Strål
säkerhets
myndigheten
Swedish Radiation Safety Authority

Author: Brenda Howard
Nicholas Beresford

Technical Note

2014:17

Assessment of radiological effects on non-human biota

Main Review Phase

Report number: 2014:17 **ISSN:** 2000-0456
Available at www.stralsakerhetsmyndigheten.se

SSM perspektiv

Bakgrund

Strålsäkerhetsmyndigheten (SSM) granskar Svensk Kärnbränslehantering AB:s (SKB) ansökningar enligt lagen (1984:3) om kärnteknisk verksamhet om uppförande, innehav och drift av ett slutförvar för använt kärnbränsle och av en inkapslingsanläggning. Som en del i granskningen ger SSM konsulter uppdrag för att inhämta information och göra expertbedömningar i avgränsade frågor. I SSM:s Technical note-serie rapporteras resultaten från dessa konsultuppdrag.

Projektets syfte

Det övergripande syftet med projektet är att ta fram synpunkter på SKB:s säkerhetsanalys SR-Site för den långsiktiga strålsäkerheten hos det planerade slutförvaret i Forsmark. Den specifika målsättningen med detta externa granskningsprojekt är att granska och bedöma SKB beräkningar och beskrivningar angående slutförvarets förväntade långsiktiga effekter på växter och djur. Har SKB utfört dessa beräkningar i enlighet med de riktlinjer som finns för den använda metodiken ”ERICA Integrated Approach”? Är det möjligt att andra relevanta angreppsätt eller parametervärden skulle kunna leda till helt andra slutsatser angående risker för växter och djur än de SKB kommer fram till?

Författarnas sammanfattning

Denna rapport utgör en granskningsrapport rörande SKB:s utvärdering av långsiktiga radiologiska effekter på växter och djur av ett geologiskt djupförvar vilken SKB redovisar i rapporten TR-10-08. SKB-rapporten är en av många som bidrar till den övergripande säkerhetsanalysen SR-Site. Slutsatsen i SKB:s rapport var att ”Utvärderingen ger ingen anledning att förvänta sig några skadliga effekter på någon art.”.

Syftet med granskningen var att bedöma ifall utvärderingen, som genomfördes enligt ERICA Integrated Approach, kunde ha genomförts på ett annat sätt som skulle ha resulterar i avsevärt annorlunda slutsatser. Vårt syfte var därmed att bedöma om konsekvenserna av en given källterm skulle kunna vara underskattade av SKB. Varje del av SKB:s utredning behandlades därför separat där lämpligheteten i SKB:s angreppsätt och effekten av relevanta alternativa angreppssätt utvärderades.

Ett viktigt skyddsmål i utvärderingen, definierat i SSM:s föreskrifter, utgår från värde av vissa typer av arter. Speciell hänsyn till nyckelarter eller arter som identifierats som rödlistade eller som av speciellt ekonomiskt värde verkar dock ha tagits endast i begränsad omfattning.

Delar av SKB:s utvärdering är konservativ. Givet osäkerheten i att göra bedömningar över de långa tidsperioder som utvärderingen behandlar är det befogat med ett konservativt angreppsätt. Med ett sådant angreppssätt hade det varit lämpligt att utgå från det scenario som ger de högsta beräknade halterna i miljön. SKB refererar till förekomsten av ett annat scenario, vilket ger upphov till högre halter i miljön än det som de slutligen utvärderat. De generella slutsatserna hade dock inte påverkats om detta andra scenario hade legat till grund för utvärderingen istället. Med syftet att göra en konservativ utvärdering som tar hänsyn till de osäkerheter som är förknippade med så långsiktiga uppskattningar anser vi att det inte var lämpligt av SKB att exkludera några av de referensorganismer som ingår i ERICA Tool. SKB har inte heller tydligt motiverat varför ett antal radionuklider som i övrigt ingår i SR-Site utelämnats i utvärderingen avseende effekter på växter och djur.

En stor del av TR-10-08 tillägnas valet av representativa arter och genomsnittsarter med det uttalade syftet att öka konfidensen i slutsatserna. Men detta arbete blir av litet värde då ofullständiga analyser genomförts för dessa organismer. Bristande information angående faktiskt använda CRwo-värden minskar transparensen i utvärderingen.

SKB:s utvärdering är inkomplett och/eller saknar transparens ur flera aspekter. Men utgående från att scenariot med resulterande aktivitetskoncentrationer i miljön är relevant visar vi, genom relevanta altenativa resonemang, angrepssätt och/eller parametervärden, att dessa frågor sannolikt inte påverkar de slutsatser som SKB drar av sin utvärdering.

Projektinformation

Kontaktperson på SSM: Pål Andersson
Diarienummer avtal: SSM2013-3686
Aktivitetsnummer: 3030012-4110

SSM perspective

Background

The Swedish Radiation Safety Authority (SSM) reviews the Swedish Nuclear Fuel Company's (SKB) applications under the Act on Nuclear Activities (SFS 1984:3) for the construction and operation of a repository for spent nuclear fuel and for an encapsulation facility. As part of the review, SSM commissions consultants to carry out work in order to obtain information and provide expert opinion on specific issues. The results from the consultants' tasks are reported in SSM's Technical Note series.

Objectives of the project

The general objective of the project is to provide review comments on SKB's postclosure safety analysis, SR-Site, for the proposed repository at Forsmark. The SR-Site assessment of effects on plants and animals is performed by applying the ERICA Integrated Approach including ERICA Tool. The specific objective of the work presented in this report is to assess if the ERICA integrated approach has been applied in accordance with existing guidelines and state of the art in the topical area, and if a credible alternative approach or parameterization could lead to significantly different assessment conclusions regarding potential effects on plants and animals.

Summary by the authors

This report presents a review of SKBs assessment of the long-term radiological effects on plants and animals of a deep geological repository as described in SKB report TR-10-08. The SKB report is one of a number contributing to the overall safety assessment, referred to as SR-Site, for the repository. The conclusion of the SKB report was that the 'study gives no reason to assume that any of the species would be harmfully affected ……'

The aim of the review was to determine if the SKB assessment, conducted using the ERICA Integrated Approach, could have been conducted differently such that a significantly different conclusion could have been reached. So our aim was to determine if the consequences of a given source term could have been underestimated by SKB. Therefore, each element of the assessment was considered separately. The appropriateness of the SKB approach and the effect of any justifiable alternatives were evaluated.

A key protection goal of the assessment, as defined by SSM, relates to the value of certain types of species. There appears to have been little 'special attention' paid to the identified red-list, functional key or economically important species.

Elements of the non-human assessment conducted by SKB are conservative. Given the uncertainties in making predictions over the long time periods considered in the assessment adopting conservative assumptions is a justified approach. However, for a conservative approach, it would

have been appropriate to consider the scenario resulting in the highest predicted media activity concentrations; SKB make reference to a scenario which would result in higher activity concentrations in the environment than the scenario they chose to assess. However, the alternative scenario SKB quote would not have altered their overall conclusion.

