. Economically important organisms found in the Forsmark area with English and scientific names, and as far as possible, related/corresponding ERICA Reference Organisms and Representative Species from the site. (F = freshwater, M = marine, T = terrestrial)

Related ERICA Reference Organism	English names	Scientific names	Related Representative Species from the site
Benthic fish	Burbot (M)	*Lota lota*	Average fish
Benthic fish	Lumpsucker (M)	*Cyclopterus lumpus*	Flounder
Bird (duck)	Common eider (M)	*Somateria mollissima*	–
Grasses & Herbs	Cloudberry (T)	*Rubus chamaemorus*	–
Grasses & Herbs	Cranberry (T)	*Vaccinium oxycoccus*	Bilberry
Lichen and bryophytes	Peat moss (T)	*Sphagnum sp*	Average moss
Mammal	Ringed seal (M)	*Pusa hispida*	–
Pelagic fish	Eel (M)	*Anguilla anguilla*	Average fish
Pelagic fish	Herring (M)	*Clupea harengus*	Average fish
Pelagic fish	Perch (F, M)	*Perca fluviatilis*	Average fish
Pelagic fish	Pike (F, M)	*Esox lucius*	Average fish/Pike
Pelagic fish	Tench (F)	*Tinca tinca*	Average fish/Tench
Tree	Norwegian spruce (T)	*Picea abies*	Norwegian spruce
Tree	Pine tree (T)	*Pinus silvestris*	Norwegian spruce

3.4.4 "Average Organisms"

For many of the selected Representative Species from the site, available data did not include all of the radionuclides considered in Table 3-1. In order to reduce the resulting data gaps, the concept of "Average Organisms" was introduced, see Table 3-6 (this refers to Forsmark; similar information concerning Laxemar is given in the appendix, Section A5.2). The properties of "Average Organisms" correspond to average values across several Representative Species from the site, from the same ecosystem and in most cases with the same occupancy factor, i.e. time spent in different habitats of the ecosystem (however, as further discussed in Section 3.5.3 and in the appendix (Section A1), molluscs have different occupancy factors).

Table 3-6. "Average Organisms" at Forsmark considered in the assessments and Representative Species from the site included in each Average Organism. For some mushrooms with no known English name, scientific names only are provided. (F = freshwater, M = marine, T = terrestrial)

Average Organism	Species at Forsmark English names	 Scientific names
Average bryophyte (T)	Glittering wood-moss	*Hylocomium splendens*
	Moss	*Bryophyta sp*
	Shaggy moss	*Rhytidiadelphus triquetrus*
Average fish (F)	Pike	*Esox lucius*
	Roach	*Rutilus rutilus*
	Ruffe	*Gymnocephalus cernuus*
Average fish (M)	Roach	*Rutilus rutilus*
	Ruffe	*Gymnocephalus cernuus*
	Smelt	*Osmerus eperlanus*
Average mollusc (M)	Baltic macoma	*Macoma baltica*
	Lagoon cockle	*Cerastoderma glaucum*
	River nerite	*Theodoxus fluviatilis*
Average mushroom (T)	Funnel chantarelle	*Cantharellus tubaeformis*
	Granulated bolete	*Suillus granulatus*
	Porcini	*Boletus edulis*
	–	*Collybia peronata*
	–	*Cortinarius armeniacus*
	–	*Cortinarius odorifer*
	–	*Cortinarius sp.*
	–	*Hypholoma capnoides*
	Saffron milk cap	*Lactarius deterrimus*
	–	*Lactarius scrobiculatus*
	–	*Lactarius trivialis*
	Scaly hedgehog	*Sarcodon imbricatus*
	Velvet bolete	*Suillus variegatus*
Average phytoplankton (M)	Phytoplankton (undefined)	
	Microphytes (undefined)	
Average rodent (T)	Common shrew	*Sorex araneus*
	Bank vole	*Myodes glareolus*
	Mouse (undefined)	
	Water vole	*Arvicola terrestris*
	Yellow necked mouse	*Apodemus flavicollis*
Average vascular plant (T)	Bilberry	*Vaccinium myrtillus*
	Small cow-wheat	*Melampyrum sylvaticum*
	Stone bramble	*Rubus saxatilis*

3.5 Dose rate assessments using the ERICA Tool

The ERICA software Tool: The ERICA Tool is a software that supports the ERICA Integrated Approach to the assessment and management of environmental risks from ionising radiation. The approach provides guidelines on problem formulation, impact assessment, and data evaluation. The ERICA Tool guides the user through the assessment process, keeps records, and performs the calculations to estimate whole-body dose rates to selected organisms. The Tool considers the majority of the radionuclides included in ICRP Publication 38 /ICRP 1983/.

The ERICA Tool also interfaces with the FREDERICA radiation effects database, which is a compilation of the scientific literature on radiation effect experiments and field studies, organised around different wildlife groups and, for most data, broadly categorised according to four effect umbrella endpoints: morbidity, mortality, reproduction, and mutation.

The databases are built up around a number of *Reference Organisms*. Each Reference Organism has its own specified geometry and is representative of either terrestrial, freshwater, or marine ecosystems. The approach is compatible with that used by ICRP; some of the geometries proposed for the ICRP "Reference Animals and Plants" /ICRP 2008/ are used as defaults in the ERICA Tool.

The assessment element is organised in three separate *Tiers* (described below), where satisfying certain criteria in Tier 1 or 2 allows the user to exit the assessment process while being confident that the effects on biota are low or negligible, and that the situation requires no further action. Where the effects are not shown in a lower Tier to be negligible, the assessment should continue to the next Tier.

The default screening criterion in the ERICA tool is an *incremental dose rate of 10 $\mu Gy\ h^{-1}$*, to be used for all ecosystems and organisms. This value was derived from a species sensitivity distribution analysis performed on chronic exposure data in the FREDERICA database, and is supported by other methods for determining predicted no-effect values. Furthermore, this screening value is below the bands of Derived Consideration Levels proposed by ICRP /ICRP 2008/.

Tier 1: This is simple and "conservative" (i.e. cautious in the sense that it is based on pessimistic assumptions) and requires a minimum of input data, so as to permit the exemption of situations of negligible concern from further evaluation. Tier 1 does not permit the addition of any other radionuclides or species than the default sets provided by the ERICA Tool, and therefore was not used in the present analysis.

Tier 2: This is also a "screening" tier, but permits a more informed assessment and allows the user to add, e.g. their own species of interest and their own choice of radionuclides. Its assumptions are, therefore, less "cautious" than those of Tier 1.

In Tier 2, Risk Quotients (RQ) are calculated for each organism and each radionuclide according to the relationship

$$RQ_i = D_i / D_{lim}$$

where D_i = the estimated whole-body absorbed dose rate to organism *i*, and D_{lim} = the Projected No-Effects ("screening") Dose Rate, summed over all radionuclides to obtain total RQ values for each organism.

The output of Tier 2 assessments are (a) "expected" RQ values obtained by deterministic calculations using mean values for all parameters, and (b) "conservative" (95^{th} or 99^{th} percentile, assuming an exponential distribution of dose rates) RQ values obtained by multiplying the "expected" RQ by an appropriate uncertainty factor.

If all "conservative" RQ's are less than one, the situation is likely to be of negligible radiological concern and the Tool suggests that the assessment be concluded. If some "conservative" RQ's exceed one, but all "expected" RQs are less than one, the Tool suggests that the results and assessments be reviewed. Finally, if any "expected" RQ exceeds one, the Tool will recommend further assessment using Tier 3.

Tier 3: This is a probabilistic risk analysis which demands more interaction from the user. The assessment does not yield a simple yes/no answer, and instead of using a single "screening dose rate", the user is expected to consider aspects such as the biological effects data in the FREDERICA database. The necessary simulations are carried out with user-selected probability distributions for selected parameters and mean values for others.

The output results in Tier 3 are dose rates for each radionuclide and organism considered and dose rates to each organism. In addition to the mean values, the standard deviation, the median, and different percentiles of these dose rates are also provided. Furthermore, sensitivity analyses are carried out in order to identify the parameters with the largest contribution to the uncertainties of the dose rate estimates.

Assessments performed in the present study: Tier 2 was used as the entry point, in order to permit the use of site-specific organisms and the addition of some radionuclides. The following steps were taken:

1. Some radionuclides were added to the default set of the ERICA Tool, version 1.0 May 2009 (see Table 3-1).
2. Representative Species from the site (Table 3-4) and Average Organisms (Table 3-6) were added to the ERICA Tool.
3. Dose Conversion Coefficients (DCC, see Section 3.7) were calculated with the ERICA Tool for each radionuclide/organism combination. The results are given in Section 4.2.
4. For each element/organism combination included in the assessment, concentration ratios (CR) were estimated based on site or generic data (see Section 3.8).
5. Using environmental media concentrations for the Forsmark site calculated with the radionuclide model for a release according to the central corrosion case (Table 3-2) as input data, deterministic (Tier 2) and probabilistic (Tier 3) dose assessments were carried out for the radionuclides and organisms considered.
6. In the Tier 3 assessments, probabilistic simulations were carried out with probability density functions (PDFs) for the concentration ratios and mean values for all other model parameters. Where available, site-specific data were used to estimate PDFs for species from the site. For all Reference Organisms, PDFs were based on default data provided by the ERICA Tool. The results of all (Tier 2 and Tier 3) dose rate assessments are presented in Section 4.3.
7. For illustrative purposes, not part of the formal assessment, background dose rates were also assessed, using site data on background radionuclide levels in environmental media and biota. The results of the background dose rate assessments are presented in the appendix (Section A4).

3.6 Exposure pathways

The ERICA Tool considers two exposure pathways: external exposure from surrounding media, and internal exposures due to intakes. The habitats are described in Section 3.7.4.

3.7 Calculation of Dose Conversion Coefficients

Dose coefficients are quantities linking amounts or concentrations of activity to doses or dose rates. In the ERICA Tool, two sets of Dose Conversion Coefficients (DCCs) are defined: for doses due to intakes, DCC_{int} is defined as the internal absorbed dose rate (µGy h^{-1}) per unit activity concentration in an organism (Bq kg^{-1} fw) and for doses due to exposures from surrounding media, DCC_{ext} is defined as the external absorbed dose rate (µGy h^{-1}) per unit concentration in environmental media (Bq kg^{-1} or Bq l^{-1} fw) /Pröhl 2003/. Using DCC_{int} and DCC_{ext}, internal and external dose rates to an organism can be computed; the total dose rate to an organism is obtained as the sum of these dose rates.

The DCCs values depend on a number of factors, most generally the radionuclide-specific radioactive decay properties. Assumptions concerning the distribution of activity in the body are necessary for internal exposure assessments (Section 3.7.1). The Relative Biological Effectiveness of different kinds of radiation is also taken into account and affects primarily internal exposures (Section 3.7.2). Assessments of external exposure (Section 3.7.3) take account of the geometrical relationship between the source of radiation and the target organisms, including the composition and shielding properties of materials and media in the environment, and of the habitat (Section 3.7.4) and size (Section 3.7.5) of the target organism.

For all radionuclides of interest for this study (Table 3-1), DCC-values were calculated for Representative Species from the site (Table 3-4) and Average Organisms (Table 3-6) using the interpolation procedure available within the ERICA Tool. (The Tool provides default DCC values for Reference Organisms).

3.7.1 Internal exposure

Assessments of internal exposure using the ERICA Tool assume that the activity is homogenously distributed in the whole body, and separate organs are not considered in the manner of the more sophisticated assessments used for human internal exposures. Moreover, it is assumed that the fraction of the emitted energy per transformation in the body that is absorbed (i.e. DCC_{int}) does not depend on properties in the environment.

3.7.2 Relative biological effectiveness

Different kinds of radiation have different Relative Biological Effectiveness (RBE). This is taken into account in human radiological protection through the use of radiation weighting factors, w_R /ICRP 2007/. However, for non-human biota, there is no agreed approach to this problem. The ERICA Tool allows the user to select weighting factors for α, low energy β, and β and γ radiation, separately for internal and external radiation. Default weighting factors are provided, viz. 10 for α radiation, 3 for low-energy β radiation ($E < 10$ keV), and 1 for γ radiation and β radiation with energies above 10 keV.

The weighting factor for α used for non-human biota, 10, is lower than the recommended value for humans which is 20. This difference is due to the fact that the human w_R value represents the RBE for stochastic effects (primarily induction of cancers), while deterministic effects will be of greater significance for non-human biota.

In the present analysis, these default values were used throughout for internal exposures. For external exposures, only β and γ radiation is considered, while weakly penetrating short-range radiation (α and low-energy β) is assumed to not contribute to external exposure.

3.7.3 External exposure

The derivation of dose conversion coefficients for external exposure differs 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. Thus, the conditions for radiation transport are relatively homogeneous.

For terrestrial animals and plants, 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, and organism sizes are selected for detailed consideration. Exposure conditions for which detailed calculations are unavailable can then be deduced by interpolation. The following source–target relationships are taken into account:

- External exposure of on-soil and above-soil reference animals and plants to a radionuclide source of uniformly contaminated volume and with a thickness of 10 cm.
- External exposure of in-soil reference animals and plants that live in the middle of a radionuclide source of uniformly contaminated volume and with a thickness of 50 cm.

3.7.4 Habitat of the organisms

For external DCC calculations it is necessary to define the source-target geometry of each organism. This depends on the habitat of the organisms. Ten habitat types can be used for calculation of DCCs with the ERICA Tool. These are shown in Figure 3-2 and summarised below:

- in-soil, and on-soil (including in-air) habitats in terrestrial ecosystems,
- in-sediment, surface-sediment, water-column, and water-surface habitats in aquatic ecosystems (marine and freshwater).

Users can combine the different habitats for dose rate calculations (e.g. in- and on-soil living organisms) by determining the percentage of time each organism spends in each habitat. It is also possible to incorporate the concept of organisms migrating away from an ecosystem; e.g. a bird spends 50 % of the time, i.e. the summer, in the terrestrial in-air habitat but the remaining 50 % of the time it is not there (migrates south during winter). Birds and flying insects are assumed to spend all of their time on the ground, since the on-soil habitat is regarded as a limiting case (i.e. maximum exposure) of the in-air habitat.

For the present analysis, all of the species assessed were assigned to a habitat. The ERICA Tool provides default habitat assignments. The author assigned Representative Species from the site and Average Organisms to habitats. Details of these assignments are provided in appendix (Table A-1).

3.7.5 Size of the organisms

For calculation of DCCs, the size and mass of each organism is also required. Two main assumptions were necessary in order to calculate DCCs under the ERICA approach:

- The representations of all organisms that were added to the ERICA Tool (Representative Species from the site, and Average Organisms) were reduced to ellipsoids or spheres. The Reference Organisms provided by default are also represented in the ERICA Tool by volumes that are either ellipsoidal or spherical.
- Mass is a mandatory parameter in the ERICA Tool. All organisms considered were assumed to have the same density as water. This approach simplified estimation, where necessary, of masses from the volumes calculated from measurements; furthermore, where required it permitted “back calculation” of width (a measure rarely found in the literature) from published mass data.

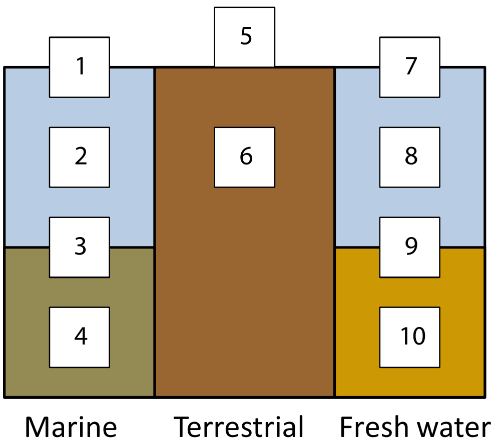


Figure 3-2. *Habitats defined in the ERICA tool for estimation of DCC to biota. 1 = marine water surface; 2 = marine pelagic; 3 = marine sediment surface; 4 = marine in sediment; 5 = terrestrial on soil; 6 = terrestrial in soil; 7 = fresh water on surface; 8 = fresh water pelagic; 9 = fresh water sediment surface; 10 = fresh water surface.*

Determining typical dimensions of the organisms being assessed is associated with uncertainties. The widths of organisms that were added to the ERICA Tool were estimated by picture analysis where literature data proved insufficient. The picture analysis was used to obtain the ratio length/height of body trunks, without consideration of the head, legs, or other extremities, as exemplified by a roe deer in Figure 3-3.

Real data on overall length, height, width, and weight were obtained from published sources or official databases. Since organisms were assumed to have the density of water, the volume in dm^3 was numerically equal to the mass in kg. Using this information, it is possible to derive a missing measurement (usually, width) of an organism using the ellipsoidal volume (V) formula,

$V = (4\pi \cdot a \cdot b \cdot c)/3$

where a, b, and c are the length, height, and width radii. It is worth noting that published mass data includes the weights of head, legs, etc, and that therefore, the derived width may be somewhat larger than the actual width that would be observed by direct measurements.

The resulting sizes and masses of all organisms added to the ERICA Tool, i.e. Representative Species from the site, and Average Organisms, are shown in appendix (Table A-1). In spite of the uncertainties inherent in the size and mass estimations, the information is regarded as sufficiently reliable, because these parameters have a limited effect on the dose rates to the organisms. This is clearly shown in Appendix A (Figure A-1, Section A1.2)

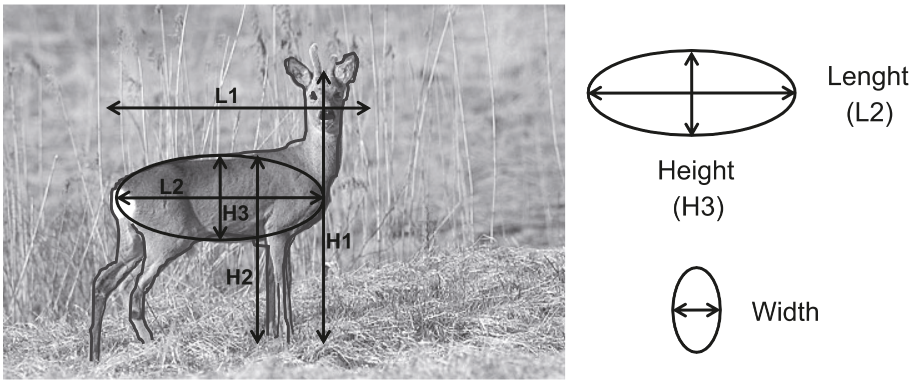


Figure 3-3. *Simplification of a roe deer's dimensions into an ellipsoid for DCC calculations. Literature data most often gives H1, H2, and L1 sizes only. By ratio measurements, H3 and L2 sizes can be defined (if at least one size is given). Width is thereafter calculated as described in the text, using the ellipsoidal formula.*

3.8 Concentration ratios (CR)

Intakes (ingestion or inhalation) will lead to an increased concentration of some elements in biota. A measure of this phenomenon is the Concentration Ratio (CR), i.e. the concentration of an element in biota divided by the concentration of the same element in surrounding media. A simple way of measuring CRs is to measure physically the amount of radioisotopes of the element being studied; in the present context, the concentration of radionuclides (rather than just "elements") is also the purpose of the study.

Thus, the CRs used in the ERICA Tool for terrestrial biota are defined as the radionuclide activity concentration in biota whole body (Bq kg^{-1} fresh weight) divided by the radionuclide activity concentration in soil (Bq kg^{-1} dry weight) or in air (Bq m^{-3}) for chronic atmospheric releases of ^{3}H, ^{14}C, ^{32}P and ^{35}S. For aquatic biota, the CRs are defined as the activity concentration in biota whole body (Bq kg^{-1} fresh weight) divided by the activity concentration in filtered water (Bq l^{-1}).

However, it is also possible to obtain CRs through chemical analysis of the element; the format of such CR calculations will be (mg kg^{-1})/(mg kg^{-1}) or (mg kg^{-1})/(mg l^{-1}). Numerically, such CRs will be the same as CRs using radiation measurements, since the proportion of radioactive isotopes of a particular element remains the same during the concentration process – it is the element as such that is being concentrated.

The CRs are used to calculate the radionuclide activity concentrations in biota from radionuclide concentrations in environmental media, assuming equilibrium conditions. The radionuclide and the corresponding stable element show the same environmental behaviour, and therefore CRs based on stable elements and radionuclide concentrations can be used interchangeably. Most CRs estimated in this study are based on measured values of stable element concentrations in biota and environmental media, reported in /Tröjbom and Nordén 2010/.

The number of samples of biota used for the calculation of CRs are presented in Table 3-4. As can be seen, the number of samples was small for all Representative Species from the site. Because of this, and because the number of radionuclides studied per organism was often also small, the Average Organisms were derived. Table 3-7 shows the number of samples per Average Organism.

3.8.1 Conversion of dry weight to fresh weight

Values of element concentrations in biota (from /Tröjbom and Nordén 2010/) were expressed in units of µg/kg *dry weight* for all organisms. In the ERICA Tool, activity concentrations need to be expressed as Bq/kg *wet weight.* A conversion from dry weight (dw) to fresh weight (fw) is therefore needed, and was performed using the equation,

$$dw = TS \cdot fw$$

where the conversion factor TS is the ratio between dry weight and fresh weight values. Values of the TS conversion factor were calculated from data on dry and fresh weights available for the two investigated sites. A full list of the TS conversion factor values used is provided in appendix (Section A2.1).

Table 3-7. Total number of samples per "Average Organism" collected at the Forsmark investigation sites and used for calculation of Concentration Ratios. (T = terrestrial, F = freshwater, M = marine).

Species	No. of samples
Average bryophyte (T)	3
Average fish (F)	7
Average fish (M)	9
Average mollusc (M)	7
Average mushroom (T)	13
Average phytoplankton (M)	5
Average rodent (T)	13
Average vascular plant (T)	5

4 Results

Section 4.1 lists the Dose Conversion Coefficient values obtained with the ERICA Tool, and Section 4.2 provides a summary of the Concentration Ratio values that were calculated. The resulting dose rates to biota, after an assumed release of radioactive material from the repository, are presented in Section 4.3.

4.1 Dose Conversion Coefficients (DCC values)

The results obtained for each kind of exposure and each type of radiation considered are provided in Section 4.1.1. Section 4.1.2 describes and discusses the variation, and hence the reliability, in the DCC values obtained in this study.

4.1.1 DCC for specific exposure and radiation situations

Biota exposed to releases from the repository will be exposed in two modes: internally, after intakes, and externally, from the surrounding media. Furthermore, they will be exposed to different kinds of radiation; this study takes into consideration α, low-energy β, and β and γ radiation. The maximum DCC values obtained for each combination of these parameters, their size and habitat dependence, and some indication of the ranges, are given in Table 4-1.

Size: Increasing size leads to increasing DCC values for internal β and γ exposure, due to the higher absorbed fractions. In contrast, DCC values decrease with increasing size for external exposure (this is due to the increase in self-shielding, especially for low energy γ-emitters). For internal α and low-energy β radiation, the DCC values are virtually independent of size.

Habitat: DCC values are mostly independent of the habitat, but the in-soil habitat of organisms living underground entails higher DCC values (due to external β/γ radiation) than for other terrestrial habitats.

The highest contribution to DCC values is caused by Ra-226 and its daughter nuclides; this is true for both internal α and γ radiation and for external γ radiation.

Table 4-1. Dose Conversion Coefficients obtained in the present study (fw = fresh weight).

Exposure mode and type of radiation	Calculated DCCs	Critical radionuclides	Comments
Internal exposure, α radiation.	Values range from 2.3E–3 to 3.3E–3 μGy h^{-1}/Bq.kg^{-1} fw for all radionuclides except Ra-226 with 1.4E–2 μGy h^{-1}/Bq.kg^{-1} fw.	Ra-226 nearly 5 times higher than other radionuclides (due to contribution from radium daughter nuclides).	19 of the 37 radio-nuclides studied are α emitters. These DCCs are mass and habitat independent.
Internal exposure, low-energy β radiation.	Values range from 6.9 E–8 to 1.2 E–5 μGy h^{-1}/Bq kg^{-1} fw.	The highest DCC is seen for U-235 followed by Th-229, Am-243 and Pa-231.	These DCCs are independent of organism mass and habitat.
Internal exposure, β and γ radiation.	Maximum value 6.8E–3 μGy h^{-1}/Bq kg^{-1} fw (moose).	Ra-226 has the highest DCC value followed by Sn-126, Ho-166m, Ag-108m and Nb-94.	DCCs *increase* with the mass of the organisms; no habitat dependencies are seen.
External exposure, α and low-energy β radiation.	These DCCs have zero value for all organisms and radionuclides.	–	–
External exposure, β and γ radiation.	Maximum value 5.3E-2 μGy h^{-1}/Bq kg^{-1} fw (phytoplankton).	The highest DCC values for all habitats are observed for Ra-226, followed by Ho-166m, Ag-108m, Nb-94 and Sn-126.	DCCs *decrease* with the mass of the organism; values are 2-3 times higher for organisms living in soil than for those living on soil; no habitat dependencies are seen for freshwater and marine organisms, nor for pelagic and benthic organisms.