With the aim of conducting a conservative assessment which tries to account for the uncertainties involved in such long-term predictions we suggest that it was not appropriate to exclude some of the default ERICA Tool Reference Organisms. Furthermore, the exclusion from the non-human biota assessment of some radionuclides considered within SR-Site is not justified by the SKB report.

A considerable proportion of TR-10-08 is devoted to the selection of Representative Species and Average Organisms with the stated aim of increasing confidence. However, this is of little value as incomplete assessments are conducted for these organisms and hence confidence is not increased. The lack of information on the CRwo values actually used does not help transparency.

A number of aspects of the SKB assessment are incomplete and/or lack transparency. However, assuming that the source term scenario is realistic and that it is the appropriate one to have been chosen for the assessment, by addressing these issues and/or using credible alternative parameters we demonstrate that these issues are unlikely to affect the conclusion reached by SKB.

Project information
Contact person at SSM: Pål Andersson

Strål
säkerhets
myndigheten
Swedish Radiation Safety Authority

Author: Brenda Howard and Nicholas Beresford
NERC's Centre for Ecology & Hydrology, Lancaster, United Kingdom

Technical Note 51

2014:17

Assessment of radiological effects on non-human biota

Main Review Phase

Date: December 2013
Report number: 2014:17 **ISSN:** 2000-0456
Available at www.stralsakerhetsmyndigheten.se

Contents

1. Introduction

This report presents a review of SKBs assessment of the long-term radiological effects on plants and animals of a deep geological repository as described in SKB report TR-10-08 (Torudd 2010)[1]. The SKB report is one of a number contributing to the overall safety assessment, referred to as SR-Site, for the repository (SKB 2011; report TR-11-01).

It was initially envisaged that an evaluation of transfer parameters (i.e. concentration ratios, see below) used within the non-human biota assessment would be included within an overall assessment of concentration ratios and distribution coefficients (i.e. K_d values) used for human and non-human assessment by SKB (see Beresford et al. 2013). However, in evaluating SKB reports R-10-28 (Tröjbom & Nordén 2013) and TR-10-07 (Nordén et al. 2010), which describe the available of site specific data and the subsequent derivation of concentration ratio and K_d values for human assessment, it was considered that an evaluation of the concentration ratios used for non-human biota was more logically placed within this report. This enables a more complete consideration of the non-human assessment conducted by SKB to be described here. The approach was agreed by SSM. This evaluation considers R-10-28 and additional SKB reports as appropriate (all reports are listed as required in Appendix 1). We also make reference to the initial review of the non-human biota assessment conducted by Stark (2012).

The report presents our assessment in response to the specific questions raised by SSM in the tender documentation. These were to:

- Assess if the ERICA Integrated Approach (Beresford et al. 2007) has been applied in accordance with guidelines and the state of the art in the topical area, or if the SKB assessment approach leaves questions about the validity of drawn conclusions.
- Review within this assessment the problem formulation including the choice of which organisms, nuclides, ecosystems, and discharges or environmental concentrations that are included in the assessment and how these are represented in the ERICA Tool (Brown et al. 2008).
- Review parameter values and characteristics used for organisms added to the ERICA Tool by SKB.

From discussions with SSM we understand that the primary aim of this review is to consider if SKB could have approached the assessment differently such that a significantly different conclusions regarding potential effects on plants and animals could have been reached. We have accordingly structured this report to consider each component of the assessment and application of the ERICA Tool and evaluate what, if anything, SKB could have done differently. Where appropriate, we have run the ERICA Tool to help in this evaluation.

We have considered that any evaluation of how the source term was calculated is outside the scope of this review.

---

[1]SKB reports will be referred to by report number for all instances after the initial reference within the text.

2. Evaluation of the SKB assessment of radiological effects on plants and animals of a deep geological repository

2.1. SKB's presentation

SKB have conducted an assessment to demonstrate that non-human biota will be protected against the harmful effects of ionising radiation as a consequence of the planned repository for spent fuel to be sited at Forsmark.

The motivation for the assessment appears to have been the requirement of SSM that the impact assessment include non-human biota as well as man. SKB state that the regulations issued by SSM (2008) require that special attention is paid to threatened or vulnerable species, functional key species and economically important species.

The assessment used the 'central corrosion case' release scenario justifying this selection on the basis that preliminary assessments had indicated that this scenario had the biggest impact of the two scenarios considered, the other scenario being the 'growing pinhole' (see section 2.4.2). The maximum predicted activity concentrations in soil or air (terrestrial ecosystem) and water and sediment (aquatic ecosystem) from this central corrosion case were used in the assessment. Dose rates were estimated by inputting these predicted radionuclide activity concentrations into the ERICA Tool (see section 2.3). However, only those radionuclides for which transfer parameter data were available were included in the assessment.

SKB state that they assessed impact by evaluating the potential effect of a radionuclide release on individual specimens of a range of important and/or sensitive species. This being rationalised on the basis that if individuals are not impacted then populations/ecosystems are unlikely to be so.

Organisms inhabiting wetlands, watercourses, lakes and the sea were considered by SKB. In addition to most of the default Reference Organisms included in the ERICA Tool SKB included a range of species to '*increase confidence in the assessment*' and comply with the above requirements of SSM. Site specific data (sources from R-10-28) were used to derive transfer parameters for the additional organisms. Otherwise, default parameters from the ERICA Tool appear to have been used.

To evaluate risk estimated dose rates were compared with a generic screening dose rate of 10 $\mu Gy\ h^{-1}$ which is the default value in the ERICA Tool.

SKB consider some sources of uncertainty in the assessment and comment on whether these would impact significantly on the estimated dose rates.

SKBs approach to each element of the assessment is discussed and reviewed within section 2.4.

2.2. Motivation of the review

As noted above, following information in the tender documentation and discussions with SSM we have approached our review with the main aim of determining if the SKB assessment could have been conducted differently such that a significantly different conclusion could have been reached (i.e. our aim was to determine if the consequences of a given source term could have been underestimated by SKB). Therefore, we isolate each element of the assessment within the subsequent text and consider the appropriateness of the SKB approach and the effect of any justifiable alternatives.

2.3. Brief overview of the ERICA Integrated Approach and the ERICA Tool

The need for a system capable of demonstrating that the environment is adequately protected from the effects of radioactive substances has been recognised by international organisations such as ICRP and the IAEA and a number of regulators. A key driver is the need to demonstrate that the environment is protected, although in some countries a system of protection is required to address conservation legislation.

As this report assess the SKB application of the ERICA Integrated Approach an overview of the approach and accompanying ERICA Tool is provided for the reader in this section. The introductory text is based on briefing notes provided at the website Radiological Protection of the Environment – sharing knowledge supplemented by additional material, largely from special issues of journals on the topic area published since 2007 (Williams 2004; Howard & Larsson 2008; Copplestone et al., 2010; Beresford 2010; Howard 2013a).

Conducting an assessment

The process steps of the ERICA Integrated Approach are described in (Beresford et al. (2007) and Howard & Larsson (2008). Problem formulation is the first step of any risk assessment and includes consideration of ecological, political and societal issues when deciding on procedures and methods, who to involve, and any benchmarks or assessment criteria that the outcome will be compared with.

An initial key element before an assessment is conducted is to specify the Protection goal, which identifies the aspect of the environment that needs to be protected. The purpose and manner of any stakeholder involvement needs to consider the type of stakeholders, the reason for involvement, stage of involvement, influence-interest category and means of engagement. The implementation of the assessment as well as the application of its outcome also requires managerial considerations and decisions (Zinger et al., 2008).

The ERICA Integrated Approach uses Reference Organisms in a way which is complementary to that of the Reference Animals and Plants proposed by ICRP (ICRP 2008; 2009). The use of the Integrated Approach is facilitated by the ERICA Tool, which is a software programme that guides the user through the various steps, keeps records and communicates with a number of purpose-built databases. All project documents can be accessed via www.ceh.ac.uk/protect.

The transfer pathways and assessment endpoints need to be described and a conceptual model developed for the system being considered. The assessment of the exposure of wildlife to ionizing radiation requires (i) quantification of the transfer of radionuclides to wildlife and (ii) dose conversion coefficients relating internal and media activity concentrations to estimate absorbed dose rates to wildlife.

Within the ERICA Tool the transfer model is highly simplified. All of the processes influencing transfer are amalgamated into one parameter, the whole organism concentration ratio (CR_{wo}) which is the ratio of the whole body activity concentrations relative to that in the appropriate environmental media. In terrestrial ecosystems, for most radionuclides, CR_{wo} is defined as:

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

The exceptions are some radionuclides released as chronic atmospheric emissions (e.g. ^{3}H, ^{14}C) are estimated as:

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

For aquatic ecosystems the majority of approaches calculate CR_{wo} as:

$$CR_{\text{wo-water}} = \frac{\text{Activity concentration in biota whole orgamism (Bq kg}^{-1}\text{ fresh weight)}}{\text{Activity concentration in water (Bq L}^{-1}\text{)}}$$

In aquatic systems the activity concentration in sediment is also required, to estimate external dose rates to benthic organisms. If this is not known then it can be estimated from the activity concentration in water by using the solid-liquid distribution coefficient (K_d) which describes the relative activity concentrations in soil solution and on soil solids:

$$K_d(L\ kg^{-1}) = \frac{activity\ concentration\ in\ solid\ phase\ (Bq\ kg^{-1})}{activity\ concentration\ in\ liquid\ phase\ (Bq\ L^{-1})}$$

If sediment activity concentrations are known but water concentrations are not, the K_d can be used to estimate activity concentrations in water.

The ERICA Tool uses CR values based on data and provides derived values, using a number of different methods, when there are no data available. An on-line transfer wildlife database CR_{wo} database has been developed (Copplestone et al., 2013) and used to produce an IAEA handbook of radionuclide transfer parameters for wildlife (Howard et al., 2013b) and an ICRP report on CR values for the RAPs (ICRP 2009). The CR_{wo} values from the wildlife transfer database are currently being used to revise the ERICA Tool.

The estimation of absorbed dose rate (µGy h^{-1}) is an essential concept within the ERICA approach, and the approach used in the ERICA Tool has been developed in tandem with ICRP Committee 5. Radionuclides in the environment lead to plants and animals being exposed both externally and internally to ionising radiation. Internal exposure arises from the uptake of radionuclides by the organism via pathways such as ingestion or root uptake; it is determined by the activity concentration in an organism, the size of the organism, and the type and energy of emitted radiation. External radiation exposure depends on various factors including contamination levels in the environment, the geometric relationship between the radiation source and the organism, habitat, organism size, shielding properties of the medium and the physical properties of the radionuclides present. From calculations for mono-energetic radiation sources, nuclide-specific dose conversion coefficients (DCCs) are derived for external and internal exposure, taking into account the type of radiation as well as energy and intensity of the emission for most radionuclides included in ICRP Publication 38 (ICRP, 1983). For external exposure, the Tool defines the position of the organisms in relation to its environment, for example whether it resides on or in soil. Weighting factors for various components of radiation (low β, β + γ and α) are used which account for the relative biological effectiveness of the different types of radiation. Default radiation weighting factors of 10 for alpha radiation and 3 for low beta radiation are assumed within Tier 1.

This approach allows model outputs to be put into context with the available data on the effects of ionizing radiation, which are typically presented as absorbed dose rates to the whole organism so that the risk to wildlife can then be considered (ICRP 2008, Copplestone et al., 2008, Andersson et al., 2009; Howard et al., 2010).

The ERICA Integrated Approach uses a tiered assessment structure (in common with other areas of risk assessments) (see Figure 1). Tiered assessment starts with a simple initial screening using a very simple and conservative series of assumptions requiring minimal data inputs. The aim is to ensure that the level of detail in a risk assessment is proportionate with the nature and complexity of the risk being addressed and consistent with decision-making needs.

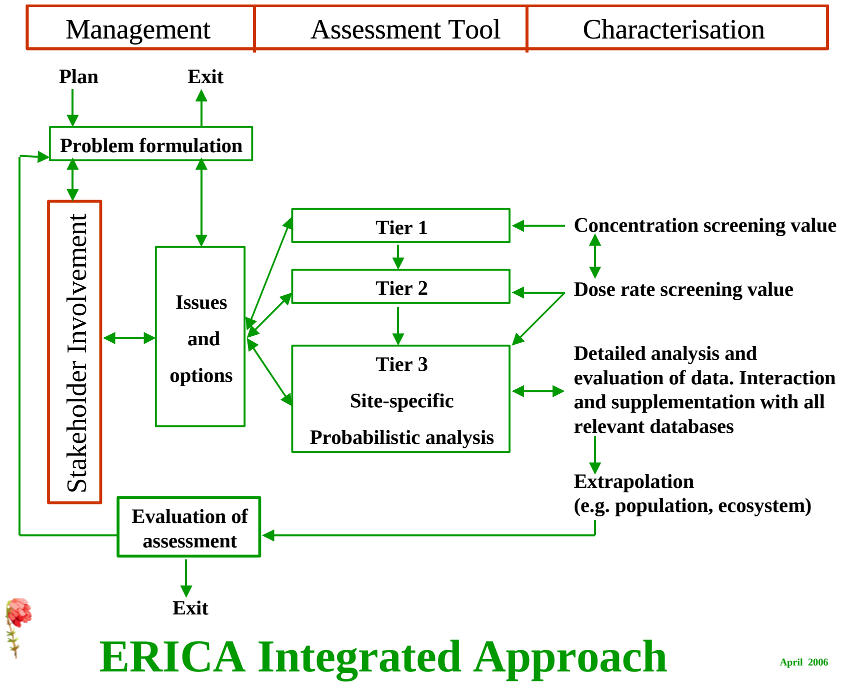

Figure 1: Schematic representation of the ERICA Integrated Approach (adapted from Beresford et al., 2007).