The behaviour observed for the DCCs is consistent with the findings of /Vives i Batlle et al. 2011/. They note, for instance, that terrestrial external DCCs are somewhat smaller than aquatic DCCs for the same organism size because, for terrestrial ecosystem, some calculations are based on models (phantoms) where the skin and fur of animals acts as shielding layer; therefore, the external dose is lower than that predicted by other approaches wich do not consider these shielding effects.

4.1.2 Variation of the Dose Conversion Coefficients

A study was carried out to investigate how masses and habitats can influence the DCC values. A spherical organism, with equal spherical ratio for organisms with different masses, is a handy model for this kind of studies. The mass ranged from 1 g to 500 kg for terrestrial organisms and from 1 g up to 1,000 kg for aquatic organisms.

Table 4-2 shows DCCs for spherical organisms of either 1 g or 1 kg in the three ecosystems with different habitats. The mass dependence is further illustrated by Figure A-1 in the appendix (Section A1.2) where the mass dependence is shown graphically for internal and external β and γ radiation for aquatic and terrestrial organisms with masses spanning from 1 g up to 500 (terrestrial) or 1,000 (aquatic) kg. It is shown that DCCs change by at most a factor of 2 from 1 g to 100 kg, and even less from 100 kg to 500 or 1,000 kg.

DCCs in the terrestrial ecosystem did not differ from those of aquatic ecosystems, with the exception of the DCCs for external β and γ radiation where terrestrial DCCs are somewhat smaller, as highlighted by the values in Table 4-2. For example: a pelagic or benthic sphere of 1 gram has a higher DCC value, 5.9E-3, than a terrestrial 1 gram sphere living on the ground with its DCC of 1.9E-3 (values in μGy h^{-1}/Bq kg^{-1} fw).

The DCCs for organisms living in soil for external β and γ radiation are around 2.5 times higher than the DCCs for organisms living on soil. The DCC values of organisms living in soil are very similar to those of aquatic organisms. DCC values for internal exposures do not depend on the habitat.

Section 3.7 indicates some simplifying assumptions that were required in the determination of parameters (such as size/mass) affecting DCC values; additional detail is provided in appendix (Section A1). However, in this study neither mass nor habitat parameters influence the dose rates to the organisms assessed to any great extent. /Vives i Batlle et al. 2011/ also observed that in most cases, mass does not influence greatly the dose rates to the organisms assessed (at least for relatively low energies), but added that for high energy γ emitters and small organism masses, DCCs can vary quite a lot with changes in dimensions.

Nevertheless, it may be concluded that the level of uncertainty in the mass determinations is unlikely to have caused any appreciable uncertainty in the dose rates that constitute the final result of the assessment.

Table 4-2. DCC values (μGy h^{-1}/Bq kg^{-1}) for spherical organisms and different types of radiation.

Radiation source (Ra-226 or U-235)	Ecosystem	Subsystem	Mass 1 g	1,000 g
Internal α (Ra-226)	All		1.4E-2	1.4E-2
Internal low energy β (U-235)	All		1.2E-5	1.2E-5
Internal β and γ (Ra-226)	All		4.5E-4	6.7E-4
External α and low energy β (independent of nuclide)	All		0	0
External β and γ (Ra-226)	Aquatic			
		In water	1.1E-3	9.0E-4
		In sediment	1.1E-3	9.0E-4
		On sediment	1.1E-3	9.0E-4
	Terrestrial			
		In soil	9.1E-4	8.1E-4
		On soil	3.5E-4	3.3E-4

4.2 Concentration Ratios, CR

Concentration Ratio (CR) mean values were calculated for Representative Species from the site and for Average Organisms for terrestrial, freshwater, and marine ecosystems, from both Forsmark and Laxemar. A complete tabulation of all CR values that were calculated, with their associated standard deviations, as well as the default CR values of the Reference Organisms in the ERICA Tool, is provided in appendix (Section A2.3).

Table 4-3, in the present Section, shows CR values for selected Representative Species from the site compared with similar Reference Organisms. Values are shown only for those elements where data is available for both Representative Species and Reference Organisms. This means that CR values for Ca, Ho, Pa, Pd, Sm, and Sn are not shown in the Table 4-3 since the ERICA database does not provide CR values for these elements.

Most of the CR values of Representative Species and Reference Organisms are reasonably similar in the sense that more than half of the values differ by less than a factor 10, and almost all differ by less than a factor 100. For well investigated organisms (e.g. terrestrial vascular plants and marine pelagic fish), the CR for organisms from the site were typically captured within the the reported CR values for the corresponding reference organism. However, for organism groups that were less well represented in the database, CRs for individual species from the site frequently fell outside the 95% interval of the distribution of the corresponding ERICA reference organism. This pattern was seen for all three ecosystems. In most cases, differences could be attributed to the limited sample size or lack of representative samples in the database, but in a few cases there were indications that CRs obtained at the site showed site-specific characteristics.

For example, for terrestrial organism there was an overall tendency for CRs at the site to be lower than in the ERICA database. Notably, CRs for Pb and Cs were systematically lower in vascular plants, rodents, and larger herbivores, possibly indicating that the transfer characteristics at the site was not fully captured by the average conditions reflected in the ERICA data. Mosses, fungi, and coniferous trees were not well represented in the ERICA database, and in these cases the use of reference organisms was clearly conservative.

For freshwater organisms, there was a similar tendency for CRs at the site to be lower than in the ERICA database. CRs for U were systematically lower, by one or two orders of magnitude, in data from fish and plants at the site, possibly reflecting the naturally elevated concentrations of uranium at Forsmark /Tröjbom and Grolander 2010/. For marine organisms there were no clear directions in the deviations of site data from the ERICA database. However, the CRs for marine mollusc at the site were systematically higher than values for the corresponding reference organism for several elements (e.g. Cl, Cs, Pb, and Th), but the difference was typically within an order of magnitude.

Nb had CR values that were consistently one or two orders of magnitude lower at the site across all ecosystem and most organism groups. However this was not surprising as the reference organisms were typically represented by a handful of samples in the ERICA database, emphasising the importance of collecting site data for elements that are not well covered in the international databases.

Table 4-3. Illustrative comparison of Concentration Ratios (CR) observed in Representative Species from the site, and generic CRs supplied in the ERICA Tool for Reference Organisms. CRs for terrestrial organisms are computed as kg_{dw}/kg_{fw} and are, thus, dimensionless; the unit of CRs for aquatic organisms is l/kg_{fw}.

	Representative Species from the site			Reference Organism
Element	**Terrestrial mammals**			**Reference mammal (small or large)**
	Common shrew	**Moose**	**Yellow-necked mouse**	
Cl	5.0E+01	4.4E+00	2.5E+01	7.0E+00
Cs	3.7E–02	3.6E–02	9.2E–02	2.9E+00
I	1.4E–01	–	–	4.0E–01
Nb	6.0E–04	4.1E–05	–	1.9E–01
Ni	–	–	2.1E–02	7.2E–02
Pb	3.6E–03	–	–	3.9E–02
Sr	1.6E–03	2.3E–04	5.3E–04	1.7E+00
U	1.0E–03	9.5E–06	7.7E–05	1.1E–04
Zr	1.7E–04	–	1.7E–04	1.2E–05
Element	**Terrestrial vascular plants**			**Reference grass and herb**
	Bilberry	**Small cow-wheat**	**Stone bramble**	
Cl	5.3E+01	7.2E+01	1.9E+02	1.7E+01
Cs	1.5E–01	2.2E–01	7.7E–03	6.9E–01
I	4.2E–02	3.8E–02	2.2E+00	1.4E–01
Nb	4.5E–04	2.2E–04	6.4E–04	4.2E–02
Ni	4.5E–02	1.5E–01	5.5E–02	1.9E–01
Pb	3.1E–03	1.6E–03	1.5E–03	6.6E–02
Sr	3.5E–02	8.8E–02	3.9E–02	2.1E–01
U	6.1E–04	3.4E–04	1.3E–03	1.5E–02
Zr	1.9E–04	1.7E–04	1.8E–04	5.3E–04
Element	**Freshwater fishes**			**Reference pelagic fish**
	Pike	**Roach**	**Tench**	
Cl	3.2E+01	1.4E+02	5.1E+01	8.2E+01
Cs	5.3E+03	1.5E+03	1.8E+03	7.1E+03
I	5.0E+01	–	–	1.8E+02
Nb	9.7E+00	–	1.2E+01	2.3E+02
Se	5.3E+02	2.1E+02	8.4E+02	2.0E+02
Sr	5.0E+00	1.3E+01	4.2E+00	1.7E+01
U	6.6E–02	4.3E–01	2.2E–01	3.0E+01
Zr	–	1.3E+02	–	3.0E+02
Element	**Marine molluscs**			**Reference mollusc**
	Baltic macoma	**Lagoon cockle**	**River nerite**	
Cl	2.3E–01	–	3.5E–01	4.6E–02
Cs	4.9E+02	2.1E+02	3.4E+02	6.6E+01
I	5.4E+01	–	2.7E+02	1.4E+01
Ni	1.7E+02	1.0E+03	3.6E+02	6.4E+03
Pb	1.4E+04	3.0E+03	6.0E+03	1.7E+03
Se	1.2E+03	7.0E+02	1.8E+03	5.0E+03
Th	2.1E+04	8.2E+03	3.4E+04	5.1E+02
Zr	1.7E+04	9.8E+03	1.4E+04	4.6E+03

4.3 Dose rates to biota after a release from the central corrosion case

This Section summarises the results of dose rate analyses performed with the ERICA Tool. Table 4-4 shows terrestrial species, Table 4-5 shows freshwater species, and Table 4-6 shows marine species.

Each Table comprises a list of the Risk Quotients (RQ) obtained in Tier 2 assessments with the ERICA Tool, and mean dose rates obtained in Tier 3 assessments. Furthermore, each Table includes the Representative Species from the (Forsmark) site, the Average Organisms, and the Reference Organisms taken from the ERICA Tool.

A complete tabulation of the resultsis provided in appendix (Section A3). In addition to the information given here, the Appendix also include dose rates from Tier 2 analyses, and medians and 5th and 95th percentiles of dose rates obtained in Tier 3 analyses.

As explained in Section 3.5, the RQ values obtained in Tier 2 are calculated by dividing the estimated dose rates with a "screening dose rate" of 10 µGy h^{-1}. Dose rates below the screening rate are assumed to be of negligible significance. Thus, RQ values less than 1 indicate that there is no cause for concern. The ERICA Tool provides two sets of RQ values, "expected" and "conservative" (in the present study, representing the 95th percentile of an exponential distribution). If any "expected" RQ value exceeds unity, a Tier 3 assessment is recommended, while if some "conservative" but no "expected" RQs exceed 1, further analysis (which may or may not entail Tier 3 assessment) is suggested.

Table 4-4. Risk Quotients (RQ) obtained in ERICA Tier 2 analyses and dose rates (µGy h^{-1}; mean values and 95th percentiles) obtained in Tier 3 analyses, for terrestrial biota at Forsmark.

Organism, habitat	Tier 2 RQ values		Tier 3 dose rates	
	"Expected"	"Conservative"	Mean value	95th percentile
Representative terrestrial species from the site				
Bank vole	5.2E-07	1.5E-06	5.2E-06	5.7E-06
Bilberry shrub	3.1E-07	9.4E-07	3.1E-06	4.0E-06
Common shrew	5.1E-07	1.5E-06	4.9E-06	5.0E-06
Moose (350 kg, 500 kg: results identical)	1.2E-07	3.5E-07	1.2E-06	1.2E-06
Norwegian spruce	2.3E-07	6.8E-07	2.3E-06	2.6E-06
Red fox	3.9E-07	1.2E-06	3.9E-06	4.4E-06
Small cow-wheat	3.9E-07	1.2E-06	3.9E-06	6.5E-06
Stone bramble	3.4E-07	1.0E-06	3.4E-06	4.7E-06
Water vole	4.8E-07	1.4E-06	4.8E-06	4.8E-06
Yellow-necked mouse	2.3E-08	6.8E-08	2.2E-07	6.3E-07
Average terrestrial organisms				
Average bryophyte	1.6E-05	4.7E-05	1.9E-04	3.2E-04
Average mushroom	9.3E-08	2.8E-07	9.6E-07	2.2E-06
Average rodent	5.1E-07	1.5E-06	5.1E-06	5.6E-06
Average vascular plant	3.6E-07	1.1E-06	3.5E-06	5.4E-06
Reference terrestrial organisms				
Amphibia (terrestrial)	2.9E-06	8.7E-06	2.9E-05	5.9E-05
Bird (terrestrial)	2.7E-06	8.1E-06	2.7E-05	5.9E-05
Detritivorous invertebrate (terrestrial)	6.4E-06	1.9E-05	6.4E-05	1.4E-04
Flying insect (terrestrial)	6.1E-06	1.8E-05	6.1E-05	1.4E-04
Gastropod (terrestrial)	5.9E-06	1.8E-05	6.0E-05	1.4E-04
Grasses & herbs (terrestrial)	3.7E-06	1.1E-05	3.6E-05	8.5E-05
Mammal, large (terrestrial)	2.2E-06	6.5E-06	2.2E-05	4.9E-05
Mammal, small (terrestrial)	2.5E-06	7.6E-06	2.5E-05	5.2E-05
Lichen & bryophytes (terrestrial)	6.7E-05	2.0E-04	6.7E-04	1.2E-03
Reptile (terrestrial)	2.9E-06	8.6E-06	2.8E-05	5.8E-05
Shrub (terrestrial)	7.6E-06	2.3E-05	7.4E-05	2.0E-04
Soil invertebrate (terrestrial)	6.3E-06	1.9E-05	6.3E-05	1.4E-04
Tree (terrestrial)	6.1E-06	1.8E-05	5.9E-05	1.6E-04

Table 4-5. Risk Quotients (RQ) obtained in ERICA Tier 2 analyses and dose rates (µGy h^{-1}; mean values and 95th percentiles) obtained in Tier 3 analyses, for freshwater biota at Forsmark.

Organism, habitat	Tier 2 RQ values		Tier 3 dose rates	
	"Expected"	"Conservative"	Mean value	95th percentile
Representative freshwater Species from the site				
Chara	7.1E-08	2.1E-07	7.1E-07	1.5E-06
Duck mussel	1.9E-06	5.6E-06	1.9E-05	1.9E-05
Pike	4.2E-10	1.3E-09	4.2E-09	8.8E-09
Roach	1.5E-09	4.6E-09	1.5E-08	4.5E-08
Ruffe	1.5E-10	4.5E-10	1.5E-09	3.9E-09
Tench	5.4E-07	1.6E-06	5.4E-06	5.4E-06
Average freshwater Organisms				
Average fish	1.7E-09	5.2E-09	1.7E-08	4.6E-08
Reference freshwater Organisms				
Bird (freshwater)	1.6E-06	4.9E-06	1.9E-05	4.4E-05
Bivalve mollusc (freshwater)	3.7E-05	1.1E-04	3.7E-04	7.7E-04
Crustacean (freshwater)	2.7E-05	8.1E-05	2.7E-04	4.8E-04
Gastropod (freshwater)	2.7E-05	8.2E-05	2.8E-04	5.3E-04
Insect larvae (freshwater)	1.9E-04	5.6E-04	1.9E-03	5.1E-03
Mammal (freshwater)	1.8E-06	5.4E-06	1.8E-05	4.3E-05
Pelagic fish (freshwater)	1.7E-06	5.0E-06	1.7E-05	4.0E-05
Phytoplankton (freshwater)	3.4E-04	1.0E-03	3.4E-03	9.7E-03
Vascular plant (freshwater)	5.2E-05	1.6E-04	5.2E-04	1.2E-03
Zooplankton (freshwater)	2.2E-05	6.5E-05	2.2E-04	4.9E-04

Table 4-6. Risk Quotients (RQ) obtained in ERICA Tier 2 analyses, and dose rates (µGy h^{-1}; mean values and 95th percentiles) obtained in Tier 3 analyses, for marine biota at Forsmark.

Organism, habitat	Tier 2 RQ values		Tier 3 dose rates	
	"Expected"	"Conservative"	Mean value	95th percentile
Representative marine Species from the site				
Baltic macoma	9.1E-09	2.7E-08	9.1E-08	9.5E-08
Bladder wrack	4.0E-09	1.2E-08	4.0E-08	5.8E-08
Brown algae	1.8E-09	5.5E-09	1.8E-08	3.3E-08
Fennel pondweed	1.9E-09	5.8E-09	1.9E-08	2.6E-08
Idothea	5.9E-09	1.8E-08	5.9E-08	6.1E-08
Lagoon cockle	7.3E-09	2.2E-08	7.3E-08	7.7E-08
Microphytes	3.8E-09	1.1E-08	3.8E-08	5.9E-08
Phytoplankton	3.3E-10	1.0E-09	3.3E-09	4.2E-09
River nerite	1.4E-09	4.3E-09	1.4E-08	1.8E-08
Roach	3.5E-11	1.0E-10	3.4E-10	5.5E-10
Ruffe	5.7E-11	1.7E-10	5.7E-10	8.0E-10
Smelt	3.5E-11	1.0E-10	3.5E-10	4.8E-10
Zoo plankton	2.1E-10	6.4E-10	2.1E-09	3.7E-09
Average marine Organisms				
Average fish	5.3E-11	1.6E-10	5.3E-10	7.2E-10
Average mollusc	6.2E-09	1.9E-08	6.2E-08	7.3E-08
Average phytoplankton	2.1E-09	6.2E-09	2.1E-08	6.8E-08
Reference marine Organisms				
Benthic fish (marine)	1.1E-07	3.4E-07	1.1E-06	1.8E-06
Benthic mollusc (marine)	1.9E-07	5.6E-07	1.9E-06	3.1E-06
Bird (marine)	3.2E-08	9.5E-08	3.2E-07	9.0E-07
Crustacean (marine)	6.3E-08	1.9E-07	6.3E-07	1.2E-06
Macroalgae (marine)	1.4E-07	4.3E-07	1.4E-06	1.8E-06
Mammal (marine)	8.5E-09	2.5E-08	8.5E-08	2.2E-07
Pelagic fish (marine)	3.4E-08	1.0E-07	3.4E-07	1.0E-06
Phytoplankton (marine)	2.9E-07	8.7E-07	2.9E-06	6.2E-06
Polychaete worm (marine)	3.0E-07	8.9E-07	3.0E-06	4.6E-06
Vascular plant (marine)	1.3E-07	4.0E-07	1.3E-06	1.9E-06
Zooplankton (marine)	3.4E-08	1.0E-07	3.4E-07	6.9E-07

As can be seen in Tables 4-4, 4-5, and 4-6, none of the RQ values is even close to 1. The highest RQ values were obtained for freshwater phytoplankton (“expected” ≈ 0.0003, 95th percentile ≈ 0.01) and for freshwater insect larvae (“expected” ≈ 0.0002, 95th percentile ≈ 0.005); all other values are even smaller.

Judging from this result alone, it would have seemed reasonable to terminate the analysis at Tier 2. However, since this study is one of the very first investigations world-wide that is performed “in earnest” to evaluate possible effects on biota at the site of a planned final repository for high-level waste, it was felt that the assessment should be as complete as possible. Also, as discussed in Section 5.2, there are a number of uncertainties in the assumptions and input data; by proceeding through Tier 3 the effects of such uncertainties will, to some extent, be assessed.

However, all of the mean dose rates obtained in Tier 3 were also well below 10 µGy h^{-1}.The “highest” values are still for freshwater phytoplankton (mean ≈ 0.003 µGy h^{-1}, 95th percentile ≈ 0.01 µGy h^{-1}) and for freshwater insect larvae (mean ≈ 0.002 µGy h^{-1}, 95th percentile ≈ 0.005 µGy h^{-1}), i.e. the mean values are about four orders of magnitude below the screening dose rate and the 95th percentile values are about three orders of magnitude below the screening dose rate. Most other dose rates are yet smaller by several orders of magnitude.

Nevertheless, it may be worthwhile to continue investigations of these organisms during the imminent construction period. Also, the problem of how best to analyse dose rates to mushrooms with their complicated morphology merits further study.

As a final step, all available CR values from each Representative Species from the site were applied to a corresponding Reference Organism by replacing the generic CR values of ERICA with site-specific CR values. In this way, all available site-related data were used and combined with generic data as necessary to fill all the gaps where no site data were available. The resulting dose rates may, in a sense, be regarded as the most relevant ones.

Table 4-7 shows a comparison of the dose rates obtained in Tier 2 analyses for Representative Species from the site, for Reference Organisms using generic CR values, and “combined” dose rates (i.e. dose rates for Reference Organisms but substituting whenever possible CRs of Representative Species for generic CRs).

The combined dose rates are consistently of the same order of magnitude as those of Reference Organisms. Thus, the conclusion above that all dose rates are at least four orders of magnitude below the screening dose rate remains robust (however, for some caveats see the analysis in Sections 5.1 and 5.2). This is equally true for combined dose rates obtained through Tier 3 analyses (the results of which are provided in the Appendix, Section A5.3).

Table 4-7. Dose rates of Reference Organisms and Representative Species from the site and "combined" dose rates (for Reference Organisms, but substituting as far as possible site-specific CR values of Representative Species for generic values) obtained in Tier 2 analyses.

Reference Organisms (in parentheses: corresponding Representative Species from the site)	Dose rates (µGy h⁻¹) Representative Species	Reference Organisms	"Combined" dose rates of Reference Organisms using CRs of Representative Species
Terrestrial			
Grasses & Herbs (Average vascular plant)	3.6E–06	3.7E–05	3.5E–05
Grasses & Herbs (Bilberry)	3.1E–06	3.7E–05	3.5E–05
Grasses & Herbs (Small cow-wheat)	3.9E–06	3.7E–05	3.6E–05
Grasses & Herbs (Stone bramble)	3.4E–06	3.7E–05	3.7E–05
Large mammal (Red fox)	3.9E–06	2.2E–05	2.0E–05
Large mammal (Moose)	1.2E–06	2.2E–05	2.1E–05
Lichen & bryophytes (Average moss)	1.6E–04	6.7E–04	8.1E–04
Lichen & bryophytes (Average mushroom)	9.3E–07	6.7E–04	6.6E–04
Small mammal (Average rodent)	5.1E–06	2.5E–05	2.4E–05
Small mammal (Bank vole)	5.2E–06	2.5E–05	2.4E–05
Small mammal (Common shrew)	4.9E–06	2.5E–05	2.5E–05
Small mammal (Water vole)	4.8E–06	2.5E–05	2.5E–05
Small mammal (Yellow necked mouse)	2.3E–07	2.5E–05	2.5E–05
Tree (Norwegian spruce)	2.3E–06	6.1E–05	6.0E–05
Freshwater			
Bivalve mollusc (Duck mussel)	1.9E–05	3.7E–04	3.9E–04
Pelagic fish (Average fish)	1.7E–08	1.7E–05	1.7E–05
Pelagic fish (Pike)	4.2E–09	1.7E–05	1.7E–05
Pelagic fish(Roach)	1.5E–08	1.7E–05	1.7E–05
Pelagic fish (Ruffe)	1.5E–09	1.7E–05	1.7E–05
Pelagic fish (Tench)	5.4E–06	1.7E–05	4.0E–05
Vascular plant (Chara)	7.1E–07	5.2E–04	4.4E–04
Marine			
Benthic mollusc (Average mollusc)	6.2E–08	1.9E–06	1.8E–06
Benthic mollusc (Baltic macoma)	9.1E–08	1.9E–06	2.6E–06
Benthic mollusc (Lagoon cockle)	7.3E–08	1.9E–06	1.8E–06
Benthic mollusc (River nerite)	1.4E–08	1.9E–06	9.9E–07
Crustacean (Idothea)	5.9E–08	6.3E–07	1.4E–06
Macroalgae (Bladder wrack)	4.0E–08	1.4E–06	2.0E–06
Macroalgae (Brown algae)	1.8E–08	1.4E–06	5.1E–07
Pelagic fish (Average fish)	5.3E–10	3.4E–07	3.4E–07
Pelagic fish (Roach)	3.5E–10	3.4E–07	3.4E–07
Pelagic fish (Ruffe)	5.7E–10	3.4E–07	3.4E–07
Pelagic fish (Smelt)	3.5E–10	3.4E–07	3.4E–07
Phytoplankton (Average phytoplankton)	2.1E–08	2.9E–06	2.7E–06
Phytoplankton (Microphytes)	3.8E–08	2.9E–06	2.7E–06
Phytoplankton (Phytoplankton)	3.3E–09	2.9E–06	2.7E–06
Vascular plant (Fennel pondweed)	1.9E–08	1.3E–06	5.2E–07
Zooplankton (Zooplankton)	2.1E–09	3.4E–07	3.3E–07

5 Discussion

There are only two scenarios in SR-Site that contribute to a significant release of radionuclides to the biosphere, namely the corrosion scenario and the shear load scenario /SKB 2011/. The consequences for biota were calculated for the central calculation cases of the corrosion scenario, but the conclusions can be generalised to encompass the whole corrosion scenario and the shear load scenarios. This is because the predicted release rates of dose contributing nuclides in the different release scenarios (and calculation cases) varies with less than an order of magnitude, and calculated dose rates were several orders of magnitude below the screening dose rate /Sections 13.5.7 and 13.6.5 in SKB 2011/.