An Integrated Assessment Approach involves, in the lower tiers of the assessment process, screening against dose rate criteria. Benchmarks, or some form of criteria (usually numeric), allow the outputs of environmental assessments to be placed into context and aid decisions on the need for further assessment or regulatory/remedial action.

In the first screening tier the approach is highly conservative (with maximum values used for contamination and transfer rates). It is intended to ensure that if an assessed site passes the first tier there is a very high likelihood that no effect of the radiation present will occur on the ecosystems wildlife populations. An aim of the initial screening tier is to identify sites of negligible concern and to remove them from further consideration with a high degree of confidence; it is envisaged that most regulated sites will only need an initial screening tier assessment.

Further tiers use approaches which increase in complexity and data requirements enabling more refined assessments where needed. As an assessor goes up the tiers the degree of conservatism goes down and the data requirements and resources needed to complete the assessment increase.

For radiological environmental risk assessments the benchmark may be in the form of a dose rate or be back-calculated using the available tools to environmental concentrations for each radionuclide that would give rise to the predicted no effect dose rate. These environmental concentrations (known as Environmental Media Concentration Limits (EMCLs) in the ERICA Tool) can be compared directly to measured or model predicted environmental media concentration values and subsequently used to determine a 'risk quotient' (see below). Such environmental concentration benchmark values are used in earlier tiers of a risk assessment for identifying (or screening out) sites where there is negligible risk of potential impact.

Risk quotients

A risk quotient (RQ) provides a simple means of assessing risk by integrating the exposure and effects data to determine the likelihood of an ecological risk occurring. It is calculated from the quotient of the estimated exposure and a numeric benchmark (in the case of radiological assessments of the environment this will be in the form of a dose rate or activity concentration). The benchmark dose rate is a dose rate which is assumed to be environmentally 'safe'. The RQ is defined as:

$$RQ = \frac{predicted\ environmental\ dose\,rate}{benchmark\ dose\,rate\ assumed\,to\,be\,environmentally\ 'safe'}$$

Where the resulting RQ is less than one, then it would generally be considered that no further effort or action would be required. Where the RQ is greater than one, then the assessment would likely need further work (such as collecting more data, refining the exposure assessment, or taking action to reduce the risk).

Benchmarks

A benchmark is designed to ensure protection of ecosystem structure and function.

A deterministic approach takes the lowest dose rate observed to give a significant biological effect available for any tested species and divides it by a predefined assessment/safety factor ranging from 10 to 1000 (10000 for marine ecosystems) according to the quality and quantity of the data available. The assessment/safety factor is supposed to account for uncertainty.

In contrast, a probabilistic approach uses available (quality-assured) ecotoxicology data to determine the level of radioactivity in a given medium giving a 10% effect resulting distribution for chronic exposure in the data (the so called effective dose rate for a 10% effect (EDR_{10})). The endpoints considered to be most relevant in determining risks to non-human biota are increased mortality, increased morbidity and decrease reproductive output. Of the three, changes in reproduction are thought to be the most sensitive to radiological exposures. Garnier-Laplace et al. (2008) applied the species sensitivity distribution (SSD) approach recommended for chemical risk assessment in Europe and described in the European Technical Guidance Document (EC, 2003) to radiation effects data from the online FREDERICA compilation (Copplestone et al., 2008) to derive an incremental screening level dose rate. The SSD approach derived a default ERICA screening dose rate (10 µGy h^{-1}). Using a different data selection, Andersson et al. (2009), Garnier-Laplace et al. (2010) also derived a generic screening value of 10 µGy h^{-1}.

The application of a generic screening value to all organism types raises some problems when used in assessments, as the most exposed organism identified may not necessarily be the organism most at risk (Beresford et al., 2010). Given the limited data available Garnier-Laplace et al. (2010) attempted to derive screening level values for three broad groups (plants, invertebrates and vertebrates). Even at this broad level there were insufficient data to apply the SSD approach with confidence and derived values were similar to background dose rates (Beresford et al., 2008b; Hosseini et al., 2010). Ultimately, it would be desirable to have screening values for as many relevant organism groups as justifiable; however, there are insufficient data currently available to do this using the SSD approach (Garnier-Laplace et al., 2010; Howard et al., 2010).

Using expert judgement, ICRP gives Derived Consideration Reference Levels for the Reference Animals and Plants defined as:

- "A band of dose rate within which there is likely to be some chance of deleterious effects of ionising radiation occurring to individuals of that type of RAP (derived from a knowledge of expected biological effects for that type of organism) that, when considered together with other relevant information, can be used as a point of reference to optimise the level of effort expended on environmental protection, dependent upon the overall management objectives and the relevant exposure situation."

Both of these two types of benchmark are now being regularly used in assessments. Since there are currently no internationally agreed values, the screening value adopted need to be agreed prior to an assessment being conducted.

The relevance of such screening (incremental) dose rates also has to be judged against adequately defined background dose rates (e.g. Beresford et al., 2008b)).

2.4. Review findings

2.4.1. Results of the SKB assessment

To evaluate the effect of any potentially justifiable alternatives to the SKB assessment we first need to consider what their results and conclusions were. We will subsequently use these to put the effect of any alternative approaches on the conclusions reached into context.

SKB have used Tiers 2 and 3 of the ERICA Tool, justifying this on the basis that organisms and radionuclides not included within the ERICA Tools default databases cannot be assessed using Tier 1. Given the inputs were the same for the Tier 2 and Tier 3 the results should have been anticipated to be the same; Tier 3 has not been used to conduct a more refined assessment.

Tables 4-4 to 4-7 present probably the most complete set of dose rates estimated in TR-10-08. Dose rates using the ERICA Tool default CR values for the ERICA reference organisms were in the range 3.4E-7 to 3.4E-3 µGy h^{-1}. With a few exceptions these dose rates are typically higher than when ERICA default values are replaced by site specific CR values (see Table A5.3 in TR-10-08). The highest 95th percentile prediction was 9.7E-3 µGy h^{-1} estimated for freshwater phytoplankton. In comparing results to screening benchmark dose rates we think that it would be appropriate to consider the 'conservative' risk quotients of Tier 2 or the 95th percentile dose rates predict at Tier 3.

All estimated dose rates, including 95th percentiles, were at least three orders of magnitude below the 10 µGy h^{-1} screening dose rate used by SKB. Based upon this SKB concluded, that the '*study gives no reason to assume that any of the species would be harmfully affected* ......' (page 3 of TR-10-08).