/Smith and Robinson 2006/ performed a somewhat similar study relating to the planned repository at Olkiluoto, but at the time of their assessment, the full ERICA system was not available and they describe their study as “a test case”. They identified some data gaps, but concluded that in general terms, the dose rates predicted for all organism types were several orders of magnitude below those at which population effects would be expected to be observed and those at which effects on the individual may be anticipated. This general result agrees with the results obtained in the present study.

They also recommended that the consistency of the developing approach for non-human biota with that applied for human protection be studied and ensured.

The more complete and final study of the Olkiluoto case by /Hjerpe et al. 2010/ was performed using the full ERICA system and tool, i.e. in a manner directly comparable to the present study. Their results concerning dose rates were similar and they concluded that any radiological consequences of releases from the repository would be negligible.

They listed the following remaining issues that were expected to require further work: transparency, traceability and robustness; management of uncertainties; formulation of scenarios and calculation cases; consistency between geosphere and biosphere assessment models; assessing doses to other biota; and ecosystem models vs. transfer factor approach in radionuclide transport modeling. The dose assessment issue referred to difficulties in applying the ellipsoidal geometry model, especially for plants. To some extent, this agrees with the complications encountered in the present study where mushrooms in particular posed problems in terms of the geometry.

Below, Section 5.1 summarises the highest mean dose rates for the various groups of organisms. Section 5.2 concerns strengths and weaknesses of the present study. Afinal discussion of the results is given in Section 5.3, and Section 5.4 provides conclusions.

5.1 Summary of dose rates to biota from an assumed future release

An overview of the results is provided in Section 4.3; a complete listing of all dose rates after an assumed release of radionuclides from the Forsmark repository, assuming the central corrosion case, is given in appendix (Sections A3.1 and A3.2). All of the mean dose rates were found to be far below the screening dose rate of 10 μGy h^{-1} for biota, suggesting that such a release would be of negligible concern for the protection of non-human biota. Sections 5.2 and 5.3 discuss the reliability of this conclusion.

Table 5-1 highlights the highest mean values obtained. It shows that the “high” mean dose rates are in fact far below the screening dose-rate value. It also confirms that, as expected, that for most species the estimated mean dose rates obtained in Tier 2 and Tier 3 assessments are virtually identical.

Table 5-2 extends the top row of Table 5-1, Representative Species from the site, by summarising the highest mean dose rates for the three nuclides that contribute most to the three most sensitive organisms at each of the three different ecosystems. Similarly, Table 5-3 extends the bottom row of Table 5-1, Reference Organisms, with the highest mean dose rates for the three nuclides contributing most to the three most sensitive organisms at each of the three ecosystems.

It should be kept in mind, though, that not all nuclides were studied for each organisms. Thus, comparisons should be avoided within as well as across Tables 5-1 to 5-3. In particular, the radionuclides that contribute the most to the dose rates (e.g. Ra-226, Np-237, and Po-210, as shown in Table 5-3) were largely missing from the site-specific data concerning Representative Species. Complete lists of nuclides studied per organism is given in appendix (Section A2.2).

The highest total dose rates in Table 5-1 are for freshwater reference phytoplankton, where the highest dose rate contributions come from Np-237 (3.2E–03 μGy h^{-1}) and Po-210 (1.3E–04 μGy h^{-1}).

No substantive difference in calculated dose rates could be detected for Reference Organism when CRs of Representative Species from the site were used (as far as possible) as compared to calculations based entirely on generic data. Thus, the use of site data did not appreciably affect the calculated dose rate; primarily because as mentioned above, site data was missing for major dose contributing radionuclides.

Table 5-2 hints that among those radionuclides that were actually studied in the Representative Organisms, in terrestrial organisms, high mean dose rate contributions often come from Cl-36, Nb-94, and perhaps U-233. For marine organisms, high contributions may often come from Ni-59 and perhaps Th-229. For freshwater organisms, the pattern seems more varied, although Ni-59 and U-233 could be candidates.

Table 5-1. Highest mean dose rates at the Forsmark site after a release in an central corrosion case scenario. All dose rates in μGy h^{-1}.

Group of organisms	Tier	Ecosystem Terrestrial	Freshwater	Marine
Representative Species from the site	2	Bank vole 5.2E–06	Duck mussel 1.9E–05	Baltic macoma 9.1E–08
	3	Bank vole 5.2E–06	Duck mussel 1.9E–05	Baltic macoma 9.1E–08
"Average Organisms"	2	Bryophyte 1.6E–04	Fish 1.7E–08	Mollusc 6.2E–08
	3	Bryophyte 1.9E–04	Fish 1.7E–08	Mollusc 6.2E–08
Reference Organisms	2	Lichen & bryophytes 6.7E–04	Phytoplankton 3.4E–03	Polychaete worm 3.0E–06
	3	Lichen & bryophytes 6.7E–04	Phytoplankton 3.4E–03	Polychaete worm 3.0E–06

Table 5-2. The three radionuclides with the highest mean dose rate contributions for the three Representative Species with the highest dose rates) for each of the three ecosystems at the Forsmark site after a release in an central corrosion case scenario. All dose rates in μGy h^{-1}.

Ecosystem Terrestrial Species	Radio-nuclide	Dose rate	Freshwater Species	Radio-nuclide	Dose rate	Marine Species	Radio-nuclide	Dose rate
Bank vole (Mammal)	Cl-36	1.0E–08	Duck mussel (Mollusc)	I-129	3.2E–07	Baltic macoma (Mollusc)	I-129	1.2E–08
	Nb-94	4.9E–06		Ni-59	6.4E–07		Ni-59	3.3E–08
	Ni-59	2.2E–07		Pb-210	5.9E–07		Pb-210	2.9E–08
	All	5.2E–06		All	1.9E–05		All	9.1E–08
Common shrew (Mammal)	Cl-36	1.5E–08	Tench (Fish)	Nb-94	5.4E–06	Lagoon cockle (Mollusc)	Ni-59	3.7E–08
	Nb-94	4.9E–06		Se-79	1.7E–09		Pb-210	2.8E–08
	U-233	3.9E–08		U-233	1.4E–09		Th-229	6.7E–09
	All	4.9E–06		All	5.4E–06		All	7.3E–08
Water vole (Mammal)	Cl-36	8.9E–09	*Chara sp.* (Aquatic plant)	Ni-59	2.3E–07	Bladder wrack (Macroalgae)	Ni-59	3.0E–08
	Nb-94	4.8E–06		Th-229	2.3E–07		Th-229	5.1E–09
	U-233	5.0E–09		U-233	1.7E–07		Zr-93	2.7E–09
	All	4.8E–06		All	7.1E–07		All	4.0E–08

Table 5-3. The three radionuclides with the highest mean dose rate contributions for the three Reference Organisms with the highest dose rates for each of the three ecosystems at the Forsmark site after a release according to the central corrosion case. All dose rates in µGy h⁻¹.

Ecosystem								
Terrestrial			Freshwater			Marine		
Species	Radio-nuclide	Dose rate	Species	Radio-nuclide	Dose rate	Species	Radio-nuclide	Dose rate
Lichen & bryophytes	Np-237	1.8E–05	Phytoplankton	Np-237	3.2E–03	Polychaete worm	Nb-94	3.7E–08
	Po-210	5.6E–04		Po-210	1.3E–04		Np-237	8.7E–07
	Ra-226	8.3E–05		Ra-226	4.1E–05		Ra-226	1.4E–06
	All	6.7E–04		All	3.4E–03		All	3.0E–06
Shrub	Np-237	5.1E–05	Insect larvae	Np-237	1.6E–03	Phytoplankton	Pu-239	4.6E–07
	Po-210	8.8E–06		Po-210	4.8E–05		Pu-242	9.4E–07
	Ra-226	1.0E–05		Ra-226	1.5E–04		Ra-226	1.0E–06
	All	7.4E–05		All	1.9E–03		All	2.9E–06
Detritivorous invertebrate	Nb-94	7.2E–06	Vascular plant	Np-237	3.4E–04	Benthic mollusc	Nb-94	1.8E–07
	Np-237	1.7E–05		Po-210	1.9E–05		Np-237	8.1E–07
	Ra-226	3.7E–05		Ra-226	1.2E–04		Ra-226	6.4E–07
	All	6.4E–05		All	5.2E–04		All	1.9E–06

5.2 Strengths and weaknesses of the analysis

The present study is based on a large set of data collected over a long time at the actual site of the planned repository, Forsmark. In addition, similar data were collected at the alternate site considered, Laxemar, permitting useful comparisons and providing an illustration of the variability (and therefore, the reliability) of the parameters under investigation.

There are, however, some drawbacks. Unfortunately, the collection of samples and the measurements performed was not fully co-ordinated between the two sites, nor fully consistent over time. Some radionuclides were measured only at one site or only on some of the samples; some of the species were sampled only at one of the sites even though they are present at both sites, and some species were not sampled at all times. Thus, there are data gaps that had to be taken into account in the analysis.

For some of the elements of interest, measurements were made, but were discarded since the values were below detection limits. In some cases, measurements were taken for surrounding media only or for the organism only, so that CR (concentration ratio) levels could not be derived. Neither the ERICA Tool nor the SKB data set included any data concerning Ac-227, Pa-231, or Pd-107, and therefore, these radionuclides could not be included in the dose-rate assessments.

In order to reduce the problem of data gaps, the concept of “Average Organisms” was used as explained in Section 3.4.4. These were created to cover cases where several radionuclides were missing for each “real” species. In a few cases, where measurements on a particular species were almost complete, activity concentrations for a single radionuclide from a similar organism in the same investigation area, ecosystem, and habitat were substituted for the missing value.

It may be mentioned that only samples taken after the 1986 Chernobyl accident were used, so as to avoid inconsistencies due to the absence of Chernobyl fallout before 1986.

5.3 Discussion of the assessment results

Below, Section 5.3.1 focuses on comparison of the results with the criteria used. Section 5.3.2 discusses uncertainties and their influence on the possible conclusions from this study, and Section 5.3.3 concerns suggested future work.

5.3.1 Comparisons of the results with criteria

A comprehensive overview of the numerical criteria for protection of non-human biota proposed by various authors and bodies is provided by /Howard et al. 2010/. In the present study, the default screening dose rate of the ERICA Tool, 10 µGy h^{-1}, was used; this is also the criterion suggested by Howard et al. and is compatible with the Derived Consideration Reference Levels proposed by /ICRP 2008/.

All of the mean dose rates obtained in the present study are several orders of magnitude below this screening value; most mean values are very far below it.

It has not been possible, and in most cases will never be possible, to assess directly dose rates to "red-listed" and other important species as mentioned by the regulatory authority /SSM 2008b/. However, dose rates to similar organisms (Representative Organisms and/or Reference Organisms) have been checked as far as possible. Based on these analyses, it is concluded that the species mentioned by /SSM 2008b/ will also be subject to dose rates well below the screening criterion.

In their study concerning the repository planned at Olkiluoto in Finland, /Hjerpe et al. 2010/ applied a differentiated set of criteria proposed by /Andersson et al. 2009/, *viz*., 2 µGy h^{-1} for vertebrates, 70 µGy h^{-1} for plants, and 200 µGy h^{-1} for invertebrates (i.e. for vertebrates, still far above the dose rates observed in the present study, and for plants and invertebrates these criteria are even less restrictive than the ERICA value).

To some extent, /Howard et al. 2010/ can be seen as a retraction of the differentiated criteria suggested by /Andersson et al. 2009/, but this reversion to the overall criterion of 10 µGy h^{-1} was because the choice of the three groups (vertebrates – plants – invertebrates) was regarded as patchy, not because of any suspicion that, e.g. a plant criterion of 70 µGy h^{-1} would be too lax. The criterion of /UNSCEAR 1996/ for terrestrial plants, 400 µGy h^{-1}, is an order of magnitude higher and thus leaves a further margin.

The screening level derived by ERICA, the Derived Consideration Levels proposed by ICRP, and the upper range of normal natural background dose rates are quite similar. In the appendix (Section A4) analyses are presented for total rather than incremental dose rates, i.e. the background dose rates are included for illustrative purposes. Basically, the conclusion of that exercise is that throughout, the total dose rate is dominated entirely by the component due to background, and that the contribution due to any release from the repository is negligible in comparison with the background.

5.3.2 How important are the uncertainties?

The present study does not consider uncertainties in the concentration of environmental media (release scenario and time, composition, and size of the release; radionuclide transport from the point of release to biota) – these aspects are covered in other parts of the SKB SR-Site project.

Moreover, this study does not consider uncertainties concerning the biological effects of a particular exposure to radiation – those aspects are discussed by, e.g. /UNSCEAR 1996/ and /ICRP 2008/.

Thus, the uncertainties considered here concern the dose rate to an organism expected from a given amount of radioactive material assumed to be present. As indicated in Section 5.2, there are data gaps in the material collected by SKB that forms the basis of the present study: a few radionuclides of interest were not studied; some of the radionuclides were only measured on some of the biota of interest; some of the biota of interest were not, or could not be, studied.

However, these uncertainties are unlikely to have had any major effect on the results obtained. All initial activity concentration data were selected in a "cautious" fashion, i.e. such as to maximise resulting dose rates. All of the Reference Organisms of the ERICA Tool, for which there are no data gaps, had dose rates much below the screening dose rate of 10 $\mu Gy\ h^{-1}$.

Admittedly, the data used for Reference Organisms are not site specific, but sensitivity analyses do not indicate that this has had any great effect on the results, and the dose rates obtained in the present study are in line with the results obtained in studies pertaining to the planned Finnish repository at Olkiluoto /Smith and Robinson 2006, Hjerpe et al. 2010/.

Parts of the uncertainties are due to the fact that for various practical reasons, samples were not always from the actual site area. For instance, some Laxemar data were used to supplement the main body of data; the NORS fish data were from the entire county rather than just from the actual site. However, given that the site environment can be expected to change significantly over the time until a release may happen, such broader sampling could be seen as an advantage rather than as an uncertainty.

Furthermore, there is a considerable amount of additional analyses, not presented here but available on request from the author. Those analyses were performed assuming an alternative release scenario (growing pinhole); an additional alternative (preliminary) set of release parameters, and an alternative site (Laxemar). Some calculations were also performed with imputed data believed to be representative for certain species of theoretical interest, for which no real data were available. None of those analyses give any reason at all to doubt the general results and conclusions obtained in the present study of the central corrosion case, with definitive release parameters, and at Forsmark.

This assessment agrees with that of /Smith and Robinson 2006/, who also concluded that their estimated dose rates were unlikely to be significantly in error (and their uncertainties were larger than those of the present study, not least because the ERICA Tool had not been fully completed at the time of their study).

However, it is prudent to remember that some sources of uncertainty may have been underestimated or entirely neglected. Some such potential uncertainties are relatively easily envisaged: a pathway for radionuclide transport could have been overlooked; there could be an unknown rare peculiarity in the local environment; relatively few species have been investigated; etc. As a complicating factor, we have limited knowledge about effects on populations. This in turn raises the epistemological question whether we know what effects to expect at dose rates just in excess of 10 $\mu Gy\ h^{-1}$. This presents a limitation when assessing the implications of exceeding a "screening dose rate". Given the amount of data that would be required, this limitation is unlikely to be resolved in the near future, if at all.

5.3.3 What remains to be done?

/Smith and Robinson 2006/ suggest that predator-prey relationships should be given continued attention in view of possible accumulation of activity through the food chain, and that possible chemotoxic actions of any release from a repository should be taken into account. These proposals appear reasonable also in a Swedish context.

The possible impact of radium and its daughter nuclides may be insufficiently known in the present study; continued attention to this issue may be warranted.

On the time scales relevant for a geological disposal facility, environments are likely to change significantly in other respects than those relating to radiation. This would be worth further study.

/Smith and Robinson 2006/ also mention the possibility of looking at total lifetime doses, rather than dose rates. This however seems unnecessary at the present stage since all dose rate criteria were chosen with chronic, life-time exposure in mind.

As stated above, it was not possible to demonstrate any appreciable effect of the use of site data on the calculated dose rates, although this may partly reflect that major dose-contributing radionuclides were missing from the site data. The comparison of transfer parameters high-lighted the importance of collecting sufficient measurements from the site, as there were significant and consistent differences between site and ERICA data for a number of radionuclides and organism groups.

5.4 Conclusions

This report assesses the impact on non-human biota of potential radioactive releases from the high-level waste repository planned at Forsmark, in order to ensure that regulatory requirements concerning protection of the environment /SSM 2008b/ are satisfied. The requirements are qualitative: biological diversity and a sustainable utilisation of biological resources are to be protected against harmful effects of ionising radiation. According to the report:

- A “source term” of activity concentrations in environmental media, assuming a release from the repository, was provided as input from another part of the SKB SR-Site project.
- Dose rates to organisms in the environment due to these activity concentrations were computed.
- The organisms studied are representative of the fauna and flora in the area of the planned repository.
- Dose rates to “red-listed” organisms, which could not be studied directly because of the value and vulnerability of each specimen, were estimated using data from similar organisms.
- There were various sources of uncertainty, but it was considered unlikely that any estimated dose rates are significantly in error.
- All dose rates were found to be several orders of magnitude smaller than the established ‘screening dose-rate criterion’ of 10 $\mu Gy\ h^{-1}$, below which the probability of deleterious effects of radiation are judged to be negligible.
- Thus, there is no reason to believe that the regulatory requirements concerning protection of the environment would be exceeded.

6 References

SKB's (Svensk Kärnbränslehantering AB) publications can be found at www.skb.se/publications.

Andersson E (ed), 2010. The limnic ecosystems at Forsmark and Laxemar-Simpevarp. SR-Site Biosphere. SKB TR-10-02, Svensk Kärnbränslehantering AB.

Andersson P, Garnier-Laplace J, Beresford N A, Copplestone D, Howard B J, Howe P, Oughton D, Whitehouse P, 2009. Protection of the environment from ionising radiation in a regulatory context (PROTECT): proposed numerical benchmark values. Journal of Environmental Radioactivity, 100, pp 1100–1108.

Andrén C, 2004. Forsmark site investigation. Amphibians and reptiles. SKB P-04-07, Svensk Kärnbränslehantering AB.

Aquilonius K (ed), 2010. The marine ecosystems at Forsmark and Laxemar-Simpevarp. SR-Site Biosphere. SKB TR-10-03, Svensk Kärnbränslehantering AB.

Avila R, Ekström P-A, Åstrand P-G, 2010. Landscape dose conversion factors used in the safety assessment SR-Site. SKB TR-10-06, Svensk Kärnbränslehantering AB.

Beresford N A, Brown J, Copplestone D, Garnier-Laplace J, Howard B, Larsson CM, Oughton D, Pröhl G, Zinger I (eds), 2007. D-ERICA: An integrated approach to the assessment and management of environmental risk from ionising radiation. Description of purpose, methodology and application. EC contract number FI6R-CT-2004-508847, European Commission, Brussels.

Beresford N A, Barnett C L, Howard B J, Scott W A, Brown J E, Copplestone D, 2008. Derivation of transfer parameters for use within the ERICA Tool and the default concentration ratios for terrestrial biota. Journal of Environmental Radioactivity, 99, pp 1393–1407.

Borgiel M, 2004. Forsmark site investigation. Sampling of freshwater fish. SKB P-04-06, Svensk Kärnbränslehantering AB.

Brown J E, Alfonso B, Avila R, Beresford N A, Copplestone D, Pröhl G, Ulanovsky A, 2008. The ERICA Tool. Journal of Environmental Radioactivity, 99, pp 1371–1383.

Copplestone D, Bielby S, Jones S R, Patton D, Daniel P, Gize I, 2001. Impact assessment of ionising radiation on wildlife. Bristol: Environment Agency. (R & D Publication 128)

Eklöv P, Jonsson P, 2007. Pike predators induce morphological changes in young perch and roach. Journal of Fish Biology, 70, pp 155–164.

Engdahl A, Ericsson U, 2004. Oskarshamn site investigation. Sampling of freshwater fish. Description of the fish fauna in four lakes. SKB P-04-251, Svensk Kärnbränslehantering AB.

Froese R, Pauly D (eds), 2008. FishBase. [Online]. Available at: www.fishbase.org. 2008-08-06.

Gochfeld M, Burger J, Vyas V, 2005. Statistical analysis of data sets with values below detection limits. Appendix 11F. In: Powers C W, Burger J, Kosson D, Gochfeld M, Barnes D (eds). Amchitka independent science assessment: biological and geophysical aspects of potential radionuclide exposure in the Amchitka marine environment: final report of the Consortium for Risk Evaluation with Stakeholder Participation. CRESP Report, August 1, Picataway, New Jersey.

Green M, 2005. Forsmark site investigation. Bird monitoring in Forsmark 2002–2004. SKB P-05-73, Svensk Kärnbränslehantering AB.

Gärdenfors U, 2010. The 2010 redlist of Swedish species. Pp. 590. ISBN 978-91-88506-35-1.

Hammarström T, 2004. Älgen (in Swedish). Stockholm: Max Ström.

Heibo E, Karås P, 2005. Forsmark site investigation. The coastal fish community in the Forsmark area SW Bothnian Sea. SKB P-05-148, Svensk Kärnbränslehantering AB.

Hjerpe T, Ikonen A T K, Broed R, 2010. Biosphere assessment report 2009. Posiva 2010-3, Posiva Oy, Finland.

Howard B J, Beresford N A, Andersson P, Brown J E, Copplestone D, Beaugelin-Seiller K, Garnier-Laplace J, Howe P D, Oughton D, Whitehouse P, 2010. Protection of the environment from ionising radiation in a regulatory context – an overview of the PROTECT coordinated action project. Journal of Radiological Protection, 30, pp 195–214.

IAEA, 1976. Effects of ionizing radiation on aquatic organisms and ecosystems. IAEA Technical Reports Series 172, International Atomic Energy Agency, Vienna.

IAEA, 1988. Assessing the impact of deep sea disposal of low level radioactive waste on living marine resources. IAEA Technical Reports Series 288, International Atomic Energy Agency, Vienna.

IAEA, 1992. Effects of ionising radiation on plants and animals at levels implied by current radiation protection standards. IAEA Technical Reports Series 332, International Atomic Energy Agency, Vienna.

ICRP, 1977. Recommendations of the International Commission on radiological protection. Oxford: Pergamon. (ICRP Publication 26; Annals of the ICRP 1)

ICRP, 1983. Radionuclide transformations: energy and intensity of emissions: report of a task group of committee 2 of the International commission on radiological protection on data used in ICRP publication 30. Oxford: Pergamon. (ICRP Publication 38; Annals of the ICRP 11–13)

ICRP, 2003. A framework for assessing the impact of ionising radiation on non-human species. Oxford: Pergamon. (ICRP Publication 91; Annals of the ICRP 33)

ICRP, 2007. The 2007 recommendations of the International Commission on Radiological Protection. Oxford: Elsevier. (ICRP Publication 103; Annals of the ICRP 37)

ICRP, 2008. Environmental protection: the concept and use of reference animals and plants. Oxford: Elsevier. (ICRP Publication 108; Annals of the ICRP 38)

Jensen B, 2004. Nordens däggdjur. 2nd ed. Stockholm: Prisma.

Kelly M, Thorne M, 2003. Radionuclides Handbook. R&D Technical Report P3-101/SP1b, Environment Agency, Bristol, UK.

Kumblad L, Bradshaw C, 2008. Element composition of biota, water and sediment in the Forsmark area, Baltic Sea. Concentrations, bioconcentration factors and partitioning coefficients (K_d) of 48 elements. SKB TR-08-09, Svensk Kärnbränslehantering AB.

Larsson C-M, 2004. The FASSET Framework for assessment of environmental impact of ionising radiation in European ecosystems – an overview. Journal of Radiological Protection, 24, pp 1–177.

Lindborg T (ed), 2006. Description of surface systems. Preliminary site description Laxemar subarea – version 1.2. SKB R-06-11, Svensk Kärnbränslehantering AB.

Lindborg T (ed), 2010. Landscape Forsmark – data, methodology and results for SR-Site. SKB TR-10-05, Svensk Kärnbränslehantering AB.

Löfgren A (ed), 2010. The terrestrial ecosystems at Forsmark and Laxemar-Simpevarp. SR-Site Biosphere. SKB TR-10-01, Svensk Kärnbränslehantering AB.

NORS, 2010. Nationellt register över sjöprovfisken – NORS. [Online]. Available at: https://www.fiskeriverket.se/vanstermeny/statistikochdatabaser/provfiskeisotkustvatten/provfiskeisjoar/databasforsjoprovfiske. 2008-08-06.

Olsen Y S, Vives i Batlle J, 2003. A model for bioaccumulation of ^{99}Tc in lobsters (Homarus gammarus) from the West Cumbrian coast. Journal of Environmental Radioactivity, 67, pp 219–33.

Pröhl G (ed), 2003. Dosimetric models and data for assessing radiation exposures to biota. Deliverable 3. FASSET Framework for the Assessment of Environmental Impact. EC contract number FIGE-CT-2000-00102, European Commission, Brussels.

Roos P, Engdahl A, Karlsson S, 2007. Oskarshamn and Forsmark site investigations. Analysis of radioisotopes in environmental samples. SKB P-07-32, Svensk Kärnbränslehantering AB.

SKB, 2007. FUD-program 2007. Program för forskning, utveckling och demonstration av metoder för hantering och slutförvaring av kärnavfall (in Swedish). Svensk Kärnbränslehantering AB.

SKB, 2008. Site description of Forsmark at completion of the site investigation phase. SDM-Site Forsmark. SKB TR-08-05, Svensk Kärnbränslehantering AB.

SKB, 2009. Site description of Laxemar at completion of the site investigation phase. SDM-Site Laxemar. SKB TR-09-01, Svensk Kärnbränslehantering AB.

SKB, 2010. Biosphere analyses for the safety assessment SR-Site – synthesis and summary of results. SKB TR-10-09, Svensk Kärnbränslehantering AB.

SKB, 2011. Long-term safety for the final repository for spent nuclear fuel at Forsmark. Main report of the SR-Site project. SKB TR-11-01, Svensk Kärnbränslehantering AB.

Smith K, Robinson C, 2006. Assessment of doses to non-human biota: review of developments and demonstration assessment for Olkiluoto repository. Posiva Working Report 2006-112, Posiva Oy, Finland.

SSM, 2008a. Strålsäkerhetsmyndighetens föreskrifter och allmänna råd om säkerhet vid slutförvaring av kärnämne och kärnavfall (in Swedish). Stockholm: Strålsäkerhetsmyndigheten (Swedish Radiation Safety Authority). (SSMFS 2008:21)

SSM, 2008b. Strålsäkerhetsmyndighetens föreskrifter och allmänna råd om skydd av människors hälsa och miljön vid slutligt omhändertagande av använt kärnbränsle och kärnavfall (in Swedish). Stockholm: Strålsäkerhetsmyndigheten (Swedish Radiation Safety Authority). (SSMFS 2008:37)

Takata H, Aono T, Tagami K, Uchida S, 2010. Concentration ratios of stable elements for selected biota in Japanese estuarine areas. Radiatation and Environmental Biophysics, 49, pp 591–601.

Truvé J, Cederlund G, 2005. Mammals in the areas adjacent to Forsmark and Oskarshamn. Population density, ecological data and carbon budget. SKB R-05-36, Svensk Kärnbränslehantering AB.

Tröjbom M, Grolander S, 2010. Chemical conditions in present and future ecosystems in Forsmark. Implications for selected radionuclides in the safety assessment SR-Site. SKB R-10-27, Svensk Kärnbränslehantering AB.

Tröjbom M, Nordén S, 2010. Chemistry data from surface ecosystems in Forsmark and Laxemar-Simpevarp. Site specific data used for estimation of CR and Kd values in SR-Site. SKB R-10-28, Svensk Kärnbränslehantering AB.

UN, 1972. Declaration of the United Nations Conference on the human environment. [Online]. Available at: http://www.unep.org/Documents.Multilingual/Default.asp?documentid=97&articleid=1503. 2010-11-05.

UNSCEAR, 1996. Sources and effects of ionizing radiation. Report to the General Assembly. New York: United Nations. (UN Sales Publication E.96.IX.3.)

US DoE, 2002. A graded approach for evaluating radiation doses to aquatic and terrestrial biota. Technical Standard DoE-STD-1153-2002, U.S. Deptartment of Energy, Washington D.C.

Viltdata, 2010. Välkommen till viltdata.se. [Online]. Available at: www.viltdata.se. 2008-08-06.

Vives i Batlle J, Beaugelin-Seiller K, Beresford N A, Copplestone D, Horyna J, Hosseini A, Johansen M, Kamboj S, Keum D-K, Kurosawa N, Newsome L, Olyslaegers G, Vandenhove H, Vives Lynch S, Wood M D, Yu C, 2011. The estimation of absorbed dose rates for non-human biota: an extended intercomparison. Radiatation and Environmental Biophysics, doi:10.1007/s00411-010-0346-5.

Wilson R C, Vives i Batlle J, Watts S J, McDonald P, Jones S R, Vives-Lynch S M, Craze A, 2010. An approach for the assessment of risk from chronic radiation to populations of phytoplankton and zooplankton. Radiatation and Environmental Biophysics, 4, pp 87–95.

Appendix A

This Section contains details and background information. Section A1 concerns Dose Conversion Coefficients, Section A2 describes the Concentration Ratios, Section A3 comprises detailed dose rate results, and Section A4 discusses the total dose rates of background and releases combined. Section A5 provides some supplementary information with respect to (a) an alternative (preliminary) set of release data, and (b) data concerning Laxemar organisms.

A1 Parameters used to calculate Dose Conversion Coefficients (DCCs)

This Section provides details of the habitats and sizes of the various organisms assessed using the ERICA Tool, and a discussion of parameter selections in “difficult” cases (cf. Section 3.7).

A1.1 Habitats and sizes

Table A-1. All organisms that were added to the ERICA Tool, shown with their occupancy factors (habitat and fraction of time), size parameters, and masses. (F = freshwater, M = marine).

Organism	Occupation factor Habitat		Length (m)	Width (m)	Height (m)	Mass (kg)
Representative Species from the sites						
Alder	On soil	1.0	10.0	0.30	0.30	471.0
Baltic macoma	Sediment	1.0	0.027	0.019	0.0096	0.00258
Bank vole	On soil/in soil	0.5/0.5	0.105	0.035	0.035	0.0275
Bilberry	on soil	1.0	0.2	0.01	0.01	0.01047
Bladder wrack	Water	1.0	0.2	0.01	0.0020	0.002094
Bleak	Water	1.0	0.2	0.0375	0.01875	0.0736
Blue mussel	Water	1.0	0.03	0.015	0.01	0.00236
Bream	Water	1.0	0.196	0.0623	0.0146	0.116
Brown algae	Water	1.0	0.2	0.0020	0.0020	4.19E–4
Chara	Water	1.0	0.1	0.0020	0.0020	2.094E–4
Common Reed	Water surface/water	0.625/0.375	3.0	0.015	0.015	0.353
Common shrew	On soil/in soil	0.5/0.5	0.065	0.02	0.02	0.014
Duck mussel	Sedimt. surface/sedimt.	0.5/0.5	0.1	0.025	0.05	0.0654
Fennel pondweed	Water	1.0	0.2	0.0020	0.0020	4.19E–4
Flounder	Sediment surface	1.0	0.4	0.0248	0.156	0.723
Green algae	Water	1.0	0.1	0.0010	0.0010	5.236E–5
Herring	Water	1.0	0.2	0.0156	0.0375	0.0613
Idothea	Sediment surface	1.0	0.03	0.01	0.0050	7.85E–4
Lagoon cockle	Sediment surface	1.0	0.01	0.01	0.005	2.62E–4
Microphytes	Water	1.0	5.00E–5	5.00E–5	5.00E–5	6.54E–11
Moose 350 kg	On soil	1.0	1.75	0.47	0.81	350.0
Moose 500 kg	On soil	1.0	1.8	0.49	1.08	500.0
Norwegian spruce	On soil	1.0	10.0	0.30	0.30	471.0
Oak	On soil	1.0	10.0	0.30	0.30	471.0
Perch	Water	1.0	0.122	0.0146	0.0315	0.02938
Phytoplankton	Water	1.0	5.00E–5	5.00E–5	5.00E–5	6.54E–11
Pike	Water	1.0	0.484	0.0401	0.0687	0.699
Red fox	On soil/in soil	0.5/0.5	0.69	0.08	0.25	6.6
River nerite	Water	1.0	0.01	0.0050	0.0050	1.31E–4
Roach	Water	1.0	0.125	0.0134	0.03125	0.02739
Roe deer	On soil	1.0	0.9	0.18	0.34	28.0
Ruffe	Water	1.0	0.086	0.0063	0.0211	0.00598
Small cow-wheat	On soil	1.0	0.2	0.0050	0.0050	0.00262
Smelt	Water	1.0	0.25	0.045	0.036	0.186
Stone bramble	On soil	1.0	0.25	0.0050	0.0050	0.0033
Tench	Water/sedimt. surface	0.5/0.5	0.44	0.082	0.163	3.06
Water lily	Water	1.0	3.0	0.015	0.015	0.353
Water vole	On soil/in soil	0.5/0.5	0.18	0.05	0.05	0.12
Wood mouse	On soil/in soil	0.5/0.5	0.085	0.034	0.034	0.025
Y-necked mouse	On soil/in soil	0.5/0.5	0.11	0.0367	0.0367	0.0375
Zoo plankton	Water	1.0	0.0062	0.0061	0.0031	6.14E–5
Average Organisms						
Average bryophyte[1]	On soil	1.0	0.0401	0.00229	0.00229	0.0011
Average fish (F)	Water	1.0	0.2174	0.0219	0.0487	0.121
Average fish (M)	Water	1.0	0.1684	0.017	0.0382	0.0573
Average mollusc	Water/sedimt. surface/sedimt.	0.33/0.34/ 0.33	0.0156	0.0113	0.0065	0.001035
Average mushroom[2]	On soil	1.0	0.1	0.02	0.02	0.02
Average phytoplankton	Water	1.0	5.00E–5	5.00E–5	5.00E–5	6.54E–11
Average rodent	On soil/in soil	0.5/0.5	0.1092	0.0354	0.0354	0.0436
Average tree	On soil	1.0	10.0	0.30	0.30	471.0
Average vascular plant	On soil	1.0	0.2167	0.0067	0.0067	0.00545

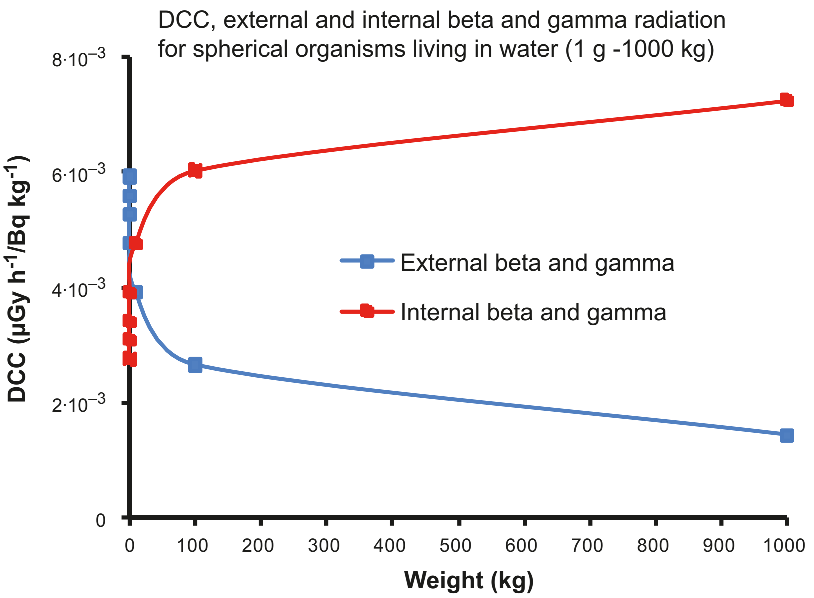
[1] Average bryophytes include all moss species due to the similarity of the parameters.
[2] Mushrooms have been compiled into one Average mushroom with one type of size. See Section A1.2 for details.

A1.2 Parameter considerations and picture analysis

Where possible, parameter values (length, height, width, mass) were obtained from published sources. However, for some of the organisms, information was collected from web-based databases. In particular, mass and/or length data were selected from the Swedish fish database /NORS 2010/, operated by the Swedish Board of Fisheries (a subordinate of the Ministry of Agriculture), and from the Swedish game database /Viltdata 2010/, operated by the Swedish Association for Hunting and Wildlife Management in co-operation with the County Administrative Boards, the Swedish Environmental Protection Agency, and other bodies.

Thus, NORS is operated by a government agency and Viltdata is operated in collaboration with government organisations. Nevertheless, a problem with web databases is that information may be changed or removed from the source.

However, neither weights nor other parameters appear to influence the dose rates to the organisms assessed to any great extent in the present study (cf. Section 4.1.2 and Figure A-1). The resulting mean values were also compared with generic data in the ERICA tool and from literature. No major differences were found.



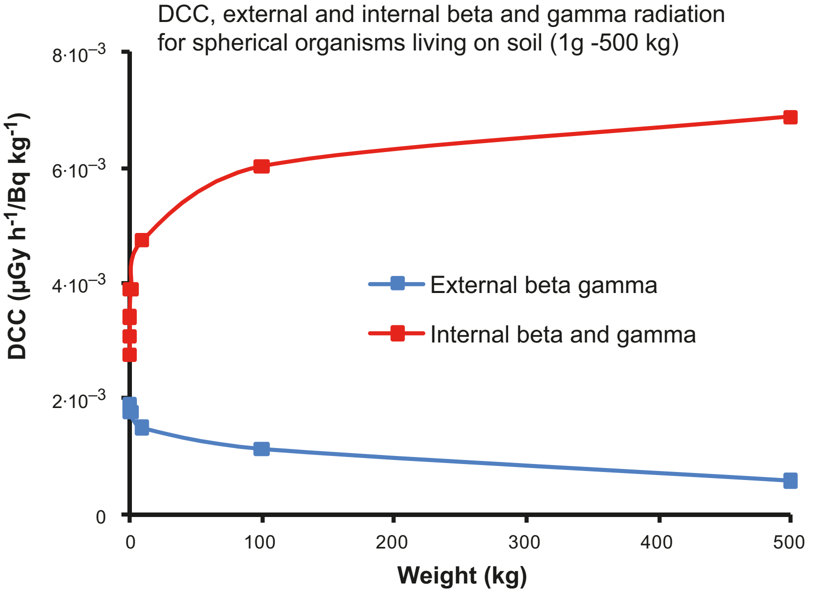


Figure A-1. *DCC and size dependence for hypothetical, spherical, aquatic (upper frame) or terrestrial (lower frame) organisms (mammals). Weights include masses of 1, 10, and 100 gram and 1, 10, 100, 500, and, for aquatic organisms, 1,000 kg (maximum weights are dictated by the ERICA Tool). DCCs are the sum of DCCs from all radionuclides considered in the assessment presented in Table 3-1*

In Table A-2, some specific cases are discussed. For most of the species, size parameters were missing for at least one of three dimensions needed to get a final shape of an ellipsoidal volume. To get as accurate estimations as possible, ratios from at least 10 pictures per organism were measured. With this information, volumes could be estimated if at least one real size parameter was available. Inevitably, the size measurements were somewhat subjective, but as discussed above and in Section 4.1.2, the influence of size on DCC values or the final dose rate is limited.

Table A-2. Comments on size and weight parameter analysis of some organisms where complete information was not easily available.

Organism	Comments
Mammals	Most data are for adults only and the mean DCCs here are restricted to the adult morphology. /Hammarström 2004/ and /Jensen 2004/ reported mean masses around 500 kg (males) and 350 kg (females); both 500 kg and 350 kg were used to calculate DCC. Due to ambiguous names of some bank voles, bank vole data were compiled to an "average rodent" with water vole, wood mouse, yellow-necked mouse and common shrew (all regarded as closely related). Activity concentrations for these species were similar.
Fish	Most mean values are taken from adults. However, means are very variable: a fish continues to grow during its entire lifetime and may attain an extreme size under optimal conditions. Also, sizes vary between lakes with varying degrees of predator threats /Eklöv and Jonsson 2007/. However, the influence of size on dose rate is limited, see above. Values for freshwater fish were obtained from 93 lakes in Uppsala county, which includes Forsmark /NORS 2008/. For marine fishes, values for bleak, flounder, herring, and smelt were determined using "FishBase" /Froese and Pauly 2008/; for bream, perch, roach, and ruffe values for freshwater specimens of the same species were taken from /NORS 2008/. These data were similar to smaller samples from Forsmark /Borgiel 2004/ and Laxemar /Engdahl and Ericsson 2004/. Data taken form SKB's database Sicada[1].
Molluscs	Only data from soft tissues was considered. An "average mollusc" was created for the marine habitat at Forsmark. Baltic macoma is the only organism that occupies sediment (occupancy factor 1.0), since it is buried almost entirely in the sediment, others are half-buried in sediment (0.5/0.5). The "average mollusc" has a mixed occupancy factor from all three habitats: water, sediment surface, and sediment (0.33/0.34/0.33)
Crustaceans	One species, Idothea, was measured. Comparison to the Reference crustacean in the ERICA Tool probably is not useful since the only marine reference species is a crab with a mass of 0.754 kg (the mass of Idothea is less than 1 gram).
Terrestrial plants	The size of plants and trees is especially difficult to estimate due to varying morphology. For simplicity, alder, oak, and spruce were all assumed to have the same size and mass as the ERICA Reference (pine) Tree. In keeping with the ERICA Reference assumptions, only samples of woody parts were taken into account.
Bryophytes	Length was derived from the ERICA Reference Bryophyte. The TS values varied much between samples: TS = 0.194, 0.881, 0.889.
Mushrooms	It was not possible to estimate the size of the mycelium, and all elemental concentration data came from fruiting body parts. The same size was assigned to the fruiting bodies of all 13 species studied (0.1·0.02·0.02 m). There is no ERICA Reference Mushroom, so parameters were taken from Lichen & moss.
Aquatic plants	Only the stems of the plants were taken into account to get approximate lengths, with the simplification that branches were regarded as small stems.
Plankton	The ERICA Reference zoo- or phytoplankton characteristics, as appropriate, were assigned to all plankton; microphytes were also given Reference phytoplankton data.

[1] SKB's database Sicada, access might be given on request.

A2 Detailed results concerning Concentration Ratios (CR)

Section A2.1 discusses the details of dry weight / wet weight conversions, which are required in the computation of CRs. Section A2.2 provides a full list of all CR values obtained.

A2.1 Dry weight / fresh weight conversions

As explained in Section 3.8.1, values of the TS conversion factors (= dry weight / fresh weight) were calculated from dry and fresh weight data available from Forsmark and, to some extent, Laxemar. Table A-33 provides a compilation of the TS factors.

A2.2 Complete set of CR values obtained in this study

Section 4.2 (Results) presents an overview of the main findings with respect to Concentration Ratios. The present Section includes all the CR values that were determined in this study (i.e. for Representative Species from the site and Average Organisms) or used (i.e. default CR values for the Reference Organisms provided in the ERICA Tool). In Tables 7-4 to 7-12, CRs for terrestrial organisms are computed as kg_{dw}/kg_{fw} and are, thus, dimensionless; the unit of CRs for aquatic organisms is l/kg_{fw}.

The results include CR values not just for the selected site, Forsmark, but also for the alternate site, Laxemar. It is hoped that to some extent, the availability of this additional information will reduce the uncertainties that are due to the relative paucity of data. As indicated in Section 3.4.2, the number of samples of each species is small. Furthermore, unfortunately the criteria for collection of samples do not seem to have been very strict. Thus, most samples were only investigated with respect to some, not all, of the radionuclides of interest, and some of the species were collected only at one of the two sites.

The tables of CR values given below are organised as follows:

Organism set	Habitat	Forsmark	Laxemar
Representative Species from the site and; Average Organisms	Terrestrial	Table A-4	Table A-5
	Freshwater	Table A-6	Table A-7
	Marine	Table A-8	Table A-9

Organism set	Habitat	–
Reference Organisms	Terrestrial	Table A-10
	Freshwater	Table A-11
	Marine	Table A-12

Table A-3. Conversion factors, TS = dry weight / fresh weight, for all organisms that were added to the ERICA Tool (F = freshwater, M = marine). Data from Forsmark (and Laxemar if there is a 2nd value).

Organism	TS	Organism	TS
Representative Species from the sites			
Alder	0.45	Moose	0.25, 0.27
Baltic macoma	0.33**	Norwegian spruce	0.34, 0.46
Bank vole	0.26, 0.24	Oak	0.64
Bilberry	0.34	Perch	n.a., 0.21*
Bladder wrack	0.26	Phytoplankton	0.02**
Bleak	0.24	Pike	0.20
Blue mussel	0.05	River nerite	0.33
Bream	0.22	Roach	0.20
Brown algae	0.08**	Roe deer	0.26
Chara	0.17	Ruffe	0.19
Common Reed	0.66	Small cow-wheat	0.14
Common shrew	0.28, 0.30	Smelt	0.20
Duck mussel	0.04, 0.05	Stone bramble	0.21
Fennel pondweed	0.12	Tench	0.20
Flounder	0.20	Water lily	0.13
Green algae	0.10	Water vole	0.23
Herring	0.22	Wood mouse	0.25
Idothea	0.17**	Yellow-necked mouse	0.26
Lagoon cockle	0.31**	Zoo plankton	0.01**
Microphytes	0.02**		
Average Organisms:			
Average bryophyte	0.63	Average phytoplankton	0.02
Average fish (F)	0.20, 0.20	Average rodent	0.27, 0.26
Average fish (M)	0.20, 0.22	Average tree	n.a., 0.52
Average mollusc	0.33	Average vascular plant	0.23
Average mushroom	0.10		

* This TS value for Laxemar perch refers to freshwater; the TS value for marine Laxemar perch is 0.23.
** TS-values from /Kumblad and Bradshaw 2008/.

Table A-4. Concentration Ratios for terrestrial Representative Species from the site and Average Organisms found at Forsmark. (–) = no data available.

Element	Bank vole		Bilberry		Common shrew		Moose		Red fox		Small cow-wheat		Spruce	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Ag	–	–	–	–	–	–	–	–	–	–	3.5E–03	4.7E–04	7.0E–03	1.5E–03
Ca	2.7E–02	1.3E–02	2.0E–01	7.7E–02	6.2E–02	2.1E–02	2.7E–03	1.0E–03	3.6E–03	1.2E–03	2.6E–01	8.8E–02	1.0E–01	8.2E–02
Cl	3.4E+01	2.8E+01	5.3E+01	5.6E+01	5.0E+01	4.0E+01	4.4E+00	3.9E+00	9.6E+00	7.7E+00	7.2E+01	5.8E+01	4.0E+01	4.4E+01
Cs	1.3E–01	1.8E–01	1.5E–01	7.4E–01	3.7E–02	2.5E–02	3.6E–02	3.4E–02	8.3E–02	5.6E–02	2.2E–01	1.5E–01	3.5E–03	3.2E–03
Ho	–	–	–	–	–	–	–	–	–	–	–	–	–	–
I	–	–	4.2E–02	1.6E–02	1.4E–01	5.4E–02	–	–	–	–	3.8E–02	1.4E–02	–	–
Nb	6.6E–02	8.6E–02	4.5E–04	3.2E–04	6.0E–04	3.6E–04	4.1E–05	3.1E–05	1.3E–04	8.0E–05	2.2E–04	1.3E–04	3.4E–04	2.1E–04
Ni	2.2E–02	4.2E–02	4.5E–02	7.9E–02	–	–	–	–	2.6E–02	4.6E–02	1.5E–01	2.6E–01	1.7E–02	3.1E–02
Pb	–	–	3.1E–03	1.5E–03	3.6E–03	9.7E–04	–	–	8.1E–03	2.2E–03	1.6E–03	4.2E–04	4.2E–03	1.9E–03
Se	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Sm	–	–	5.3E–04	4.0E–04	–	–	–	–	–	–	2.6E–04	1.7E–04	–	–
Sn	–	–	–	–	–	–	3.1E–03	1.5E–03	8.1E–03	4.0E–03	–	–	–	–
Sr	1.1E–03	7.0E–04	3.5E–02	1.4E–02	1.6E–03	5.7E–04	2.3E–04	7.9E–05	2.4E–04	8.3E–05	8.8E–02	3.0E–02	5.4E–02	4.5E–02
Th	–	–	–	–	–	–	–	–	–	–	–	–	–	–
U	–	–	6.1E–04	9.2E–04	1.0E–03	7.9E–04	9.5E–06	7.5E–06	5.0E–05	4.0E–05	3.4E–04	2.7E–04	–	–
Zr	4.9E–04	2.7E–04	1.9E–04	1.9E–04	1.7E–04	9.3E–05	–	–	3.4E–04	1.8E–04	1.7E–04	9.0E–05	–	–

	Stone bramble		Water vole		Yellow-necked mouse		Average moss		Average mushroom		Average rodent		Average vasc. plant	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Ag	–	–	–	–	–	–	4.7E–03	6.3E–04	–	–	–	–	5.6E–03	7.5E–04
Ca	1.8E–01	6.5E–02	1.4E–02	8.6E–03	1.5E–02	4.9E–03	5.1E–01	4.2E–01	5.8E–03	1.1E–02	2.2E–02	1.5E–02	2.2E–01	1.4E–01
Cl	1.9E+02	1.8E+02	3.0E+01	2.4E+01	2.5E+01	2.0E+01	7.4E+01	1.9E+02	–	–	3.4E+01	2.9E+01	1.4E+02	2.5E+02
Cs	7.7E–03	9.9E–03	1.0E–02	8.0E–03	9.2E–02	6.2E–02	1.0E–01	9.2E–02	4.7E+00	1.6E+01	2.6E–02	4.4E–02	1.4E–01	1.0E+00
Ho	–	–	–	–	–	–	3.0E–02	5.8E–02	–	–	–	–	–	–
I	2.2E+00	1.5E+01	–	–	–	–	9.6E–01	7.2E–01	4.6E–03	5.4E–03	1.3E–01	5.0E–02	7.6E–01	1.9E+00
Nb	6.4E–04	4.4E–04	3.0E–04	3.0E–04	–	–	5.3E–02	1.1E–01	–	–	2.4E–02	5.5E–01	4.7E–04	4.1E–04
Ni	5.5E–02	9.9E–02	–	–	2.1E–02	3.7E–02	4.0E–01	7.6E–01	2.1E–02	2.5E–02	2.1E–02	3.9E–02	8.5E–02	2.3E–01
Pb	1.5E–03	7.7E–04	–	–	–	–	1.8E–01	9.5E–02	1.9E–03	2.2E–03	3.3E–03	8.9E–04	2.0E–03	9.0E–04
Se	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Sm	4.2E–04	3.7E–04	–	–	–	–	6.9E–02	1.8E–01	–	–	–	–	4.0E–04	3.0E–04
Sn	5.2E–03	2.6E–03	–	–	–	–	1.0E–01	7.9E–02	–	–	–	–	5.7E–03	2.8E–03
Sr	3.9E–02	2.7E–02	9.3E–04	6.9E–04	5.3E–04	1.8E–04	2.0E–01	1.5E–01	7.8E–03	1.5E–02	1.0E–03	7.1E–04	5.5E–02	5.8E–02
Th	–	–	–	–	–	–	4.8E–02	8.2E–02	8.0E–04	1.5E–03	–	–	–	–
U	1.3E–03	2.7E–03	1.3E–04	1.1E–04	7.7E–05	6.1E–05	3.8E+00	1.8E+02	1.2E–02	2.0E–01	2.1E–04	2.9E–04	7.3E–04	1.1E–03
Zr	1.8E–04	1.1E–04	2.4E–04	1.6E–04	1.7E–04	9.0E–05	3.6E–02	9.9E–02	–	–	2.8E–04	2.1E–04	1.9E–04	1.6E–04

Table A-5. Concentration Ratios for terrestrial Representative Species from the site and Average Organisms found at Laxemar. (–) = no data available.