2.4.2. Source term and radionuclides considered

Source term

SKB have used predicted activity concentrations is soil, air[2], freshwater water and sediments, and marine waters and sediments for the 'central corrosion' case noting that a preliminary assessment indicated this would have a greater impact than the alternative scenario considered (the 'growing pinhole'). As inputs to the ERICA Tool, SKB selected the maximum values for each radionuclide and media over the simulation period (~20,000 years). Therefore, this would appear to be a conservative assumption likely to result in dose rates higher than would be observed in reality. However, in TR-11-01(section 13.5.7) SKB note that the total dose rates from other corrosion scenarios are an order of magnitude higher than that presented for the central corrosion scenario. Given the low dose rates calculated for the central corrosion case, SKB state that their conclusion (with respect to no species being harmfully affected) holds for the other corrosion cases considered. Whilst we consider that it may have been more appropriate to base the non-human assessment on the worst case scenario, or to justify not doing so, on the basis of the assessment as presented in the TR-10-08 reports we agree that the overall conclusion would have been the same, despite the order of magnitude difference.

Stark (2012) requested clarification on the size of landscape objects to evaluate if they were appropriate for, for instance, localised vulnerable populations. We support the need for this issue to be clarified. If they are not appropriate then media concentrations for smaller areas may need to be derived.

Radionuclides

TR-10-08 states that the non-human assessment considered all of the radionuclides included in the SR-Site safety assessment with the exceptions of ^{227}Ac, ^{231}Pa and ^{107}Pd. The justification for not including these isotopes is that there are no site specific or literature CR values. Whilst the ERICA Tool does not include radionuclides for these three elements it does present guidance on how to derive CR values when none are available. Similar guidance is used/suggested by the ICRP (2009), IAEA (in-press) and indeed by SKB for the derivation of CR values for the human food chain (see TR-10-07). Furthermore, TR-10-07 presents CR values for ^{227}Ac, ^{231}Pa and ^{107}Pd for some terrestrial and aquatic organisms for human food chain modelling. These are sourced from R-02-28 (Karlsson & Bergström 2002)

---

[2]Air activity concentrations are input for the ERICA Tool for a few radionuclides only. For the radionuclides considered in SR-SITE safety assessment air concentrations are used for ^{14}C and ^{3}H in terrestrial ecosystems (although ^{3}H appears not to be included in the non-human assessment, see main text).

which, in itself, is a review of parameter values with values for the three elements in some cases being based on data for analogous elements.

The exclusion of these radionuclides is, in our opinion, unwarranted on the basis of a stated lack of CR values. To investigate the likely underestimation of dose rates by SKB having omitted these three radionuclides we have estimated dose rates to organisms from each to the ERICA reference organisms using a conservative approach. It is likely that for the three elements being considered here the CR values presented in R-02-28 would underestimate whole-organism CR values (which is the relevant type of value needed as an input into the ERICA Tool) as R-02-28 should present CR values for edible tissues. The international Wildlife Transfer Database (WTD; see Copplestone et al. in-press), includes the ERICA Tool CR database together with a more recent and extensive data compilation. However, the WTD does not contain data for Ac, Pa or Pd so we have therefore selected CR values using the guidance from the ERICA Integrated Approach. Using this, the most appropriate, and likely conservative, CR values are the highest transition element CR for Pd and the highest actinide CR for both Ac and Pa. The selected values are presented in Table 1. The selected CR values are approximately an order of magnitude, or more, higher than those presented in R-02-28.

To estimate dose rates from ^{227}Ac, ^{231}Pa and ^{107}Pd we have used the soil, water and sediment activity concentrations as presented in Table 3-2 of TR-10-08. Whilst this table does not give activity concentrations for ^{227}Ac we have assumed that it is in equilibrium with ^{231}Pa, its parent radionuclide (^{227}Ac is considered to contribute to dose in the human assessment although only via well water (Avila et al. 2010; TR-10-06). The media concentrations and selected CR values were input to Tier 2 of the ERICA Tool[3] and the resultant maximum conservative (i.e. applying the default uncertainty factor of 3 to the reported expected dose rate) dose rates for any ERICA reference organism in each ecosystem are presented in Table 2. Under these conservative assumptions dose rates from these three radionuclides would not influence the overall conclusion reached by SKB. Note that for these three radionuclides internal dose dominates and the resultant dose rates are therefore largely dependent upon the CR values used (for the given inputs).

Table 1: CR values selected for the three generic ecosystems for Ac, Pa and Pd. Selected CR values are the highest relevant values available from the Wildlife Transfer Database (version February 2011[4]) and were applied for all organisms in a given ecosystem type to estimate resultant dose rates.

Element	Marine	Freshwater	Terrestrial
Ac	7.3E+5 Th phytoplankton	1.1E+5 U vascular plant	2.5 U lichens & bryophytes
Pa	7.3E+5 Th phytoplankton	1.1E+5 U vascular plant	2.5 U lichens & bryophytes
Pd	9.0E+4 Cd Mollusc	2.8E+5 Cd Mollusc	21 Mn Shrub

[3] The ERICA Tool version update February 2013 has been used throughout this report

[4] Downloaded from http://www.wildlifetransferdatabase.org

Table 2: Maximum predicted conservative dose rates (µSv h^{-1}) for each generic ecosystem; predictions made using Tier 2 of the ERICA Tool.

Radionuclide	Marine	Freshwater	Terrestrial
Ac-227	2.5E-08	1.6E-06	2.5E-07
Pa-231	1.8E-06	1.1E-04	1.8E-05
Pd-107	3.5E-09	9.7E-07	1.7E-06

Whilst not explicitly acknowledged in TR-10-08, there are further radionuclides included in the SR-Site assessment which are not considered within the non-human biota assessment. This has already been highlighted by Stark (2012) in an initial evaluation of TR-10-08. The additional radionuclides, considered in SR-Site, but not in the non-human biota assessment, are: ^{242m}Am, ^{113m}Cd, ^{152}Eu, ^{3}H, ^{93}Mo, ^{93m}Nb, ^{238}Pu and ^{121m}Sn (see Table 9-2 of SKB 2010 (TR-10-09) versus Table 3-2 of TR-10-08). Confidence in the comprehensiveness and conclusion of the SKB assessment would be increased if the reasons for the lack of consideration of these radionuclides were given and justified. Similarly, a number of radionuclides considered within TR-10-08 are presented as having predicted activity concentrations in environmental media of 0 Bq per unit mass/volume (see TR-10-08) without an explanation about why this is the case in the report text.

2.4.3. Ecosystems

The ecosystems considered by SKB are wetland, watercourses/lakes and sea/brackish waters. These ecosystems have been allocated to the generic ERICA terrestrial, freshwater and marine ecosystems respectively.

TR-10-08 suggests that the marine ecosystem is probably adequate for brackish waters based upon Takata et al. (2010). If this is an inference that Takata et al. suggest that estuarine CR_{wo} values are similar to marine CR_{wo} values then we note that the Japanese estuaries sampled by Takata et al. have relatively high salinity values (c. 26-34 practical salinity units). That said there are comparatively few estuarine/brackish water CR_{wo} values in international compilations (Copplestone et al. in-press; http://www.wildlifetransferdatabase.org) and the majority of these come either from studies likely to have been considered within R-10-28 or data from Japanese estuaries (i.e. Takata et al. and grey literature reports presenting additional data from the same monitoring programme).

TR-10-08 notes that agricultural ecosystems were not considered. Would different wild species need to be considered if agricultural land were assessed? However, it is unclear whether agricultural land would have the same estimated soil activity concentrations as the wetland. If that is the case then estimated dose rates would be same as those presented in TR-10-08. If not then an assessment of wild species in agricultural, and potentially other terrestrial, ecosystems should have been conducted.

Considerations for wetland ecosystems

Having defined the terrestrial ecosystem to be assessed as a wetland raises some points for consideration. Wetland (or riparian) animals are likely to utilise both the terrestrial and aquatic ecosystems. The US DOE model RESRAD-BIOTA (USDOE 2004) specifically includes riparian animals which can be modelled using allometric parameters. However, these assessments require knowledge of the diet, and predictions of radionuclide activity concentrations in the diet. Model intercomparison exercises have demonstrated that selection of these parameters leads to variation between outputs of different modellers (Beresford et al. 2009). From the information presented, and having reproduced some of the results obtained, it appears that SKB have assumed that organisms are present in each contaminated ecosystem for 100 % of their time (i.e. they do not migrate or move to less contaminated areas). This is a conservative approach and correct for the nature of the assessment. For those animals inhabiting both terrestrial and freshwater components of wetlands assuming 100 % occupancy in both should identify any organisms at risk. However, this assumes that such organisms have been considered in both ecosystem types. In the case of amphibians this was not the case as they were included in the terrestrial assessment only; this issue is further evaluated in section 2.4.4.

Dry weight soil activity concentrations are the required input for the ERICA Tool. However, the dose conversion coefficients (DCCs) to estimate external dose rates from contaminated soil (and aquatic sediments) are supposed to be applied to fresh weight soil activity concentrations. The ERICA Tool therefore enables the user to enter a soil percentage dry weight content to correct the input soil activity concentrations for application of the DCCs. There is no discussion of assumptions of the soil moisture content in TR-10-08 and it would appear that the conservative assumption of 100% dry weight has been used. However, it is likely that wetland soils will have a comparatively high moisture content. To investigate the effect of this discrepancy we have run the ERICA Tool using the soil activity concentrations presented in Table 3-2 of TR-10-08 assuming 100% dry weight and 10 % dry weight. Predictions have been made for all the terrestrial reference organisms assuming default parameters other than for the soil dry weight content. A comparison of the results is presented in Table 3. For all organisms other than the Mammal(Rat) geometry there is less than 15% difference between the dose rates estimated for the two different soil moistures. The dose rate assuming 10 % soil dry weight is 30 % lower than that assuming 100 % dry weight for the Mammal(Rat) geometry, which as a default is assumed to be located underground in the ERICA Tool. The majority of this difference is due to reductions in predicted ^{95}Nb and ^{226}Ra (external) dose rates.

2.4.4. Organisms assessed

ERICA Reference Organisms

As noted above the ERICA Reference Organisms were selected to include different trophic levels, radioecologically sensitive organisms, radiobiologically sensitive organism and to enable all European protected species to be assessed. SKB state that they have included '*a selection of Reference Organisms most likely to be seen at the site*' (TR-10-08). They note that both the sea anemones and marine reptiles Reference Organisms have been omitted from the assessment as they do not occur at the Forsmark site. The exclusion of terrestrial bird egg Reference Organism was omitted because most organisms were measured as adults other than insect larvae in the freshwater ecosystem.

Table 3: A comparison of best estimate dose rates (μSv h^{-1}) for terrestrial ERICA Reference Organisms assuming 10 % and 100 % soil dry weight; predictions made using Tier 2 of the ERICA Tool.

Reference organism	10% soil dry weight	100 % soil dry weight
Amphibian	2.3E-05	2.6E-05
Bird	2.4E-05	2.7E-05
Bird egg	3.0E-05	3.4E-05
Detritivorous invertebrate	5.5E-05	6.4E-05
Flying insects	5.8E-05	6.1E-05
Gastropod	5.6E-05	5.9E-05
Grasses & Herbs	3.3E-05	3.7E-05
Lichen & bryophytes	6.8E-04	6.8E-04
Mammal (Deer)	2.0E-05	2.2E-05
Mammal (Rat)	2.0E-05	2.8E-05
Reptile	2.3E-05	2.6E-05
Shrub	7.4E-05	7.7E-05
Soil Invertebrate (worm)	5.4E-05	6.3E-05
Tree	5.8E-05	6.1E-05

The freshwater amphibian and benthic fish Reference Organisms were excluded from the assessment without acknowledgement. Given the uncertainties involved in making predictions of very long time periods it is difficult to justify the exclusion of any ERICA default Reference Organism. Consequently, we have run the ERICA Tool at Tier 2 inputting the soil, water and sediment activity concentrations presented in Table 3-2 of TR-10-08 using default ERICA parameter values. The resultant expected and conservative dose rate estimates are presented for the Reference Organisms excluded by SKB in Table 4. For direct comparison with TR10-08 we have not included ^{227}Ac, ^{231}Pa and ^{107}Pd in the assessment. Similarly we have excluded ^{126}Sn as SKB appear to not have assessed this radionuclide (see 2.4.6 below).

The estimated dose rates presented for those organisms not assessed by SKB would not alter their conclusion that there is no reason to assume that any of the species would be harmfully affected. The 'Sea anemones or true corals' Reference Organism has the highest estimated dose rate of any of the marine Reference Organisms.

Whilst the aim of the model runs reported here was to consider the missing Reference Organisms it also served as a check on the values reported by SKB for the Reference Organisms that they did consider. Our estimated dose rates were the same, or very similar, to those reported in TR-10-08 with the exception of Marine Crustacean for which we estimated a dose rate of 1.4E-6 μSv h^{-1} compared with a value of 6.3E-7 μSv h^{-1} reported in Table 4-6 of TR-10-08[5].

[5] It is possible that the Reference Organism and Combined dose rates (see Table A-33 of TR-10-08) have been interchanged.

Table 4: Estimated dose rates (µSv h^{-1}) for those ERICA Reference Organisms excluded from TR-10-08; predictions made using Tier 2 of the ERICA Tool.