Element	Alder		Bank vole (field)		Bank vole (forest)		Common shrew		Moose		Oak		Red fox		Roe deer	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Ag	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Ca	7.4E–01	5.6E–01	3.7E–02	3.1E–02	1.5E–01	2.6E–01	1.8E–01	1.3E–01	1.5E–02	1.2E–02	7.3E+00	5.5E+00	1.2E–02	9.7E–03	1.4E–02	1.1E–02
Cl	1.7E+01	1.1E+02	3.2E+01	4.4E+02	3.2E+01	2.2E+02	6.0E+00	4.0E+01	1.0E+01	7.3E+01	1.9E+01	1.3E+02	1.6E+01	1.1E+02	1.3E+01	8.8E+01
Cs	5.8E–03	7.6E–03	1.2E–01	2.4E–01	1.5E+00	3.4E+00	2.1E–01	2.8E–01	3.1E–01	6.6E–01	1.3E–02	1.8E–02	8.7E–01	1.3E+00	1.8E+00	2.9E+00
Ho	3.2E–04	2.2E–04	–	–	2.3E–04	1.6E–04	–	–	–	–	3.8E–03	2.6E–03	–	–	–	–
I	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Nb	1.2E–03	2.5E–03	3.7E–04	8.1E–04	8.3E–04	2.0E–03	2.4E–03	4.8E–03	1.3E–04	2.8E–04	4.0E–03	8.1E–03	2.9E–04	6.4E–04	1.3E–04	2.8E–04
Ni	8.9E–02	5.2E–02	2.4E–03	1.4E–03	3.0E–03	4.3E–03	2.2E–03	1.3E–03	–	–	8.2E–02	4.8E–02	–	–	7.8E–04	4.6E–04
Pb	1.3E–03	4.0E–04	–	–	5.7E–04	1.8E–04	3.3E–03	9.8E–04	2.3E–03	6.8E–04	8.2E–03	2.4E–03	4.4E–04	1.3E–04	–	–
Se	–	–	6.3E–02	7.3E–02	1.2E–01	4.2E–02	2.9E–01	6.1E–02	4.4E–02	1.1E–02	–	–	9.1E–02	2.0E–02	8.1E–02	1.8E–02
Sm	3.3E–04	2.3E–04	3.8E–05	3.2E–05	5.0E–05	7.0E–05	2.5E–04	1.8E–04	2.2E–05	1.5E–05	6.9E–03	4.8E–03	2.6E–05	1.9E–05	–	–
Sn	4.3E–02	5.0E–02	3.5E–02	4.0E–02	2.3E–02	2.7E–02	4.0E–02	4.6E–02	2.6E–01	3.1E–01	–	–	2.2E–01	2.6E–01	2.0E–01	2.4E–01
Sr	8.3E–01	9.6E–01	2.9E–03	4.0E–03	4.8E–03	8.8E–03	6.5E–03	7.5E–03	4.9E–04	5.6E–04	1.3E+00	1.5E+00	6.4E–04	8.5E–04	4.7E–04	5.5E–04
Th	–	–	2.1E–03	3.2E–03	–	–	1.2E–02	1.8E–02	–	–	–	–	–	–	–	–
U	7.4E–01	5.6E–01	4.5E–05	4.4E–05	6.4E–05	7.5E–05	3.9E–04	3.7E–04	–	–	7.3E+00	5.5E+00	5.2E–05	6.3E–05	–	–
Zr	1.7E+01	1.1E+02	1.0E–03	2.9E–03	6.2E–04	1.0E–03	4.2E–03	6.9E–03	1.1E–04	1.8E–04	1.9E+01	1.3E+02	9.6E–05	1.6E–04	7.9E–05	1.3E–04

	Spruce		Wood mouse		Average rodent		Average tree	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Ag	1.1E–01	1.0E–02	–	–	–	–	1.2E–01	1.1E–02
Ca	5.3E+00	4.0E+00	3.4E–02	3.6E–02	8.1E–02	1.3E–01	5.8E+00	1.2E+01
Cl	9.7E+00	6.6E+01	7.2E+00	4.9E+01	2.1E+01	2.0E+02	1.6E+01	1.1E+02
Cs	1.4E–01	1.9E–01	5.0E–01	8.5E–01	7.3E–01	2.2E+00	1.0E–01	7.2E–01
Ho	–	–	–	–	2.4E–04	1.7E–04	3.3E–03	1.2E–02
I	–	–	–	–	–	–	–	–
Nb	1.2E–03	2.6E–03	2.8E–04	6.3E–04	7.0E–04	2.0E–03	2.1E–03	1.4E–02
Ni	1.7E–02	1.0E–02	1.5E–03	8.7E–04	2.4E–03	2.3E–03	7.4E–02	9.9E–02
Pb	4.5E–03	1.3E–03	–	–	1.6E–03	2.0E–03	5.0E–03	5.0E–03
Se	–	–	7.9E–02	5.1E–02	1.1E–01	9.7E–02	–	–
Sm	2.0E–04	1.4E–04	–	–	7.8E–05	1.2E–04	3.5E–03	1.8E–02
Sn	–	–	4.4E–02	5.5E–02	3.8E–02	4.8E–02	4.9E–02	5.7E–02
Sr	1.4E+00	1.7E+00	6.1E–04	8.1E–04	3.4E–03	8.6E–03	1.2E+00	1.5E+00
Th	1.1E–01	1.0E–02	2.9E–03	5.0E–03	4.4E–03	9.3E–03	1.2E–01	1.1E–02
U	5.3E+00	4.0E+00	3.1E–05	3.0E–05	7.7E–05	1.2E–04	5.8E+00	1.2E+01
Zr	9.7E+00	6.6E+01	1.6E–03	3.1E–03	1.4E–03	3.3E–03	1.6E+01	1.1E+02

Table A-6. Concentration Ratios for freshwater Representative Species from the site and Average Organisms found at Forsmark. (–) = no data available.

Element	Chara		Duck mussel		Pike		Roach		Ruffe		Tench		Average fish	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Ag	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Ca	6.3E+02	3.0E+02	6.4E+01	3.8E+01	1.8E+01	8.9E+00	1.6E+01	9.7E+00	4.1E+00	9.3E–01	7.3E+00	7.0E+00	1.2E+01	6.5E+00
Cl	2.2E+01	9.9E+01	1.4E+01	4.1E+01	3.2E+01	9.0E+01	1.4E+02	4.1E+02	1.6E+02	4.5E+02	5.1E+01	1.5E+02	1.1E+02	3.2E+02
Cs	6.1E+02	1.7E+03	1.3E+02	3.9E+02	5.3E+03	1.6E+04	1.5E+03	7.3E+03	2.0E+03	4.8E+03	1.8E+03	5.3E+03	2.9E+03	9.4E+03
Ho	6.8E+02	3.6E+02	7.6E+01	2.8E+01	–	–	–	–	–	–	–	–	–	–
I	3.1E+02	2.1E+02	4.6E+01	2.6E+01	5.0E+01	2.8E+01	–	–	–	–	–	–	5.0E+01	2.8E+01
Nb	1.2E+03	5.9E+02	2.0E+02	9.8E+01	9.7E+00	6.0E+00	–	–	–	–	1.2E+01	5.5E+00	9.7E+00	6.0E+00
Ni	3.3E+02	1.3E+02	6.0E+01	2.5E+01	–	–	–	–	–	–	–	–	–	–
Pb	4.8E+03	3.7E+03	2.6E+03	2.4E+03	–	–	–	–	–	–	–	–	–	–
Se	3.9E+02	1.2E+02	7.1E+02	4.9E+01	5.3E+02	1.6E+02	2.1E+02	1.2E+01	2.2E+02	–	8.4E+02	1.3E+02	3.2E+02	5.6E+01
Sm	1.9E+03	1.8E+03	2.5E+02	2.4E+02	–	–	–	–	–	–	–	–	–	–
Sn	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Sr	4.2E+02	1.1E+03	9.4E+01	2.8E+02	5.0E+00	1.3E+01	1.3E+01	7.1E+01	9.8E–01	2.5E+00	4.2E+00	1.6E+01	6.3E+00	2.9E+01
Th	1.5E+03	4.8E+03	2.8E+02	6.4E+02	–	–	–	–	–	–	–	–	–	–
U	9.2E+01	7.9E+01	7.9E+00	6.9E+00	6.6E–02	1.0E–01	4.3E–01	3.5E–01	–	–	2.2E–01	5.4E–01	2.5E–01	2.7E–01
Zr	5.1E+02	8.6E+02	6.8E+01	9.7E+01	–	1.8E+02	1.3E+02	1.8E+02	–	–	–	–	1.3E+02	1.8E+02

Table A-7. Concentration Ratios for freshwater Representative Species from the site and Average Organisms found at Laxemar. (–) = no data available.

Element	Duck mussel		Perch		Reed		Roach		Water lily		Average fish	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Ag	6.8E+02	4.6E+01	–	–	–	–	–	–	–	–	–	–
Ca	2.6E+02	4.7E+01	5.6E+01	6.3E+01	2.3E+02	1.2E+02	6.3E+01	9.0E+00	4.0E+02	6.2E+01	5.8E+01	4.4E+01
Cl	4.0E+01	5.9E+00	2.9E+01	5.7E+00	3.9E+02	2.0E+02	1.7E+01	3.3E+00	8.7E+01	2.2E+01	2.2E+01	7.3E+00
Cs	2.6E+02	6.4E+01	2.4E+04	3.6E+03	4.5E+03	4.9E+02	4.1E+03	8.1E+02	7.4E+02	9.0E+01	1.5E+04	1.8E+04
Ho	3.8E+02	5.1E+02	2.2E+01	2.9E+01	6.6E+01	1.0E+02	2.2E+01	2.9E+01	8.8E+01	1.4E+02	2.1E+01	2.7E+01
I	4.5E+01	5.7E+01	1.0E+02	1.3E+02	2.4E+02	3.6E+02	3.8E+01	4.7E+01	1.8E+02	2.4E+02	6.8E+01	1.0E+02
Nb	1.2E+02	1.2E+02	4.4E+00	3.9E+00	2.0E+02	1.8E+02	8.8E+00	1.1E+01	1.5E+02	1.6E+02	7.5E+00	9.1E+00
Ni	6.3E+01	2.9E+01	4.7E+00	2.0E+00	1.2E+02	7.4E+01	4.7E+00	2.0E+00	1.2E+02	8.7E+01	4.7E+00	2.0E+00
Pb	1.3E+03	2.7E+03	–	–	1.2E+03	2.8E+03	–	–	7.5E+02	1.7E+03	–	–
Se	7.7E+02	1.2E+02	2.1E+03	3.0E+02	1.1E+03	1.6E+02	1.3E+03	2.9E+02	2.5E+02	4.8E+01	1.7E+03	4.8E+02
Sm	8.3E+02	1.1E+03	3.8E+00	4.7E+00	6.0E+01	8.4E+01	3.8E+00	4.7E+00	1.5E+02	2.7E+02	3.6E+00	4.5E+00
Sn	–	–	–	–	–	–	–	–	–	–	–	–
Sr	1.4E+02	4.2E+01	1.2E+01	3.2E+01	1.8E+02	7.6E+01	1.1E+01	2.4E+00	7.6E+01	4.5E+01	1.1E+01	1.7E+01
Th	1.6E+02	9.6E+01	–	–	8.4E+01	4.2E+01	–	–	8.5E+01	5.2E+01	–	–
U	1.4E+02	3.9E+01	1.4E+00	5.8E–01	2.7E+01	1.4E+01	1.4E+00	5.8E–01	7.2E+01	4.7E+01	1.4E+00	5.8E–01
Zr	7.4E+01	6.6E+01	1.8E+01	1.8E+01	6.6E+01	6.0E+01	1.8E+01	1.8E+01	6.8E+01	6.9E+01	1.8E+01	1.8E+01

Table A-8. Concentration Ratios for marine Representative Species from the site and Average Organisms found at Forsmark. (–) = no data available.

Element	Baltic macoma		Bladder wrack		Brown algae		Fennel pondweed		Idothea		Lagoon cockle		Microphyte		Phytoplankton	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Ag	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Ca	1.2E+03	2.3E+02	5.3E+01	3.5E+00	1.3E+01	9.2E+00	3.8E+01	2.1E+01	2.8E+02	6.8E+00	1.3E+03	9.5E+01	8.0E+00	2.8E+00	9.2E–01	5.7E–02
Cl	2.3E–01	2.7E–02	9.1E–01	2.0E–02	1.2E+00	8.8E–02	–	–	–	–	–	–	3.1E–01	7.0E–02	4.7E–01	1.9E–02
Cs	4.9E+02	1.0E+02	6.9E+02	4.8E+02	1.3E+03	1.0E+03	1.1E+03	4.6E+02	4.4E+02	9.3E+01	2.1E+02	2.0E+02	1.4E+03	3.1E+02	3.0E+02	1.0E+02
Ho	4.9E+02	1.5E+02	2.5E+02	1.3E+02	1.5E+01	1.4E+01	4.7E+01	2.8E+01	3.4E+01	1.3E+01	2.6E+02	7.8E+01	4.7E+01	1.5E+01	–	7.6E+00
I	5.4E+01	1.2E+01	2.7E+03	1.2E+03	3.9E+02	3.4E+01	–	–	–	–	–	–	6.6E+02	3.9E+02	3.1E+01	4.4E+01
Nb	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Ni	1.7E+02	4.1E+01	4.6E+03	1.3E+03	4.8E+02	2.5E+02	8.7E+02	3.6E+02	3.3E+02	9.9E+01	1.0E+03	1.0E+02	3.1E+03	2.8E+03	1.2E+02	1.6E+04
Pb	1.4E+04	2.4E+04	9.5E+03	1.7E+04	1.6E+04	3.0E+04	1.6E+04	2.7E+04	3.4E+03	1.1E+04	3.0E+03	5.0E+03	9.9E+04	2.9E+05	9.7E+03	1.0E+01
Se	1.2E+03	3.4E+02	1.3E+03	6.1E+01	8.0E+01	–	2.3E+02	6.9E+01	9.2E+02	5.5E+01	7.0E+02	2.6E+02	1.2E+02	2.6E+00	9.0E+01	1.1E+00
Sm	1.6E+03	3.7E+02	4.7E+02	1.2E+02	5.1E+01	4.3E+01	1.5E+02	8.3E+01	1.2E+02	2.1E+01	6.2E+02	–	1.6E+02	–	3.1E+00	1.7E+03
Sn	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Sr	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Th	2.1E+04	4.9E+03	1.9E+04	1.2E+04	3.8E+04	2.6E+04	3.5E+04	9.8E+03	1.4E+04	–	8.2E+03	4.3E+03	1.2E+05	4.4E+04	9.4E+03	9.0E+02
U	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Zr	1.7E+04	6.7E+03	1.8E+04	8.7E+03	2.4E+04	1.4E+04	2.0E+04	5.4E+03	8.0E+03	1.7E+03	9.8E+03	1.3E+04	4.8E+04	7.8E+03	5.5E+03	5.7E–02

	River nerite		Roach		Ruffe		Smelt		Zooplankton		Average fish		Average mollusc		Average phytoplankt.	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Ag	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Ca	1.4E+03	2.5E+01	9.3E+01	2.2E+01	1.5E+02	6.9E+01	3.6E+01	1.8E+01	6.8E–06	1.4E–06	1.0E+02	8.6E+01	1.3E+03	2.0E+02	4.3E+00	7.4E+00
Cl	3.5E–01	3.6E–02	6.9E–02	2.0E–03	1.1E–01	1.5E–02	1.1E–01	2.0E–03	–	–	9.9E–02	2.6E–02	2.9E–01	8.2E–02	3.9E–01	1.1E–01
Cs	3.4E+02	1.0E+02	1.2E+02	2.4E+01	1.7E+02	7.2E+01	3.2E+02	7.3E+01	9.4E+01	1.9E+01	2.0E+02	1.1E+02	3.8E+02	2.6E+02	8.3E+02	9.5E+02
Ho	3.1E+02	9.0E+01	–	–	–	–	–	–	2.6E+02	7.5E+01	–	–	3.8E+02	1.6E+02	4.7E+01	1.5E+01
I	2.7E+02	1.1E+01	–	–	2.0E+01	4.4E+00	3.9E+01	1.3E+00	7.1E+01	–	3.1E+01	1.2E+01	1.9E+02	2.2E+02	5.8E+02	2.6E+03
Nb	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Ni	3.6E+02	6.2E+01	1.7E+01	5.6E+00	1.9E+01	1.3E+01	1.6E+01	2.6E+00	1.2E+02	1.2E+01	1.7E+01	6.5E+00	5.0E+02	5.1E+02	1.6E+03	6.8E+03
Pb	6.0E+03	9.9E+03	7.2E+02	1.4E+03	5.7E+02	9.9E+02	4.6E+02	7.9E+02	7.8E+03	1.3E+04	5.8E+02	1.0E+03	8.6E+03	1.8E+04	3.8E+04	1.3E+05
Se	1.8E+03	1.9E+02	2.7E+03	1.6E+02	3.3E+03	5.1E+02	2.8E+03	1.1E+02	9.4E+02	–	3.0E+03	4.2E+02	1.3E+03	6.0E+02	1.0E+02	1.9E+01
Sm	6.6E+02	–	–	–	–	–	–	–	7.4E+02	–	–	–	1.0E+03	5.1E+02	1.7E+02	1.9E+03
Sn	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Sr	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Th	3.4E+04	6.4E+03	–	–	4.8E+02	–	–	–	1.8E+03	–	5.1E+02	–	2.2E+04	1.6E+04	6.2E+04	1.4E+05
U	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Zr	1.4E+04	1.9E+03	6.3E+01	2.8E+01	4.6E+02	2.7E+02	8.7E+01	2.4E+01	9.0E+02	1.2E+02	2.1E+02	2.6E+02	1.4E+04	1.0E+04	2.6E+04	4.6E+04

Table A-9. Concentration Ratios for marine Representative Species from the site and Average Organisms found at Laxemar. (–) = no data available.

Element	Bladder wrack		Bleak		Blue mussel		Bream		Chara		Flounder		Green algae		Herring	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Ag	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Ca	5.7E+01	8.5E+00	8.4E+00	3.0E+00	1.0E+01	2.3E+00	4.0E+00	6.5E–01	3.0E+02	5.5E+01	1.3E+00	6.6E–01	8.5E+00	2.1E+00	3.1E+00	1.5E+00
Cl	1.6E+00	1.6E+00	1.7E–01	1.7E–01	1.2E+00	7.6E–01	7.8E–02	9.5E–03	1.7E+00	5.5E–01	2.4E–01	6.3E–02	1.4E+00	5.4E–01	1.8E–01	2.2E–02
Cs	1.5E+02	4.2E+01	1.4E+02	3.8E+01	1.1E+01	1.5E+00	4.9E+02	5.0E+02	2.6E+02	1.1E+02	3.0E+02	3.9E+01	4.6E+01	4.7E+01	1.1E+02	3.1E+01
Ho	3.6E+02	2.2E+02	–	–	4.6E+01	2.0E+01	–	–	4.4E+03	2.3E+03	–	–	2.9E+02	2.0E+02	–	–
I	1.8E+03	5.7E+02	–	–	7.7E+01	2.2E+01	–	–	8.2E+02	5.1E+02	–	–	2.9E+02	1.7E+02	–	–
Nb	4.2E+02	2.4E+02	2.2E+01	1.2E+01	8.6E+01	4.0E+01	1.8E+01	8.2E+00	5.1E+03	2.8E+03	1.1E+01	4.5E+00	1.0E+03	2.7E+03	–	–
Ni	2.6E+03	1.6E+03	–	–	1.2E+02	3.7E+01	5.7E+00	1.7E+00	6.5E+02	2.7E+02	3.3E+01	9.6E+00	1.8E+02	5.8E+01	–	–
Pb	7.6E+02	1.3E+02	–	–	9.4E+02	5.3E+02	–	–	4.8E+03	6.4E+02	1.6E+02	–	2.7E+03	5.1E+03	–	–
Se	1.4E+03	4.8E+02	3.7E+03	1.8E+02	2.2E+03	2.1E+02	3.0E+03	5.2E+01	8.6E+02	3.5E+02	3.0E+03	3.9E+02	7.0E+02	9.9E+01	3.5E+03	1.9E+02
Sm	1.9E+03	4.6E+03	4.4E+01	9.7E+01	3.5E+02	8.2E+02	–	–	4.0E+04	9.1E+04	–	–	3.2E+03	8.2E+03	–	–
Sn	7.1E+02	1.7E+02	4.8E+02	–	1.9E+02	3.8E+01	6.6E+02	–	2.0E+03	2.7E+02	–	–	5.0E+02	1.5E+02	4.4E+02	–
Sr	1.8E+02	2.4E+01	2.1E+00	8.8E–01	2.8E+00	4.4E–01	1.1E+00	2.3E–01	2.6E+02	5.0E+01	1.8E–01	1.3E–01	5.1E+00	1.4E+00	2.1E–01	1.0E–01
Th	3.1E+02	1.8E+02	–	–	1.9E+02	2.3E+02	–	–	9.3E+03	6.6E+03	–	–	4.6E+02	5.7E+02	–	–
U	2.9E+02	6.4E+01	1.9E–01	5.9E–02	1.9E+01	1.8E+00	2.1E–01	1.7E–01	1.6E+02	4.2E+01	1.6E–01	8.9E–02	1.2E+01	8.8E+00	1.4E–01	1.6E–02
Zr	2.7E+03	6.6E+03	–	–	1.8E+02	3.7E+02	–	–	9.2E+03	1.9E+04	–	–	3.1E+03	7.2E+03	–	–

	Perch		Average fish	
	Mean	SD	Mean	SD
Ag	–	–	–	–
Ca	1.7E+00	3.0E–01	3.5E+00	3.0E+00
Cl	9.3E–02	3.6E–02	1.6E–01	8.5E–02
Cs	4.0E+02	1.2E+02	2.7E+02	1.9E+02
Ho	–	–	–	–
I	1.5E+01	7.2E+00	1.4E+01	7.0E+00
Nb	–	–	1.6E+01	8.3E+00
Ni	–	–	3.4E+01	7.5E+01
Pb	–	–	1.8E+02	–
Se	3.7E+03	1.0E+02	3.4E+03	2.9E+02
Sm	–	–	4.0E+01	8.8E+01
Sn	7.0E+02	2.5E+02	5.6E+02	1.5E+02
Sr	6.4E–02	1.2E–02	7.2E–01	1.6E+00
Th	3.0E+02	1.8E+02	2.9E+02	1.7E+02
U	–	–	1.6E–01	6.3E–02
Zr	1.0E+03	2.6E+03	9.8E+02	2.5E+03

Table A-10. Concentration Ratios (default values from the ERICA Tool) for terrestrial Reference Organisms. NB.: The same CR values apply to large and small mammals.