Organism	Expected dose rate	Conservative dose rate
Marine		
Reptile	3.1E-7	9.4E-7
Sea anemones or true corals[1]	4.1E-6	1.2E-5
Freshwater		
Amphibian	1.8E-5	5.5E-5
Benthic fish	6.4E-5	1.9E-4
Terrestrial		
Bird egg	3.4E-5	1.0E-4

[1]Reported dose rates are for the polyp geometry as these were higher than for the colony geometry.

Organisms added for the Forsmark site

In addition to considering the ERICA Reference Organisms, as described above, SKB have considered a number of additional organisms. A number of species commonly found in Forsmark were included to 'increase the confidence in the analysis'. These have been termed *Representative Species* and are also noted to include keystone species for the Forsmark ecosystems. The identification of Representative Species was based on site investigation data and knowledge of the local ecosystems. TR-10-08 notes that the list of Representative Species is not exhaustive in terms of species present at Forsmark but that it is deemed to be representative. Some justification for this statement would improve confidence in the coverage achieved by including the Representative Species which were selected within the assessment.

The site specific data on which to derive CR_{wo} values for the Representative Species are limited. Table 3-4 of TR-10-08 shows that for the 45 Representative Species selected only five had more than three samples on which to base a site specific CR_{wo} value. To address this lack of data, SKB combined available data for similar species to create Average Organisms. For instance, available data for Pike, Roach and Ruffe were combined to provide site specific CR_{wo} values for an 'Average (freshwater) fish'. This appears to be a reasonable approach, however, because of the lack of clarity in the presentation of CR_{wo} values as used for each organism and the acknowledged lack of parameter values for the added organisms (Representative Species and Average Organisms) (see p42 of TR-10-08) the improvement in confidence sought by SKB is not achieved. For instance, in the case of freshwater fish an estimated dose rate is presented for Average fish but also for the three component species individually (Tables 4-5, 4-7 and A-33 of TR-10-08). The dose rates vary by more than one-order of magnitude with no explanation as to why. The answer is, apparently, that different radionuclides are included in the assessment of the four freshwater fish organism considered. There appears little merit in presenting such results as they are detrimental to clarity and overall confidence. A more thorough consideration of CR_{wo} values is presented in section 2.4.6.

TR-10-08 states that SSM regulations stipulated that red-list (i.e. species recognised as being threatened), functional key and economically important species need special attention.

We note that the red list species for the freshwater environment include two amphibians (*Rana lessonae* and *Triturus cristatus*) (Table 3-5b of TR-10-08) with *Rana lessonae* also being listed as a 'key functional and dominant organism' (Table 3-5d). The benthic fish *Lota lota* is listed as an economically important marine species (Table 3-5e). This species also inhabits freshwater ecosystems and the assessment did not include freshwater benthic fish; is the species absent from local freshwaters? These observations reinforce our suggestion above that the complete set of ERICA Reference Organisms should have been included within the assessment.

It is unclear why all of the key functional and dominant species identified in TR-10-08 (Table 3-5d) were not included within the Representative Species listing (Table 3-4) given that this was supposed to include keystone species.

Other than to be listed, there appears to be little 'special attention' paid to the red-list, functional key or economically important species.

Concluding comment of organisms assessed

Whilst some of the above comments identify potential short comings with regard to the organisms included in the assessment these mainly relate to issues of transparency and confidence. However, the issues identified are unlikely to impact upon the overall conclusion made by SKB.

2.4.5. Characteristics of the added organisms

To create the DCC values for the additional organisms added to the assessment, SKB had to give the organisms a mass and dimensions (these are presented in Table A1.1 of TR-10-08). There is obviously an element of judgement associated with the selection of these parameters. However, as demonstrated in Figure A-1 of TR-10-8 for most organisms variation in the values selected will have little impact on the resultant DCC values and hence estimated dose rates. As acknowledged in TR-10-08 (p34) the mass selected to represent the organism is likely to only contribute to the uncertainty for relatively small organisms. Vives i Batlle et al. (2011) suggest that '*.....organism geometry selection is important for small-sized organisms such as eggs which have dimensions in the order of millimetres*'.

Whilst organisms can be added to the ERICA Tool there are some restrictions on the mass of the organisms for which DCC values can be generated (see Table 5). Reference to Table A1.1 of TR-10-08 indicates that some of the masses assigned to the organisms added are outside of the ranges for which new organism can be added. These are aquatic microphytes, phytoplankton and average phytoplankton. These all have an indicated mass of 6.54E-11 kg which is the ERICA Tool default mass for marine phytoplankton (see ERICA Help document p91). As an indication of the likely lack of impact of uncertainty in size selected for most organisms we created marine organisms of 1E-4, 1E-5 and 1E-6 kg (i.e. the smallest which could be created) all of which were given ksi and chi values of 1. Inputting the water and sediment activity concentrations from Table 3-1 of TR-10-08 and assuming the three organisms were all located within the water column and had the CR_{wo} values of phytoplankton, total estimated total dose rates across the three organisms were found

Table 5: Limitations on mass of organisms which can be added to the ERICA Tool (adapted from the ERICA Tool help document (dated 13 June 2007).

Organism type	Minimum kg	Maximum kg
Terrestrial on soil surface	1.7E-3	550
Terrestrial underground	1.7E-3	6.6
Terrestrial flying	3.5E-2	2
Aquatic	1E-6	1000

to vary by less than 2% and by less than 3% compared to the dose rate estimated for the default phytoplankton geometry.

Table A1-1 of TR-10-08 also presents the occupancy factors allocated to the added organisms which appear to have been selected to be representative of the actual habits of the organisms within the confines of what the Tool allows. This introduces a difference to the treatment of the ERICA Reference Organisms for which the default occupancy factors appear to have been used. The default occupancy factors are supposed to reflect the occupancy which will result in the highest external dose rate. Therefore, the doses estimated for the organisms added will be lower than if the default occupancy factors for the appropriate ERICA Reference Organisms had been used. However, this difference does not impact on the overall assessment does not impact on the overall assessment conclusions given that the ERICA Organisms were included by SKB with their default occupancy factors.

We note that in Table 3-4 of TR-10-08 SKB have related the fungi species added to the ERICA lichen/bryophytes Reference Organism. Whilst this may appear strange to the reader we note that a geometry was created for fungi and assume the allocation of fungi to this Reference Organism was simply because there is no Reference Organism representing fungi.

2.4.6. Concentration ratios – derivation and application

Both sediment and water concentrations were input into the assessment, and hence k_d values are not used. Therefore of the user defined parameters the CR_{wo} values are the most likely to impact on the assessment (see previous evaluations of environmental assessment models, e.g., Beresford et al. 2009).

Derivation of site specific parameters

As noted above, whilst TR-10-07 describes the derivation of concentration ratios for the SR-Site assessment these are for application in human dose estimates only. For the non-human assessment CR values have been calculated using the studies reviewed in R-10-28 for Forsmark and also Laxemar-Simpevarp which had previously been a candidate site for a repository.