Element	Amphibian	Bird	Detrit. invertebrate	Flying insect	Gastropod	Grass and herb	Lichen & bryophyte	Mammal (large)	Mammal (small)	Reptile	Shrub	Soil inverte-brate	Tree
Ag	2.9E–01	2.9E–01	7.0E–01	7.0E–01	7.0E–01	2.9E+00	9.7E–02	2.9E–01	2.9E–01	2.9E–01	6.2E+00	7.0E–01	6.2E+00
Am	4.1E–02	4.1E–02	1.0E–01	1.3E–01	2.0E–01	5.0E–03	1.0E–01	4.1E–02	4.1E–02	4.1E–02	5.0E–03	1.0E–01	1.1E–04
C	1.3E+03	1.3E+03	4.3E+02	4.3E+02	4.3E+02	8.9E+02	8.9E+02	1.3E+03	1.3E+03	1.3E+03	8.9E+02	4.3E+02	1.3E+03
Cl	7.0E+00	7.0E+00	3.0E–01	3.0E–01	1.7E–01	1.7E+01	9.6E–01	7.0E+00	7.0E+00	7.0E+00	1.0E+00	1.8E–01	1.4E+00
Cm	4.1E–02	4.1E–02	1.4E–01	1.4E–01	1.4E–01	2.8E–04	1.0E–01	4.1E–02	4.1E–02	4.1E–02	9.4E–03	1.4E–01	9.4E–03
Cs	5.4E–01	7.5E–01	1.3E–01	5.5E–02	4.3E–02	6.9E–01	5.6E+00	2.9E+00	2.9E+00	3.6E+00	4.0E+00	8.9E–02	1.6E–01
I	4.0E–01	4.0E–01	3.0E–01	3.0E–01	1.8E–01	1.4E–01	3.6E–01	4.0E–01	4.0E–01	4.0E–01	1.4E–01	1.6E–01	1.4E–01
Nb	1.9E–01	1.9E–01	5.0E–04	5.0E–04	5.0E–04	4.2E–02	1.6E–02	1.9E–01	1.9E–01	1.9E–01	3.4E–02	5.0E–04	3.4E–02
Ni	7.2E–02	7.2E–02	8.6E–03	8.6E–03	1.8E–02	1.9E–01	8.6E–02	7.2E–02	7.2E–02	7.2E–02	3.4E–02	6.5E–02	1.8E–02
Np	4.1E–02	4.1E–02	1.0E–01	1.3E–01	2.0E–01	1.7E–02	1.0E–01	4.1E–02	4.1E–02	4.1E–02	3.1E–01	1.0E–01	3.1E–01
Pb	1.2E–01	6.2E–02	7.5E–01	6.1E–02	7.3E–03	6.6E–02	6.0E+00	3.9E–02	3.9E–02	6.2E–02	3.1E–01	2.8E–02	7.6E–02
Po	2.8E–03	2.8E–03	2.8E–03	2.8E–03	2.8E–03	1.2E–01	6.3E+00	2.8E–03	2.8E–03	2.8E–03	9.8E–02	2.8E–03	3.8E–02
Pu	2.3E–02	2.3E–02	3.9E–02	1.7E–02	1.1E–01	1.4E–02	1.0E–01	2.3E–02	2.3E–02	2.3E–02	3.2E–02	2.9E–02	3.2E–02
Ra	3.6E–02	3.6E–02	9.0E–02	9.0E–02	4.8E–02	3.9E–02	2.1E–01	2.6E–02	2.6E–02	3.6E–02	2.4E–02	9.0E–02	6.8E–04
Se	6.3E–02	6.3E–02	1.5E+00	1.5E+00	3.5E–02	5.6E–01	2.0E+01	6.3E–02	6.3E–02	6.3E–02	1.8E+00	1.5E+00	1.8E+00
Sr	8.2E–01	5.5E–01	4.1E–01	6.3E–02	9.2E–02	2.1E–01	8.7E+00	1.7E+00	1.7E+00	1.2E+01	5.0E–02	9.0E–03	4.9E–01
Tc	5.8E–01	2.7E–01	3.7E–01	3.7E–01	3.7E–01	2.0E+01	2.0E+01	3.7E–01	3.7E–01	3.7E–01	2.0E+01	3.7E–01	2.7E–01
Th	3.9E–04	3.9E–04	8.8E–03	8.8E–03	8.8E–03	4.4E–02	1.0E–01	1.2E–04	1.2E–04	3.9E–04	1.6E–02	8.8E–03	1.1E–03
U	5.0E–04	5.4E–04	8.8E–03	8.8E–03	8.8E–03	1.5E–02	7.1E–02	1.1E–04	1.1E–04	5.0E–04	7.1E–03	8.8E–03	6.8E–03
Zr	1.2E–05	1.2E–05	5.0E–04	5.0E–04	5.0E–04	5.3E–04	1.7E–02	1.2E–05	1.2E–05	1.2E–05	9.4E–05	5.0E–04	2.1E–04

Table A-11. Concentration Ratios (default values from the ERICA Tool) for freshwater Reference Organisms.

Element	Bird	Crustacean	Gastropod	Insect larvae	Mammal	Mollusc	Pelagic fish	Phytoplank-ton	Vascular plant	Zoo-plankton
Ag	1.0E+02	1.6E+04	3.2E+04	1.6E+04	1.0E+02	3.2E+04	1.0E+02	5.6E+04	2.0E+03	1.7E+04
Am	2.0E+00	9.7E+01	1.8E+02	2.0E+04	2.0E+00	4.7E+02	1.8E+00	4.0E+04	4.2E+03	4.0E+02
C	7.3E+03	7.3E+03	7.3E+03	7.3E+03	7.3E+03	7.3E+03	4.6E+03	1.8E+03	4.6E+03	4.0E+03
Cl	8.2E+01	5.0E+01	5.0E+01	5.0E+01	8.2E+01	5.0E+01	8.2E+01	3.6E+02	3.6E+02	3.6E+02
Cm	1.5E+02	9.7E+01	3.3E+02	1.1E+03	1.5E+02	3.3E+02	1.5E+02	1.9E+04	3.0E+02	1.9E+04
Cs	3.0E+03	1.0E+04	2.8E+03	1.0E+04	9.3E+03	4.6E+02	7.1E+03	4.7E+03	1.1E+03	1.6E+03
I	1.3E+02	4.0E+02	2.5E+01	4.0E+02	1.3E+02	2.5E+01	1.8E+02	2.3E+03	3.0E+02	1.3E+03
Nb	2.3E+02	3.5E+02	3.5E+02	3.5E+02	2.3E+02	3.5E+02	2.3E+02	1.0E+03	8.0E+02	1.0E+03
Ni	1.0E+02	5.5E+02	6.4E+03	5.5E+02	1.0E+02	6.4E+03	1.0E+02	5.0E+03	5.0E+01	5.0E+03
Np	1.5E+02	1.1E+03	8.2E+02	2.0E+04	1.5E+02	8.2E+02	1.5E+02	4.0E+04	4.2E+03	4.5E+02
Pb	3.0E+02	1.0E+04	5.0E+04	1.0E+04	3.0E+02	1.7E+03	3.0E+02	4.9E+05	1.0E+03	2.6E+04
Po	2.4E+02	9.9E+03	2.2E+04	9.9E+03	2.4E+02	3.8E+04	2.4E+02	2.7E+04	4.0E+03	2.7E+04
Pu	2.0E+00	1.1E+03	8.2E+02	1.1E+03	2.3E+02	8.2E+02	6.0E+01	5.9E+03	2.6E+03	4.5E+02
Ra	8.0E+01	1.5E+03	9.4E+02	1.5E+03	8.0E+01	1.5E+03	8.0E+01	1.1E+03	1.8E+03	1.1E+03
Se	2.0E+02	7.1E+03	5.0E+03	7.1E+03	2.0E+02	5.0E+03	2.0E+02	3.6E+03	1.0E+03	6.0E+03
Sr	1.7E+01	2.0E+02	2.7E+02	2.0E+02	1.7E+01	2.7E+02	1.7E+01	4.0E+01	2.5E+02	6.0E+01
Tc	4.0E+01	1.3E+01	2.4E+01	1.3E+01	4.0E+01	2.4E+01	4.0E+01	8.0E+00	1.3E+03	2.0E+01
Th	1.1E+02	1.0E+02	1.0E+02	1.0E+02	1.1E+02	1.0E+02	1.1E+02	4.0E+03	1.3E+03	2.0E+03
U	3.0E+01	5.0E+02	1.8E+02	5.0E+02	3.0E+01	1.8E+02	3.0E+01	1.2E+02	2.9E+03	4.8E+01
Zr	3.0E+02	2.2E+02	2.5E+02	7.5E+01	3.0E+02	2.5E+02	3.0E+02	3.3E+04	1.9E+03	3.3E+04

Table A-12. Concentration Ratios (default values from the ERICA Tool) for marine Reference Organisms.

Element	Benthic fish	Bird	Crustacean	Macroalgae	Mammal	Mollusc	Pelagic fish	Phytoplank-ton	Polychaete	Vascular plant	Zoo-plankton
Ag	2.9E+03	2.2E+04	1.6E+04	1.3E+03	2.2E+04	3.2E+04	2.9E+03	5.6E+04	2.7E+04	1.3E+03	1.7E+04
Am	5.8E+01	1.5E+02	1.3E+03	8.3E+02	2.8E+02	8.1E+03	5.8E+01	2.1E+05	8.1E+03	8.3E+02	4.0E+03
C	1.2E+04	1.7E+04	1.0E+04	8.0E+03	1.7E+04	1.0E+04	1.2E+04	5.6E+03	1.0E+04	8.0E+03	1.0E+04
Cl	5.6E–02	3.0E–02	5.6E–02	8.4E–01	3.3E–02	4.6E–02	5.6E–02	1.0E+00	5.0E–02	8.4E–01	1.0E+00
Cm	1.0E+02	1.5E+02	1.3E+03	1.2E+04	2.8E+02	3.2E+04	1.0E+02	2.7E+05	1.5E+03	1.2E+04	7.8E+03
Cs	8.6E+01	4.6E+02	4.1E+01	1.2E+02	2.1E+02	6.6E+01	8.6E+01	1.3E+02	1.8E+02	2.2E+01	1.1E+02
I	3.6E+00	6.8E–01	3.6E+00	4.1E+03	6.8E–01	1.4E+01	3.6E+00	9.6E+02	1.4E+01	4.1E+03	3.0E+03
Nb	8.3E+01	8.3E+01	1.0E+02	6.1E+02	8.3E+01	8.5E+02	8.3E+01	1.0E+03	8.5E+02	6.1E+02	2.2E+04
Ni	1.7E+02	1.7E+02	5.5E+02	7.9E+02	1.7E+02	6.4E+03	1.7E+02	1.4E+03	4.2E+03	7.9E+02	1.0E+03
Np	1.0E+00	4.0E+00	1.0E+02	5.3E+01	4.0E–01	4.2E+02	1.0E+00	1.4E+02	4.2E+02	5.3E+01	1.7E+01
Pb	2.0E+02	1.9E+04	1.0E+04	1.0E+03	1.9E+04	1.7E+03	2.0E+02	4.9E+05	1.0E+04	1.0E+03	2.6E+04
Po	1.7E+04	1.0E+04	6.0E+04	1.0E+03	1.0E+04	3.5E+04	1.7E+04	2.6E+04	2.0E+04	1.0E+03	7.6E+04
Pu	3.5E+03	1.5E+02	1.6E+02	4.1E+03	2.8E+02	1.1E+03	3.5E+03	1.2E+05	1.5E+03	4.1E+03	7.8E+03
Ra	2.8E+02	2.8E+02	1.5E+02	8.9E+01	6.0E+01	6.5E+01	2.8E+02	1.0E+03	1.5E+02	8.9E+01	8.1E+01
Se	9.3E+03	8.3E+03	7.1E+03	2.2E+02	8.3E+03	5.0E+03	9.3E+03	3.6E+03	4.5E+03	2.2E+02	6.0E+03
Sr	2.3E+01	1.4E+00	1.3E+01	4.2E+01	1.4E+00	1.2E+02	2.3E+01	2.1E+02	4.7E–01	4.2E+01	4.6E+00
Tc	3.1E+01	3.1E+01	2.2E+04	3.0E+04	2.4E+01	8.9E+03	3.1E+01	3.5E+00	2.2E+04	3.0E+04	1.0E+02
Th	6.0E+02	3.3E+01	1.0E+03	2.0E+03	1.8E+02	5.1E+02	6.0E+02	7.3E+05	5.1E+02	2.0E+03	7.5E+03
U	1.4E+01	4.0E+00	1.0E+01	1.2E+02	4.0E–01	3.2E+01	1.4E+01	1.4E+02	3.2E+01	2.3E+02	3.0E+01
Zr	8.3E+01	8.3E+01	2.2E+02	1.7E+03	8.3E+01	4.6E+03	8.3E+01	3.3E+04	4.6E+03	1.2E+03	2.2E+04

A3 Detailed results concerning dose rates

This Section tabulates all dose rate results obtained for a release according to the central corrosion case at the Forsmark site. All studied biota, i.e. Representative Species from the site, Average Organisms and Reference Organisms, have been assessed. Section A3.1 concerns results from Tier 2 assessments with the ERICA Tool; Section A3.2 concerns Tier 3 results.

A3.1 Dose rates and Risk Quotients obtained in Tier 2 assessments

Tables A-13, A-14 and A-15 include dose rates and "expected" and "conservative" (95th percentile) Risk Quotients (see Section 3.4 for a description and a discussion of how these two types of RQ values should be interpreted). Table A-13 concerns terrestrial biota, Table A-14 shows freshwater biota, and Table A-15 shows marine biota.

Table A-13. Dose rates and RQ values for terrestrial biota at Forsmark

Organisms	Dose rate µGy/h	Risk Quotient, RQ "Expected" value	"Conservative" value
Representative Species from the site			
Bank vole	5.2E–06	5.2E–07	1.5E–06
Bilberry shrub	3.1E–06	3.1E–07	9.4E–07
Common shrew	4.9E–06	4.9E–07	1.5E–06
Moose (350 or 500 kg)	1.2E–06	1.2E–07	3.5E–07
Norwegian spruce	2.3E–06	2.3E–07	6.8E–07
Red fox	3.9E–06	3.9E–07	1.2E–06
Small cow–wheat	3.9E–06	3.9E–07	1.2E–06
Stone bramble	3.4E–06	3.4E–07	1.0E–06
Water vole	4.8E–06	4.8E–07	1.4E–06
Yellow necked mouse	2.3E–07	2.3E–08	6.8E–08
Average Organisms			
Average bryophyte	1.6E–04	1.6E–05	4.7E–05
Average mushroom	9.3E–07	9.3E–08	2.8E–07
Average rodent	5.1E–06	5.1E–07	1.5E–06
Average vascular plant	3.6E–06	3.6E–07	1.1E–06
Reference Organisms			
Amphibia	2.9E–05	2.9E–06	8.7E–06
Bird (terrestrial)	2.7E–05	2.7E–06	8.1E–06
Detritivorous invertebrate	6.4E–05	6.4E–06	1.9E–05
Flying insect	6.1E–05	6.1E–06	1.8E–05
Gastropod (terrestrial)	5.9E–05	5.9E–06	1.8E–05
Grasses & herbs	3.7E–05	3.7E–06	1.1E–05
Mammal, large	2.2E–05	2.2E–06	6.5E–06
Mammal, small	2.5E–05	2.5E–06	7.6E–06
Lichen & bryophytes	6.7E–04	6.7E–05	2.0E–04
Reptile (terrestrial)	2.9E–05	2.9E–06	8.6E–06
Shrub	7.6E–05	7.6E–06	2.3E–05
Soil invertebrate	6.3E–05	6.3E–06	1.9E–05
Tree	6.1E–05	6.1E–06	1.8E–05

Table A-14. Dose rates and RQ values for freshwater biota at Forsmark.

Organisms	Dose rate µGy/h	Risk Quotient, RQ "Expected" value	"Conservative" value
Representative Species from the site			
Chara	7.1E–07	7.1E–08	2.1E–07
Duck mussel	1.9E–05	1.9E–06	5.6E–06
Pike	4.2E–09	4.2E–10	1.3E–09
Roach	1.5E–08	1.5E–09	4.6E–09
Ruffe	1.5E–09	1.5E–10	4.5E–10
Tench	5.4E–06	5.4E–07	1.6E–06
Average Organisms			
Average fish	1.7E–08	1.7E–09	5.1E–09
Reference Organisms			
Bird (freshwater)	1.6E–05	1.6E–06	4.9E–06
Bivalve mollusc (fw)	3.7E–04	3.7E–05	1.1E–04
Crustacean (freshwater)	2.7E–04	2.7E–05	8.1E–05
Gastropod (freshwater)	2.7E–04	2.7E–05	8.2E–05
Insect larvae (freshwater)	1.9E–03	1.9E–04	5.6E–04
Mammal (freshwater)	1.8E–05	1.8E–06	5.4E–06
Pelagic fish (freshwater)	1.7E–05	1.7E–06	5.0E–06
Phytoplankton (freshwater)	3.4E–03	3.4E–04	1.0E–03
Vascular plant (freshwater)	5.2E–04	5.2E–05	1.6E–04
Zooplankton (freshwater)	2.2E–04	2.2E–05	6.5E–05

Table A-15. Dose rates and RQ values for marine biota at Forsmark.

Organisms	Dose rate µGy/h	Risk Quotient, RQ "Expected" value	"Conservative" value
Representative Species from the site			
Baltic macoma	9.1E–08	9.1E–09	2.7E–08
Bladder wrack	4.0E–08	4.0E–09	1.2E–08
Brown algae	1.8E–08	1.8E–09	5.5E–09
Fennel pondweed	1.9E–08	1.9E–09	5.8E–09
Idothea	5.9E–08	5.9E–09	1.8E–08
Lagoon cockle	7.3E–08	7.3E–09	2.2E–08
Microphytes	3.8E–08	3.8E–09	1.1E–08
Phytoplankton	3.3E–09	3.3E–10	1.0E–09
River nerite	1.4E–08	1.4E–09	4.3E–09
Roach	3.5E–10	3.5E–11	1.0E–10
Ruffe	5.7E–10	5.7E–11	1.7E–10
Smelt	3.5E–10	3.5E–11	1.0E–10
Zoo plankton	2.1E–09	2.1E–10	6.4E–10
Average Organisms			
Average fish	5.3E–10	5.3E–11	1.6E–10
Average mollusc	6.2E–08	6.2E–09	1.9E–08
Average phytoplankton	2.1E–08	2.1E–09	6.2E–09
Reference Organisms			
Benthic fish (marine)	1.1E–06	1.1E–07	3.4E–07
Benthic mollusc (marine)	1.9E–06	1.9E–07	5.6E–07
Bird (marine)	3.2E–07	3.2E–08	9.5E–08
Crustacean (marine)	6.3E–07	6.3E–08	1.9E–07
Macroalgae (marine)	1.4E–06	1.4E–07	4.3E–07
Mammal (marine)	8.5E–08	8.5E–09	2.5E–08
Pelagic fish (marine)	3.4E–07	3.4E–08	1.0E–07
Phytoplankton (marine)	2.9E–06	2.9E–07	8.7E–07
Polychaete worm (marine)	3.0E–06	3.0E–07	8.9E–07
Vascular plant (marine)	1.3E–06	1.3E–07	4.0E–07
Zooplankton (marine)	3.4E–07	3.4E–08	1.0E–07

A3.2 Dose rates and statistical descriptions obtained in Tier 3 assessments

The Tables in this Section provide mean values of the dose rates from the Tier 3 assessments, together with medians, 5th and 95th percentile values, and minimum and maximum values. Table A-16 shows terrestrial biota, Table A-17 shows freshwater biota, and Table A-18 shows marine biota.

Table A-16. Dose rates (µGy h^{-1}) and descriptive statistics for terrestrial biota at Forsmark.

Organism	Mean value	5th percentile	Median	95th percentile
Representative Species from the site				
Bank vole	5.2E–06	5.0E–06	5.1E–06	5.7E–06
Bilberry	3.1E–06	2.8E–06	3.0E–06	4.0E–06
Common shrew	4.9E–06	4.9E–06	4.9E–06	5.0E–06
Moose (350 kg, 500 kg)	1.2E–06	1.2E–06	1.2E–06	1.2E–06
Norwegian spruce	2.3E–06	2.1E–06	2.2E–06	2.6E–06
Red fox	3.9E–06	3.7E–06	3.8E–06	4.4E–06
Small cow-wheat	3.9E–06	2.9E–06	3.4E–06	6.5E–06
Stone bramble	3.4E–06	2.9E–06	3.2E–06	4.7E–06
Water vole	4.8E–06	4.8E–06	4.8E–06	4.8E–06
Yellow-necked mouse	2.2E–07	6.7E–08	1.4E–07	6.3E–07
Average Organisms				
Average bryophyte	1.9E–04	4.5E–06	1.2E–05	3.2E–04
Average mushroom	9.6E–07	2.2E–07	4.5E–07	2.2E–06
Average rodent	5.1E–06	4.9E–06	5.0E–06	5.6E–06
Average vascular plant	3.5E–06	2.9E–06	3.1E–06	5.4E–06
Reference Organisms				
Amphibia	2.9E–05	1.2E–05	2.5E–05	5.9E–05
Bird (terrestrial)	2.7E–05	9.2E–06	2.3E–05	5.9E–05
Detritivorous invertebrate	6.4E–05	2.1E–05	5.4E–05	1.4E–04
Flying insect	6.1E–05	1.5E–05	5.1E–05	1.4E–04
Gastropod (terrestrial)	6.0E–05	1.8E–05	4.9E–05	1.4E–04
Grasses & herbs	3.6E–05	1.3E–05	2.8E–05	8.5E–05
Mammal, large	2.2E–05	7.6E–06	1.8E–05	4.9E–05
Mammal, small	2.5E–05	1.1E–05	2.2E–05	5.2E–05
Lichen & bryophytes	6.7E–04	3.2E–04	6.0E–04	1.2E–03
Reptile (terrestrial)	2.8E–05	1.1E–05	2.5E–05	5.8E–05
Shrub	7.4E–05	1.8E–05	3.0E–05	2.0E–04
Soil invertebrate	6.3E–05	2.0E–05	5.4E–05	1.4E–04
Tree	5.9E–05	1.0E–05	4.4E–05	1.6E–04

Table A-17. Dose rates (µGy h⁻¹) and descriptive statistics for freshwater biota at Forsmark.

Organism	Mean value	5th percentile	Median	95th percentile
Representative Species from the site				
Chara	7.1E–07	3.1E–07	5.7E–07	1.5E–06
Duck mussel	1.9E–05	1.9E–05	1.9E–05	1.9E–05
Pike	4.2E–09	1.9E–09	3.3E–09	8.8E–09
Roach	1.5E–08	3.1E–09	9.9E–09	4.5E–08
Ruffe	1.5E–09	5.4E–10	9.8E–10	3.9E–09
Tench	5.4E–06	5.4E–06	5.4E–06	5.4E–06
Average Organisms				
Average fish	1.7E–08	4.6E–09	1.2E–08	4.6E–08
Reference Organisms				
Bird (freshwater)	1.6E–05	4.3E–06	1.6E–05	4.4E–05
Bivalve mollusc (fw)	3.7E–04	1.5E–04	3.0E–04	7.7E–04
Crustacean (freshwater)	2.7E–04	1.6E–04	2.5E–04	4.8E–04
Gastropod (freshwater)	2.7E–04	1.3E–04	2.4E–04	5.3E–04
Insect larvae (freshwater)	1.9E–03	3.4E–04	1.4E–03	5.1E–03
Mammal (freshwater)	1.8E–05	4.6E–06	1.5E–05	4.3E–05
Pelagic fish (freshwater)	1.7E–05	5.3E–06	1.4E–05	4.0E–05
Phytoplankton (fw)	3.4E–03	3.7E–04	2.5E–03	9.7E–03
Vascular plant (fw)	5.2E–04	1.7E–04	4.2E–04	1.2E–03
Zooplankton (freshwater)	2.2E–04	5.9E–05	1.8E–04	4.9E–04

Table A-18. Dose rates (µGy h⁻¹) and descriptive statistics for marine biota at Forsmark.

Organism	Mean value	5th percentile	Median	95th percentile
Representative Species from the site				
Baltic macoma	9.1E–08	8.8E–08	9.0E–08	9.5E–08
Bladder wrack	4.0E–08	2.7E–08	3.9E–08	5.8E–08
Brown algae	1.8E–08	9.3E–09	1.7E–08	3.3E–08
Fennel pondweed	1.9E–08	1.4E–08	1.9E–08	2.6E–08
Idothea	5.9E–08	5.8E–08	5.9E–08	6.1E–08
Lagoon cockle	7.3E–08	7.0E–08	7.3E–08	7.7E–08
Microphytes	3.8E–08	2.3E–08	3.6E–08	5.9E–08
Phytoplankton	3.3E–09	2.6E–09	3.3E–09	4.2E–09
River nerite	1.4E–08	1.2E–08	1.4E–08	1.8E–08
Roach	3.4E–10	2.4E–10	3.1E–10	5.5E–10
Ruffe	5.7E–10	4.2E–10	5.4E–10	8.0E–10
Smelt	3.5E–10	2.9E–10	3.3E–10	4.8E–10
Zooplankton	2.1E–09	1.5E–09	1.8E–09	3.8E–09
Average Organisms				
Average fish	5.3E–10	4.1E–10	5.0E–10	7.2E–10
Average mollusc	6.2E–08	5.5E–08	6.1E–08	7.3E–08
Average phytoplankton	2.1E–08	2.1E–09	1.0E–08	6.8E–08
Reference Organisms				
Benthic fish (marine)	1.1E–06	8.5E–07	1.0E–06	1.8E–06
Benthic mollusc (marine)	1.9E–06	1.2E–06	1.7E–06	3.1E–06
Bird (marine)	3.2E–07	4.1E–08	2.4E–07	9.0E–07
Crustacean (marine)	6.3E–07	2.7E–07	5.7E–07	1.2E–06
Macroalgae (marine)	1.4E–06	1.2E–06	1.4E–06	1.8E–06
Mammal (marine)	8.5E–08	1.9E–08	6.7E–08	2.2E–07
Pelagic fish (marine)	3.4E–07	6.5E–08	2.1E–07	1.0E–06
Phytoplankton (marine)	2.9E–06	1.2E–06	2.4E–06	6.2E–06
Polychaete worm (mar.)	3.0E–06	2.1E–06	2.8E–06	4.6E–06
Vascular plant (marine)	1.3E–06	9.9E–07	1.3E–06	1.9E–06
Zooplankton (marine)	3.4E–07	1.6E–07	2.9E–07	6.9E–07

A4 Total dose rates combining background radiation and radionuclide releases

The default approach to radiological protection is to assess and evaluate incremental doses and dose rates. In the evaluation, incremental levels are often compared to existing “background” levels. Here, in a somewhat different take on the issues, incremental and background levels are added to each other for illustrative purposes. Some of the observations are from Forsmark, and some are from the alternate (now dismissed) site, Laxemar. The background includes both natural radiation and existing radiation due to fallout from weapons testing and the Chernobyl accident.

Section A4.1 presents the radionuclides considered, and the organisms considered are shown in Section A4.2. In Section A4.3, the activity concentrations in soil and sediment are discussed, and the activity concentrations in biota are given in Section A4.4. The results in terms of background and combined dose rates are presented in Section A4.5 and discussed in Section A4.6.

A4.1 Radionuclides considered in the derivation of background dose rates

Those 14 radioisotopes were studied that were reported by /Roos et al. 2007/ and were among those regarded by SKB as important for their assessment of the repository (see Section 3.2), viz., I-129, Pu-239, Pu-240, Pu-242, Ra-226, Tc-99, Th-229, Th-230, Th-232, U-233, U-234, U-235, U-236, and U-238 Roos et al. also reported on Pu-238). These data were used for the present analysis. All of these radionuclides were also studied with respect to releases from the repository; the analysis of releases included 25 further radionuclides as shown in Table 3-1.

Some of the natural radioisotopes are quite rare in the environment, e.g. Th-229, U-233, and U-236. Plutonium originates from atmospheric fallout from atmospheric weapons testing during the 1950ies and 1960ies. Tc-99, here measured in bladder wrack and blue mussel, is known to be highly accumulated in seaweed, molluscs and some crustaceans /Copplestone et al. 2001, Kelly and Thorne 2003, Olsen and Vives i Batlle 2003/.

A4.2 Organisms considered in the derivation of background dose rates

Of the 45 Representative Organisms from the site, shown in Table 3-4, 19 organisms from terrestrial, marine, and freshwater habitats (listed in Table A-19) were studied with respect to background dose rates. For bladder wrack, common reed, duck mussel, moose, and pond weed, data were obtained from the same habitats at both investigation sites (Forsmark and Laxemar), permitting a direct comparison between activity concentrations for the same species. Radioisotopes for the other species were studied either at one site only or at both sites but within different habitats.

A4.3 Activity concentrations in soil and sediment

Samples were collected for determination of activity concentrations at different depths ranging from 2.5 cm or less to 10 cm or less for soil, from 3 cm or less to 5 cm or less for marine sediment, and at 5 cm or less for freshwater sediment; see Tables A-20 and A-21. It was assumed that radionuclides were evenly distributed in soil and sediment. (Since water samples were never collected, activity concentrations for water were back-calculated within the ERICA Tool.)

Table A-19: Organisms studied with respect to background dose rates, with English, Swedish and scientific names.

English name	Swedish name	Scientific name
Bank vole	Ängssork	*Clethrinonomys glareolus*
Bilberry	Blåbär	*Vaccinium myrtillus*
Bladder wrack	Blåstång	*Fucus vesiculosus*
Bleak	Löja	*Alburnus alburnus*
Blue mussel	Blåmussla	*Mytilus edulis*
Charophyte	Kransalg	*Chara sp.*
Common reed	Bladvass	*Phragmites australis*
Duck mussel	Dammussla	*Anodonta anatina*
Moose	Älg	*Alces alces*
Moss	mossa	*Bryophyta*
Norwegian spruce	Gran	*Picea abies*
Perch	Abborre	*Perca fluviatilis*
Pike	Gädda	*Esox lucius*
Pond weed	Ålnate	*Potamogeton perfoliatus*
Roach	Mört	*Rutilus rutilus*
Smelt	Nors	*Osmerus eperlanus*
Stone bramble	Stenbär	*Rubus saxatilis*
Water lily	Näckros	*Nymphaeaceae*
Yellow-necked mouse	Större skogsmus	*Apodemus flavicollis*

Table A-20. Activity concentrations in soil and sediment at Forsmark. All values are in Bq/kg dry weight. For more details, see /Roos et al. 2007/.

Isotopes	Terrestrial soil 0–2.5 cm	Freshwater sediment 0–5 cm	Marine sediment 0–3 cm
I-129	0.004359	0.000332	0.000487
Pu-239	1.51	1.12	0.102
Pu-240	1.29	0.685	0.048
Pu-242	< 0.0035*	< 0.0016	< 0.0017
Ra -226	14	30	8.5
Tc-99	n.a.**	n.a.	0.6
Th-229	< 0.153	< 0.069	< 0.074
Th-230	8.926	28.766	5.56
Th-232	9.15	21.91	5.82
U-233	< 0.0411	< 0.0185	< 0.0197
U-234	46.4	187.7	8.5
U-235	1.769	7.731	0.382
U-236	< 0.0014	< 0.0006	< 0.0007
U-238	38	164	8

* < = Value is below detectable limit.
** Not analysed.

Table A-21. Activity concentrations in soil and sediment at Laxemar. All values are in Bq/kg dry weight. For more details, see /Roos et al. 2007/.

Isotopes	Terrestrial soil 0–10 cm	Freshwater sediment 0–5 cm	Marine sediment 0–5 cm
I-129	0.00303	0.00055	0.00084
Pu-239	1.475	1.782	0.527
Pu-240	0.991	1.135	0.491
Pu-242	< 0.0005*	< 0.0017	< 0.0017
Ra -226	15.6	69.8	8.5
Tc-99	n.a.**	n.a.	0.19
Th-229	< 0.01	< 0.044	< 0.04
Th-230	5.605	27.75	27.186
Th-232	4.5	24	26
U-233	< 0.007	< 0.0233	< 0.0233
U-234	48	160	99
U-235	1.806	6.204	4.006
U-236	< 0.0002	< 0.0008	< 0.0008
U-238	34	127	81

* < = value is below detectable limit.
** not analysed.

A4.4 Activity concentrations in biota

A large part of radioisotopes measured in biota, soil and sediment were below the detection limit (for details, see /Roos et al. 2007/). Therefore the derived background dose rates will be difficult to interpret. /Gochfeld et al. 2005/ discusses how to deal with such uncertain values. In brief, the options are:

1) to ignore them entirely,
2) to assume that values are zero,
3) to assume that values are close to detection values and use those for calculation,
4) to arbitrarily set values to half the detection values,
5) to treat the uncertain values as real,
6) to use statistical extrapolation, and
7) to use only a non-parametric representation such as the median.

In this report the decision was to treat values as real values, i.e. option 5 since they were assumed to equate the detection limit value as a conservative estimation, yielding the highest background doses. This has the advantage that it gives the most "cautious" values, i.e. it minimises the risk of underestimating dose rates, which is beneficial for safety reasons.

Table A-22 shows the activity concentrations for organisms studied at Forsmark; Table A-23 shows the activity concentrations for organisms studied at Laxemar.

A4.5 Results: dose rates to biota

The resulting background dose rates for actual organisms (some of the Representative Species from the site) found at Forsmark and Laxemar are summarised in Table A-24.

Figures A-2 a–c provide a graphical representation of these results, supplemented with dose rates for Reference Organisms in order to obtain a broader spectrum of species. The dose rates for Reference Organisms are not remarkable compared to the dose rates for observed Representative Species from the site. Dose rates for aquatic organisms are mostly higher at Forsmark than at Laxemar, although not by a great deal.

The total dose rates obtained when background and a release are combined are shown in Table A-25. For aquatic organisms, the dose rates due to a release are consistently orders of magnitude smaller than the background dose rates, and therefore the total dose rates are virtually equal to the background dose rates. For the organisms studied, none of the total dose rates is even close to the screening dose rate, 10 μGy h^{-1}.

Table A-22. Activity concentrations (Bq kg^{-1} fresh weight for each radioisotope) for terrestrial, freshwater, and marine organisms at Forsmark. < denotes value below the detection limit.

	Terrestrial				Freshwater				
Isotope	Bank vole	Moose	Moss	Stone bramble	Charophyte	Common reed	Duck mussel	Pike	Roach
I-129	n.a.	0.000108	0.002382	3.98E–05	0.000232	0.000151	1.32E–05	n.a.	n.a.
Pu-239	< 0.00375	< 0.000446	0.0756	< 0.0025	0.012635	< 0.000669	0.001102	< 0.000669	< 0.001784
Pu-240	< 0.005	< 0.000446	0.054	< 0.0025	0.011501	< 0.000669	0.000479	< 0.000669	< 0.001275
Pu-242	< 0.000775	< 4.46E–05	< 0.000144	< 0.00015	< 9.72E–05	< 6.69E–05	< 2.4E–05	< 0.000786	< 0.000178
Ra -226	0.125	0.044595	1.728	0.1	5.183648	1.271685	0.95848	0.066866	0.509804
Tc-99	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Th-229	< 0.03325	< 0.001338	< 0.00684	< 0.00625	< 0.004536	< 0.003012	< 0.000958	< 0.033934	< 0.007647
Th-230	0.00725	0.001605	0.432	0.00525	0.042765	0.00937	0.011741	0.003343	0.000765
Th-232	0.0025	0.000892	0.3528	0.005	0.021059	0.006693	0.005751	0.001672	0.002549
U-233	< 0.0089	< 0.000401	< 0.001872	< 0.00165	< 0.001215	< 0.00077	< 0.000254	< 0.009094	< 0.002039
U-234	0.015	0.00446	24.912	0.0375	1.636089	0.100396	0.23962	0.026746	0.127451
U-235	0.00075	0.000134	0.96192	0.0015	0.068521	0.003681	0.009585	0.001003	0.004843
U-236	< 0.0003	< 1.34E–05	< 0.000072	< 0.00005	< 4.86E–05	< 2.68E–05	< 9.58E–06	< 0.000318	< 7.65E–05
U-238	0.0125	0.00446	20.88	0.0325	1.457901	0.073624	0.206073	0.021731	0.096863

	Marine			
Isotope	Bladder wrack	Pond weed	Roach	Smelt
I-129	n.a	n.a.	n.a.	n.a.
Pu-239	< 0.002202	< 0.000428	< 0.002346	< 0.001167
Pu-240	0.002202	< 0.000428	< 0.002346	< 0.001167
Pu-242	< 0.001432	< 0.001386	< 0.002112	< 0.001143
Ra -226	9.294044	0.941171	0.234649	0.07
Tc-99	< 0.330357	n.a.	n.a.	n.a.
Th-229	< 0.061887	< 0.060321	< 0.091748	< 0.0497
Th-230	0.18544	0.183015	0.008917	0.0049
Th-232	0.125536	0.129197	0.000375	0.000233
U-233	< 0.016606	< 0.016154	< 0.024591	< 0.013323
U-234	3.986308	0.889834	0.04693	0.007
U-235	0.158571	0.036877	0.001643	0.000233
U-236	< 0.000573	< 0.000548	< 0.000845	< 0.000443
U-238	3.30357	0.770049	0.035197	0.004667

Table A-23. Activity concentrations (Bq kg^{-1} fresh weight for each radioisotope) for terrestrial, freshwater, and marine organisms at Laxemar. < denotes value below the detection limit.

	Terrestrial				Freshwater				
Isotope	Bilberry sprigs	Moose	Spruce needles	Yellow-necked mouse	Common reed	Duck mussel	Perch, piscivorous	Perch, planktivorous	Water lily
I-129	0.000129	2.59E–05	0.000171	1.78E–05	8.18E–05	2.52E–05	0.000106	0.000356	6.96E–05
Pu-239	< 0.000431	< 0.000312	< 0.002086	< 0.005	< 0.001779	0.002448	< 0.000287	< 0.005749	0.001958
Pu-240	< 0.000431	< 0.000312	< 0.002086	< 0.005	< 0.001779	0.001399	< 0.000287	< 0.005749	0.001088
Pu-242	< 4.31E–05	< 6.24E–05	< 4.17E–05	< 0.0003	< 7.12E–05	< 0.000119	< 0.000115	< 0.000374	< 5.44E–05
Ra-226	6.983561	0.012476	0.750812	0.025	1.031953	2.04219	0.100606	0.057489	0.576582
Tc-99	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Th-229	< 0.002155	< 0.000936	< 0.001668	< 0.00425	< 0.003203	< 0.005315	< 0.002874	< 0.010636	< 0.002285
Th-230	0.00776	0.001684	0.004588	0.000525	0.018148	0.036927	0.00023	0.000747	0.023607
Th-232	0.008622	0.002495	0.005423	0.0005	0.017081	0.030073	0.000287	0.000575	0.02067
U-233	< 0.00069	< 0.000717	< 0.000709	< 0.004075	< 0.00121	< 0.001623	< 0.001725	< 0.005232	< 0.000794
U-234	0.033193	0.003119	0.008342	0.001	0.039143	0.839256	0.020696	0.003449	0.315488
U-235	0.001698	0.000147	0.000459	0.00005	0.001922	0.032241	0.000862	0.000144	0.011858
U-236	< 4.31E–05	< 3.12E–05	< 4.17E–05	< 0.00015	< 3.56E–05	< 5.6E–05	< 5.75E–05	< 0.000172	< 2.18E–05
U-238	0.034487	0.002807	0.009594	0.001	0.039143	0.664411	0.017247	0.002587	0.239336

	Marine						
Isotope	Bladder wrack	Bleak	Blue mussel, muscle	Blue mussel, shell	Charophyte	Perch, piscivorous	Pond weed
I-129	0.003832	0.000118	0.001164	0.001995	0.001166	0.000117	0.00051
Pu-239	0.001606	< 0.000296	< 0.001108	< 0.000887	0.004212	< 0.000569	0.003873
Pu-240	0.00087	< 0.000296	< 0.001108	< 0.000887	0.002754	< 0.000569	0.002854
Pu-242	< 6.69E–05	< 2.96E–05	< 0.000233	< 8.87E–05	< 0.000113	< 8.54E–05	< 6.12E–05
Ra -226	1.455667	0.059149	0.11082	1.640266	0.89094	0.002847	0.417897
Tc-99	0.71947	n.a.	0.9863	0.035465	n.a.	n.a.	n.a.
Th-229	< 0.003514	< 0.002366	< 0.012855	< 0.004876	< 0.004212	< 0.002277	< 0.001733
Th-230	0.002844	0.001952	0.007314	0.001419	0.119062	0.00037	0.116399
Th-232	0.003346	0.002662	0.004987	0.001773	0.106913	0.000569	0.109061
U-233	< 0.000837	< 0.000591	< 0.003203	< 0.001374	< 0.001474	< 0.001167	< 0.000856
U-234	1.823766	0.032532	0.698166	0.664973	1.393105	0.014233	0.97849
U-235	0.072616	0.001479	0.0338	0.031032	0.052322	0.000598	0.038834
U-236	< 3.35E–05	< 2.96E–05	< 0.000111	< 4.43E–05	< 4.86E–05	2< .85E–05	< 3.06E-05
U-238	1.472398	0.032532	0.687084	0.620641	1.052929	0.011386	0.795023

Table A-24. Calculated background dose rates (μGy h⁻¹) for the studied organisms at Forsmark and Laxemar. Default DCC values for Reference Organisms were taken from the ERICA Tool for species where the closest Reference Organism is indicated in parentheses (in italics).

Organisms	Terrestrial		Freshwater		Marine	
	Forsmark	Laxemar	Forsmark	Laxemar	Forsmark	Laxemar
Bank vole	2.9E–02					
Bladder wrack					1.5E+00	2.9E–01
Bleak						9.9E–03
Bilberry		9.6E–01				
Blue mussel						5.7E–02
Blue mussel shell						2.6E–01
Charophyte			8.0E–01			2.0E–01
Duck mussel			1.6E–01	3.5E–01		
Moose 350 kg	8.8E–03	4.5E–03				
Moose 500 kg	8.2E–03	6.2E–02				
Moss	1.5E+00					
Perch (piscivourus)				1.5E–02		1.2E–03
Perch (planktivourus)				9.1E–03		
Pike			1.2E–02			
Fennel pond weed					1.9E–01	1.1–E–01
Reed			2.0E–01	1.9E–01		
Roach			7.7E–02		3.9E–02	
Smelt					1.2E–02	
Spruce needles		1.1E–01				
Stone bramble	2.1E–02					
Water lily				1.4E–01		
Yellow-necked mouse		1.4E–02				

Table A-25. Total dose rates (μGy h⁻¹) at Forsmark due to a release according to the central corrosion case and background radiation combined. Only species where both types of measurement were available are listed.

Terrestrial organisms	Future release	Background	Future release + Background
Bank vole	5.2E–06	2.9E–02	2.9E–02
Moose (350 kg)	1.2E–06	8.8E–03	8.8E–03
Moose (500 kg)	1.2E–06	8.2E–03	8.2E–03
Moss	1.6E–04	1.5E+00	1.5E+00
Stone bramble	3.4E–06	2.1E–02	2.1E–02

Freshwater organisms	Future release	Background	Future release + Background
Charophyte (phytoplankton)	7.1E–07	8.0E–01	8.0E–01
Duck mussel	1.9E–05	1.6E–01	1.6E–01
Pike	4.2E–09	1.2E–02	1.2E–02
Roach	1.5E–08	7.7E–02	7.7E–02

Marine organisms	Future release	Background	Future release + Background
Bladder wrack	4.0E–08	1.5E+00	1.5E+00
Fennel pond weed	1.9E–08	1.9E–01	1.9E–01
Roach	3.5E–10	3.9E–02	3.9E–02
Smelt	3.5E–10	1.2E–02	1.2E–02

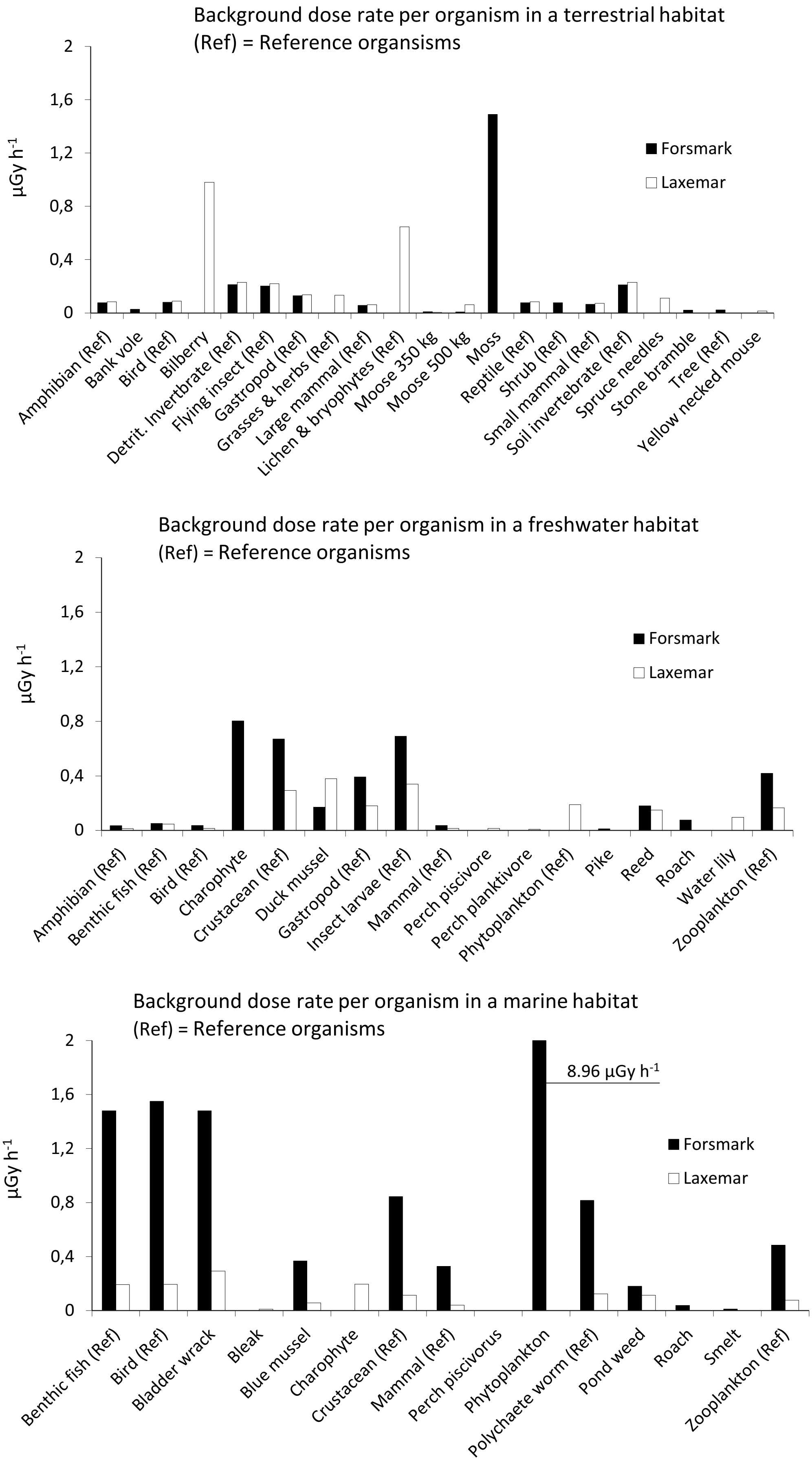


Figure A-2a–c. *Dose rates due to for terrestrial, freshwater, and marine Representative Species and Reference Organisms at Forsmark and Laxemar.*

A4.6 Discussion: total dose rates combining background and releases from the repository

Background dose rates were estimated for some organisms in Forsmark and Laxemar. All dose rates were found to be below 10 μGy h^{-1}. Data with below – detection values were assumed to equate the detection limit value as a conservative estimation yielding the highest background dose rates.

Clearly, the background dose rates to organisms investigated in this study (Table A-24 and Figures A-2 a–c) never exceed 2 μGy h^{-1} except for one organism, *viz.*, phytoplankton that reach a background dose rate of almost 9 μGy h^{-1} (see Figure A-2c). As explained below, the phytoplankton value is likely to be an artefact. The terrestrial background dose rates to biota are comparatively low, less than 0.2 μGy h^{-1} for all organisms except for moss and bilberry that have higher dose rates, both compared to the most similar reference organisms (bryophyte and shrub) and to the rest of the terrestrial biota.

Background dose rates to freshwater biota seem to be higher for those measured in Forsmark than those in Laxemar. A few species exceed the background dose rate of 0.6 μGy h^{-1}. The highest value is found in charophyte, 0.8 μGy h^{-1}, which may be compared to the similar reference phytoplankton 0.2 μGy h^{-1}.

The background radiation includes fallout from atmospheric weapons testing and from the Chernobyl accident. If there is a release from the repository, it will happen in the far future when these particular sources of contamination will be at least partially gone; on the other hand, including these sources of radiation allows for possible future contaminations. Nevertheless, all dose rates are below the screening value of 10 μGy h^{-1}.

The reference organism phytoplankton found in the marine water habitat came close to the screening dose rate level. However, the dose rate for marine reference phytoplankton after a release given in Table 4-7 (3.2E–06) is many orders of magnitude lower than the estimated background rate.

The high background rate for phytoplankton is likely to be an artefact, caused by the absence of actual measurements of activity concentrations in water. In such cases the ERICA Tool, in the version used, substitutes values computed by back-calculation from activity concentrations in other species. Since phytoplankton have much higher CR values than fish (10–1,000 times per nuclide), input data from fish with a moderately high activity concentration can yield spuriously high dose rates for phytoplankton.

In general, background dose rates seem to be higher for almost all water organisms found at the Forsmark site compared to organisms found at Laxemar. This should also be further investigated. One should stress that in order to make comparable evaluations of background dose rates, the same species from the same habitats need to be compared for both investigation sites. This was not the case for the majority of organisms described in this report due to lack of matching data.

For most organisms, DCCs were taken from the ERICA Tool and not from real data. This may influence the resulting background dose rates in either direction. Therefore it would be advisable to derive DCC values for those Representative Species from the site (as well as transfer factors) before any final conclusion can be established concerning the total dose rates including background radiation.

A5 Supplementary information

This Section presents some background information that does not readily fit into other areas.

The release data in Table 3-2 that constitute the primary input to the present study rest on a number of assumptions. Some alternative assumptions, generating somewhat different release data, were tried before it was decided to use the assumptions of /Avila et al. 2010/. During the course of this study, dose rates were calculated for several such earlier release data sets, thus providing a kind of sensitivity analysis. Dose rates from the penultimate iteration are summarised in Section A5.1, and dose rate results from still earlier release data sets are available on request from the author. The results in Section A5.1 are all within one order of magnitude from the most recent results given in Chapter 4, and thus all dose rates are well below the screening dose rate.

As mentioned above, initially an alternative site, Laxemar, was also considered, and data collected for Laxemar could be used as a background, supplementing and increasing confidence in the Forsmark data. Section A5.2 summarises some of the data concerning the organisms studied in Laxemar. This facilitates comparison of data between the two sites data and shows organisms that were missing in Forsmark.

For some organisms, it was not possible to obtain direct data. As far as possible, related Representative/Reference/Average Organisms were substituted for these missing values.

In Section 4.3, "combined" dose rates (for Reference Organisms, but with CRs of site-specific Representative Species) were presented based on Tier 2 ERICA analyses. The corresponding Tier 3 analysis is provided below in Section A5.3.

A5.1 Dose rates based on an earlier set of release data

Table A-26 shows the activity concentrations in media under a previous set of assumptions concerning releases due to the central corrosion case.

Thus, it comprises the primary input to a set of dose-rate calculations in the same manner that Table 3-2 shows the primary input to the final dose-rate calculations. Tables A-27, A-28 andA-29 provide the corresponding dose rates.

The dose rates in Tables A-27, A-28 andA-29 differ from those in Chapter 4, of course; some values are smaller and some are larger than the final ones in Chapter 4. However, all differences are within an order of magnitude. In other words, the earlier data fully support the conclusion drawn from the final data set used in Chapter 4, that all dose rates are far below the screening dose rate.

Table A-26. Maximum values, over time and across all "biosphere objects", of activity concentrations in: Soil (Bq/kg dw and Bq/m^3 for C-14), freshwater, and marine (Bq/l) sediments (Bq/kg dw) predicted with the penultimate iteration of the radionuclide model for the central corrosion case at Forsmark.

Activity concentration after a release according to the central corrosion case						
	Terrestrial		Freshwater		Marine	
Nuclides	Soil	Air	Water	Sediment	Water	Sediment
Ag-108m	2.8E–27	1.4E–34	3.5E–32	1.5E–25	2.2E–33	1.0E–26
Am-241	1.6E–28	7.8E–36	8.3E–33	2.7E–27	6.1E–35	9.6E–29
Am-243	4.9E–27	2.5E–34	5.0E–31	1.3E–25	1.7E–33	1.6E–27
C-14	2.5E–28	7.9E–32	1.5E–29	5.2E–27	3.5E–30	2.3E–27
Ca-41	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Cl-36	6.4E–03	3.2E–10	6.8E–05	5.1E–03	3.8E–06	7.9E–03
Cm-244	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Cm-245	5.4E–27	2.7E–34	1.3E–31	7.4E–26	3.3E–34	1.2E–27
Cm-246	2.7E–27	1.3E–34	5.3E–32	4.8E–26	2.1E–34	7.5E–28
Cs-135	1.0E+00	5.0E–08	9.2E–06	2.2E+00	8.9E–08	2.6E–02
Cs-137	2.5E–32	1.2E–39	1.3E–36	2.6E–30	2.7E–37	4.8E–31
Ho-166m	7.2E–28	3.6E–35	9.9E–33	1.2E–26	5.3E–34	3.8E–28
I-129	1.0E+00	5.0E–08	5.7E–04	4.4E+01	1.3E–05	1.1E+00
Nb-94	1.5E–04	7.7E–12	5.0E–10	4.7E–04	9.2E–12	7.5E–06
Ni-59	3.5E+00	1.7E–07	3.3E–04	4.8E+01	3.0E–06	6.5E–01
Ni-63	1.0E–28	5.2E–36	6.3E–33	1.4E–27	2.6E–34	1.7E–28
Np-237	4.5E–04	2.3E–11	2.1E–07	1.9E–02	4.9E–09	3.8E–04
Pa-231	1.5E–04	7.7E–12	2.2E–08	1.9E–03	5.3E–11	2.7E–05
Pb-210	5.4E–03	2.7E–10	2.9E–08	1.4E–01	7.2E–10	1.9E–03
Pd-107	6.9E–03	3.5E–10	3.0E–07	8.3E–04	3.1E–09	8.1E–05
Po-210	5.4E–03	2.7E–10	2.8E–07	1.4E–01	8.6E–11	2.1E–03
Pu-239	5.2E–06	2.6E–13	1.8E–09	6.9E–05	4.2E–12	1.4E–06
Pu-240	4.6E–27	2.3E–34	1.9E–30	1.1E–25	7.0E–33	2.4E–27
Pu-242	8.5E–04	4.2E–11	2.8E–07	6.5E–03	4.0E–10	1.3E–04
Ra-226	5.4E–03	2.7E–10	5.1E–07	1.2E–01	1.2E–08	1.9E–03
Se-79	2.4E–03	1.2E–10	1.3E–06	6.1E–02	3.3E–08	2.0E–03
Sm-151	4.1E–30	2.0E–37	9.8E–35	8.7E–29	4.2E–36	1.5E–29
Sn-126	3.2E–04	1.6E–11	1.1E–08	2.6E–03	1.2E–10	2.8E–05
Sr-90	5.8E–30	2.9E–37	6.9E–33	1.6E–29	3.0E–34	4.0E–30
Tc-99	1.7E–04	8.7E–12	3.2E–06	1.4E–03	1.3E–07	6.0E–04
Th-229	7.3E–04	3.7E–11	1.9E–09	4.3E–03	4.3E–12	1.2E–04
Th-230	8.3E–04	4.1E–11	2.4E–09	9.6E–04	1.1E–12	2.2E–05
Th-232	3.6E–08	1.8E–15	2.5E–13	9.6E–08	2.3E–17	4.5E–10
U-233	1.0E–04	5.1E–12	4.9E–09	1.1E–03	8.1E–11	1.2E–05
U-234	1.9E–06	9.3E–14	8.6E–11	1.0E–05	6.6E–13	1.1E–07
U-235	7.9E–08	3.9E–15	3.7E–12	4.1E–07	2.7E–14	4.6E–09
U-236	1.3E–06	6.7E–14	6.3E–11	7.1E–06	4.7E–13	7.9E–08
U-238	9.2E–07	4.6E–14	4.3E–11	4.7E–06	3.1E–13	5.3E–08
Zr-93	2.5E–02	1.2E–09	1.3E–06	2.0E–01	1.9E–09	4.5E–03

Table A-27. Risk Quotients (RQ) obtained in ERICA Tier 2 analyses and dose rates (µGy h^{-1}) obtained in Tier 3 analyses, for terrestrial biota at Forsmark based on activity concentrations from Table A-26.

Organism, habitat	Tier 2 analysis "Expected" RQ	 "Conservative" RQ	Tier 3 analysis Mean dose rate
Representative terrestrial species from the site			
Bank vole	4.0E–06	1.2E–05	4.0E–05
Bilberry shrub	6.2E–06	1.9E–05	6.2E–05
Common shrew	6.0E–06	1.8E–05	6.0E–05
Moose (350 kg, 500 kg: results identical)	6.0E–07	1.8E–06	6.0E–06
Norwegian spruce	4.1E–06	1.2E–05	4.1E–05
Red fox	1.4E–06	4.2E–06	1.4E–05
Small cow-wheat	8.1E–06	2.4E–05	8.1E–05
Stone bramble	2.8E–05	8.4E–05	2.9E–04
Water vole	3.0E–06	9.0E–06	3.1E–05
Yellow-necked mouse	2.9E–06	8.7E–06	2.9E–05
Average terrestrial organisms			
Average bryophyte	1.4E–05	4.3E–05	1.5E–04
Average mushroom	1.9E–05	5.7E–05	1.8E–04
Average rodent	4.5E–06	1.3E–05	4.5E–05
Average vascular plant	1.6E–05	4.8E–05	1.6E–04
Reference terrestrial organisms			
Amphibia (terrestrial)	8.5E–06	2.5E–05	8.5E–05
Bird (terrestrial)	9.4E–06	2.8E–05	9.4E–05
Detritivorous invertebrate (terrestrial)	9.9E–06	3.0E–05	9.7E–05
Flying insect (terrestrial)	8.9E–06	2.7E–05	8.7E–05
Gastropod (terrestrial)	5.5E–06	1.7E–05	5.5E–05
Grasses & herbs (terrestrial)	1.1E–05	3.4E–05	1.2E–04
Mammal, large (terrestrial)	1.7E–05	5.2E–05	1.7E–04
Mammal, small (terrestrial)	1.7E–05	5.2E–05	1.7E–04
Lichen & bryophytes (terrestrial)	1.5E–04	4.4E–04	1.5E–03
Reptile (terrestrial)	2.1E–05	6.2E–05	2.1E–04
Shrub (terrestrial)	2.1E–05	6.4E–05	2.1E–04
Soil invertebrate (terrestrial)	9.1E–06	2.7E–05	9.1E–05
Tree (terrestrial)	3.1E–06	9.4E–06	3.1E–05

Table A-28. Risk Quotients (RQ) obtained in ERICA Tier 2 analyses and dose rates (µGy h^{-1}) obtained in Tier 3 analyses, for freshwater biota at Forsmark based on activity concentrations from Table A-26.

Organism, habitat	Tier 2 analysis "Expected" RQ	 "Conservative" RQ	Tier 3 analysis Mean dose rate
Representative freshwater Species from the site			
Chara	9.8E–07	2.9E–06	9.8E–06
Duck mussel	3.7E–05	1.1E–04	3.7E–04
Pike	3.8E–07	1.1E–06	3.7E–06
Roach	2.0E–07	6.1E–07	2.1E–06
Ruffe	2.3E–07	7.0E–07	2.4E–06
Tench	1.2E–07	3.7E–07	1.3E–06
Average freshwater Organisms			
Average fish	4.1E–07	1.2E–06	4.2E–06
Reference freshwater Organisms			
Bird (freshwater)	1.5E–06	4.5E–06	1.5E–05
Bivalve mollusc (freshwater)	7.7E–05	2.3E–04	7.6E–04
Crustacean (freshwater)	6.5E–05	2.0E–04	6.5E–04
Gastropod (freshwater)	6.5E–05	1.9E–04	6.5E–04
Insect larvae (freshwater)	1.2E–04	3.6E–04	1.2E–03
Mammal (freshwater)	2.0E–06	5.8E–06	2.0E–05
Pelagic fish (freshwater)	1.8E–06	5.6E–06	1.8E–05
Phytoplankton (freshwater)	6.0E–05	1.8E–04	6.0E–04
Vascular plant (freshwater)	6.5E–05	2.0E–04	5.5E–04
Zooplankton (freshwater)	3.7E–05	1.1E–04	3.7E–04

Table A-29. Risk Quotients (RQ) obtained in ERICA Tier 2 analyses, and dose rates (µGy h^{-1}) obtained in Tier 3 analyses, for marine biota at Forsmark, based on activity concentrations from Table A-26.

Organism, habitat	Tier 2 analysis "Expected" RQ	 "Conservative" RQ	Tier 3 analysis Mean dose rate
Representative marine Species from the site			
Bladder wrack	1.8E–07	5.5E–07	1.8E–06
Brown algae	2.7E–08	8.0E–08	2.7E–07
Fennel pondweed	3.4E–09	1.0E–08	3.4E–08
Idothea	1.4E–09	4.2E–09	1.4E–08
Lagoon cockle	2.1E–08	6.2E–08	2.1E–07
Baltic macoma	1.4E–06	4.3E–06	1.4E–05
Microphytes	2.0E–09	5.9E–09	2.0E–08
Phytoplankton	2.8E–10	8.5E–10	2.8E–09
River nerite	1.9E–08	5.6E–08	1.9E–07
Roach	4.0E–10	1.2E–09	4.0E–09
Ruffe	1.8E–09	5.3E–09	1.8E–08
Smelt	3.1E–09	9.3E–09	3.1E–08
Zoo plankton	5.0E–09	1.5E–08	5.0E–08
Average marine Organisms			
Average fish	2.5E–09	7.4E–09	7.7E–08
Average mollusc	7.5E–07	2.2E–06	7.5E–06
Average phytoplankton	1.1E–09	3.4E–09	1.1E–08
Reference marine Organisms			
Benthic fish (marine)	6.4E–07	1.9E–06	6.4E–06
Benthic mollusc (marine)	8.0E–07	2.4E–06	8.0E–06
Bird (marine)	5.3E–08	1.6E–07	5.2E–07
Crustacean (marine)	6.3E–08	1.9E–07	6.3E–07
Macroalgae (marine)	1.1E–06	3.4E–06	1.2E–05
Mammal (marine)	1.5E–08	4.5E–08	1.5E–07
Pelagic fish (marine)	5.5E–08	1.6E–07	5.3E–07
Phytoplankton (marine)	3.2E–07	9.6E–07	3.2E–06
Polychaete worm (marine)	1.7E–06	5.1E–06	1.7E–05
Vascular plant (marine)	1.1E–06	3.2E–06	1.1E–05
Zooplankton (marine)	2.3E–07	6.9E–07	2.3E–06

A5.2 Data concerning organisms sampled at the Laxemar site

At an initial stage, Laxemar was considered as a possible alternative site for the repository for spent nuclear fuel. Data collected there provide a useful backdrop for comparison with the Forsmark data.

The basic descriptive data in Table A-1 include information on specimens found at Laxemar. A list of Representative Species from the Laxemar site is given in Table A-30. Table A-31 shows Average Organisms from Laxemar, and Table A-32 lists the number of samples per Representative Species and per Average Organism.

For some species, information on conversion factors is available from both sites, as shown in Table A-3. Tables A-5, A-7, and A-9 contain concentration ratio values obtained for Laxemar.

Table A-30. Representative Species from the Laxemar site considered in the assessments.

English name	Swedish name	Scientific name	Related species in ERICA
Terrestrial			
Alder	Al	*Alnus sp*	Tree
Bank vole ("field")	Ängssork	*Myodes glareolus*	Small mammal
Bank vole ("forest")	Ängssork	*Myodes glareolus*	Small mammal
Common shrew	Vanlig näbbmus	*Sorex araneus*	Small mammal
Moose	Älg	*Alces alces*	Large mammal
Norwegian spruce	Gran	*Picea abies*	Tree
Oak	Ek	*Quercus robur*	Tree
Red fox	Rödräv	*Vulpes vulpes*	Large mammal
Roe deer	Rådjur	*Capreolus capreolus*	Large mammal
Wood mouse	M. skogsmus	*Apodemus*	Small mammal
Freshwater			
Duck mussel	Dammussla	*Anodonta anatina*	Bivalve mollusc
Perch	Abborre	*Perca fluviatilis*	Pelagic fish
Reed	Vass	*Phragmites australis*	Vascular plant
Roach	Mört	*Rutilus rutilus*	Pelagic fish
Water lily	Näckros	*Nymphaeaceae*	Vascular plant
Marine			
Bladder wrack	Blåstång	*Fucus vesiculosus*	Macroalgae
Bleak	Löja	*Alburnus alburnus*	Pelagic fish
Bream	Braxen	*Abramis brama*	Pelagic fish
Blue mussel	Blåmussla	*Mytilus edulis*	Benthic mollusc
Chara	Chara	*Chara sp*	Vascular plant
Flounder	Flundra	*Platichthys flesus*	Benthic fish
Green algae	Grönalg	–	Vascular plant
Herring	Strömming	*Clupea harengus*	Pelagic fish

Table A-31. "Average Organisms" at Laxemar considered in the assessments and "Representative Species from the site" included in each Average organism (F = freshwater, M = marine).

Average Organisms	Species at Laxemar English names	Scientific names
Average rodent (T)	Bank vole ("field")	*Myodes glareolus*
	Bank vole ("forest")	*Myodes glareolus*
	Common shrew	*Sorex araneus*
	Wood mouse	*Apodemus*
Average tree (T)	Alder	*Alnus sp*
	Norwegian spruce	*Picea abies*
	Oak	*Quercus robur*
Average fish (F)	Perch	*Perca fluviatilis*
	Roach	*Rutilus rutilus*
Average fish (M)	Bleak	*Alburnus alburnus*
	Bream	*Abramis brama*
	Flounder	*Platichthys flesus*
	Herring	*Clupea harengus*

Table A-32. Total number of samples per Representative Species from the site and Average Organism collected at the Laxemar investigation site and used for calculation of Concentration Ratios.

Species	No. of samples
Alder	1
Bank vole ("field")	2
Bank vole ("forest")	3
Bladder wrack	3
Bleak	3
Blue mussel	2
Bream	2
Chara	3
Common shrew	1
Duck mussel	3
Flounder	3
Green algae	3
Herring	3
Moose	3
Norwegian spruce	1
Oak	1
Perch (lake)	3
Perch (marine)	3
Red fox	3
Reed	3
Roach	3
Roe deer	3
Water lily	3
Wood mouse	3
Average Organisms	
Average fish (F)	3
Average fish (M)	14
Average rodent	9
Average Tree	3

A5.3 "Combined" dose rates obtained in Tier 3 analyses

In the concluding part of Section 4.3, all available CR values from each Representative Species from the site were applied to a corresponding Reference Organism by replacing the generic CR values of ERICA with site-specific CR values. The resulting "combined" dose rates obtained in Tier 2 analyses were consistently similar to those obtained for Reference Organisms using generic CR values, indicating that the dose rate results were robust.

Below, similar combined dose rates obtained in Tier 3 analyses, with 5th and 95th percentiles and medians, are provided in Table A-33. The conclusions remain unchanged, i.e. the combined dose rates are similar to those of the Reference Organisms and many orders of magnitude below the screening criterion.

Table A-33. Dose rates of Reference Organisms and Representative Species from the site and "combined" dose rates (for Reference Organisms, substituting when possible CRs of Representative Species for generic values), and medians and 5th and 95th percentiles, obtained in Tier 3 analyses.

Reference Organisms (in parentheses: corresponding Representative Species from the site)	Dose rates (μGy h^{-1})					
	Repr. Species	Ref. Organisms	Combined dose rates (Reference Organisms using CRs of Representative Species			
			Mean	5th percentile	Median	95th percentile
Terrestrial						
Grasses & Herbs (Average vascular plant)	3.5E–06	6.0E–05	3.6E–05	1.2E–05	2.7E–05	8.7E–05
Grasses & Herbs (Bilberry)	3.1E–06	6.0E–05	3.6E–05	1.2E–05	2.6E–05	8.6E–05
Grasses & Herbs (Small cow-wheat)	3.9E–06	6.0E–05	3.6E–05	1.2E–05	2.7E–05	8.7E–05
Grasses & Herbs (Stone bramble)	3.4E–06	6.0E–05	3.5E–05	1.2E–05	2.6E–05	8.6E–05
Large mammal (Red fox)	3.9E–06	2.2E–05	2.0E–05	6.1E–06	1.6E–05	4.6E–05
Large mammal (Moose)	1.2E–06	2.2E–05	2.0E–05	6.6E–06	1.7E–05	4.6E–05
Lichen & bryophytes (Average moss)	1.9E–04	6.7E–04	8.1E–04	3.4E–04	6.4E–04	1.5E–03
Lichen & bryophytes (Average mushroom)	9.6E–07	6.7E–04	6.6E–04	3.1E–04	5.9E–04	1.2E–03
Small mammal (Average rodent)	5.1E–06	2.5E–05	2.4E–05	1.1E–05	2.1E–05	4.9E–05
Small mammal (Bank vole)	5.2E–06	2.5E–05	2.4E–05	1.1E–05	2.1E–05	4.9E–05
Small mammal (Common shrew)	4.9E–06	2.5E–05	2.5E–05	1.1E–05	2.1E–05	5.1E–05
Small mammal (Water vole)	4.8E–06	2.5E–05	2.4E–05	1.1E–05	2.1E–05	4.9E–05
Small mammal (Yellow necked mouse)	2.2E–07	2.5E–05	2.5E–05	1.1E–05	2.1E–05	5.0E–05
Tree (Norwegian spruce)	2.3E–06	5.9E–05	6.1E–05	1.0E–05	4.5E–05	1.7E–04
Freshwater						
Bivalve mollusc (Duck mussel)	1.9E–05	3.7E–04	4.0E–04	1.7E–04	3.2E–04	8.5E–04
Pelagic fish (Average fish)	1.7E–08	1.7E–05	1.7E–05	5.2E–06	1.3E–05	3.9E–05
Pelagic fish (Pike)	4.2E–09	1.7E–05	1.7E–05	5.3E–06	1.4E–05	3.8E–05
Pelagic fish(Roach)	1.5E–08	1.7E–05	1.7E–05	5.5E–06	1.4E–05	4.0E–05
Pelagic fish (Ruffe)	1.5E–09	1.7E–05	1.7E–05	5.6E–06	1.4E–05	3.9E–05
Pelagic fish (Tench)	5.4E–06	1.7E–05	4.0E–05	2.9E–05	3.7E–05	6.3E–05
Vascular plant (Chara)	7.1E–07	5.2E–04	4.4E–04	9.5E–05	3.4E–04	1.1E–03
Marine						
Benthic mollusc (Average mollusc)	6.2E–08	1.9E–06	1.8E–06	1.2E–06	1.7E–06	3.1E–06
Benthic mollusc (Baltic macoma)	9.1E–08	1.9E–06	2.7E–06	2.0E–06	2.5E–06	4.0E–06
Benthic mollusc (Lagoon cockle)	7.3E–08	1.9E–06	1.8E–06	1.2E–06	1.7E–06	3.1E–06
Benthic mollusc (River nerite)	1.4E–08	1.9E–06	9.9E–07	3.4E–07	8.0E–07	2.2E–06
Crustacean (Idothea)	5.9E–08	6.3E–07	1.4E–06	1.0E–06	1.3E–06	2.0E–06
Macroalgae (Bladder wrack)	4.0E–08	1.4E–06	1.5E–06	1.2E–06	1.4E–06	1.9E–06
Macroalgae (Brown algae)	1.8E–08	1.4E–06	5.1E–07	2.7E–07	4.7E–07	9.0E–07
Pelagic fish (Average fish)	5.3E–10	3.4E–07	3.4E–07	6.5E–08	2.2E–07	1.0E–06
Pelagic fish (Roach)	3.4E–10	3.4E–07	3.4E–07	6.4E–08	2.1E–07	1.0E–06
Pelagic fish (Ruffe)	5.7E–10	3.4E–07	3.5E–07	6.5E–08	2.2E–07	1.0E–06
Pelagic fish (Smelt)	3.5E–10	3.4E–07	3.3E–07	6.3E–08	2.1E–07	9.8E–07
Phytoplankton (Average phytoplankton)	2.1E–08	2.9E–06	2.8E–06	1.0E–06	2.3E–06	6.1E–06
Phytoplankton (Microphytes)	3.8E–08	2.9E–06	2.8E–06	1.1E–06	2.3E–06	5.9E–06
Phytoplankton (Phytoplankton)	3.3E–09	2.9E–06	2.7E–06	1.0E–06	2.3E–06	6.1E–06
Vascular plant (Fennel pondweed)	1.9E–08	1.3E–06	5.2E–07	1.8E–07	4.6E–07	1.1E–06
Zooplankton (Zooplankton)	2.1E–09	3.4E–07	3.3E–07	1.5E–07	2.8E–07	6.7E–07