The data used to derive site specific CR_{wo} values originate from a review of various studies rather than a concerted effort to derive values for the organisms included in the assessment. Of the 45 Representative Species there is only one sample for 21 of the species. The maximum number of samples available was 9 for *Tinca tinca* (tench). Tables A-4 to A-9 of TR-10-08 present CR_{wo} values derived from samples collected at the two sites; these appear to present standard deviation values for sample size of n=1.

The majority of CR_{wo} values are derived from stable element measurements. The assumption that stable element CR_{wo} values are representative of radioisotopes of those elements is common with the approach used by ICRP (2009), IAEA (in-press) and the ERICA Tool (Beresford et al. 2008a). For long-term predictions this would appear to be a valid assumption. However, Wood et al. (2013) note that a number of comparisons of CR_{wo} values for stable and radioisotopes of the same element appear to show significant differences. However, only limited evaluation has been conducted to date and it is likely that some of the apparent differences are the consequence of sampling bias. The reliance on stable element analyses means that there are no site data for many radionuclides (e.g. actinides). However, for many of the radionuclides included in the source term site specific data would not be available even if measurements had been attempted.

As the data presented in R-10-28 are for application in human foodchain models they are for edible tissues (i.e. muscle of animals). The ERICA Tool, and other environmental assessment models, determine whole-organism dose rates and hence require whole-organism activity concentrations to be predicted. The application of muscle CR_{wo} values in TR-10-08 will underestimate organism radionuclide activity concentrations and hence dose rates (Yankovich et al. 2010).

A major short coming of TR-10-08 is a lack of clarity with regard to the actual CR_{wo} values used for the added organisms. Namely it is unclear to what extent the Laxemar and Forsmark data were combined to derived the CR_{wo} values used: '*For instance, some Laxemar data were used to supplement the main body of data'* (p45 of TR-10-08). Furthermore, there is an implication that for some organisms extrapolation approaches were used if '*measurements for a particular species were almost complete*' (see p43 of TR-10-08). Which radionuclide-species combinations was this approach used for?

Concentration ratios for the ERICA Reference Organisms

To make predictions of dose rates to the ERICA Reference Organisms SKB have used the ERICA Tool default CR_{wo} values. They also compare the resultant dose rates to those estimated if the defaults CR_{wo} values are replaced by appropriate site derived values where possible (Tables 4-7 and A-33 of TR-10-08). The similarity in results (p84 of TR-10-08) is used to conclude that '*the dose rate results were robust*'. However, the lack of site specific data for those radionuclides dominating the Reference Organism dose rates (Table 5-3 of TR-10-08) means that the outcome of this comparison is of little value and potentially misleading.

SKB added a number of radionuclide included in the source term to the ERICA Tool. Some of these were radionuclides of elements already included (e.g. ^{108m}Ag, ^{245}Cm) in the Tool and hence default CR_{wo} values were available. However, a number of radionuclides were for elements not included in the ERICA Tool: ^{41}Ca, ^{166m}Ho, ^{151}Sm and ^{126}Sn. There appears to have been no attempt to derive CR_{wo} values for these elements and hence we conclude they were not actually included in the assessment. Given that Table 3-2 (TR-10-08) presents soil, sediment and water activity concentrations as '0' Bq kg^{-1} or Bq l^{-1} for ^{41}Ca, ^{166m}Ho and ^{151}Sm then this omission is likely to be of no consequence. In the case of ^{126}Sn, SKB could have used the CR_{wo} values derived from the

Forsmark and Laxemar data at least for terrestrial and marine organisms (i.e. Tables A-4 to A-9); no site data were available for Sn transfer to freshwater organisms. This would have demonstrated that maximum conservative dose rates due to ^{126}Sn were estimated to be <4E-7 μGy h^{-1} and <2E-8 μGy h^{-1} for terrestrial and marine organisms respectively. As for the other radionuclides omitted from the SKB assessment (see section 2.4.2 above) this would not have affected the overall assessment conclusion.

The ERICA Tool contains a complete set of CR_{wo} values for its Reference Organisms. However, in many instances no data were available and hence many of the default CR_{wo} values are not based upon data for the given radionuclide-Reference Organism combination but have been derived using a set of extrapolation rules (Beresford et al. 2008a). If we look at the radionuclides which SKB calculate to contribute most to the estimated dose rates of the Reference Organisms (Table 5-3 of TR-10-08) then some of the values for each radionuclide are derived by extrapolation rather than being based upon data. In the cases of ^{237}Np and ^{94}Nb the majority of the CR_{wo} values are not based on data. There is no acknowledgement of the deficiencies of the default ERICA CR databases by SKB or consideration of the impact of these deficiencies. Recently, Brown et al. (2013) have evaluated how well the ERICA extrapolation rules performed against the WTD. Brown et al. report that the values derived by extrapolation were not always conservative (i.e. they were lower than newly compiled data) and in the case of the terrestrial ecosystem were as likely to under-predict as over-predict. Some of the CR_{wo} values shown to under predict have been used in the SKB assessment.

Howard et al. (2013b) and Yankovich (2013) compare the ERICA Tool CR_{wo} default values based upon empirical data with revised values in the WTD. Relatively few of the values changed by more than an order of magnitude: 29 (terrestrial) 39 (freshwater) and 8 (marine) (Howard et al. 2013b). Although some of these changes have implications for the assessment presented in TR-10-08 we note the WTD is being further revised and will then be used to provide an updated set of CR_{wo} values for the ERICA Tool.

Inconsistencies between the human and non-human assessments with respect to transfer

In the Discussion section of TR-10-08, SKB appears to support the development of an approach for non-human biota protection consistent with that used for humans; this is in agreement with the ICRP aim of developing parallel approaches (ICRP, 2008). However, notwithstanding that the CR values for human foodchain modelling are normalised to the C content of the foodstuff, there are a number of inconsistencies between the derivation of CR values for the human and non-human assessments:

- To cope with the considerable lack of site data to derive human foodstuff CR values, TR-10-07 utilises ‘analogues’ (e.g. the reasoned use of data for a different organism or element). This is consistent with the approach used to proved a complete set of default CR_{wo} values for the ERICA Tool (see Beresford et al. 2008a), and guidance given in IAEA (in-press) and ICRP (2009). However, for wildlife species where no CR_{wo} value for a given radionuclide is available it appears to simply have been ignored within the assessment (i.e. not included as a contributor to total dose rate). Although as noted above TR-10-08 (page 43) suggests that extrapolation approaches might have been used when few values were missing for a given species. The lack of clarity means we cannot determine what has been done.

- Where both literature and site data were available to estimate CR values for the human foodchain these were combined using Bayesian inference methods. Given the low number of samples collected from the site, and indeed often available within the literature, this appears to be a reasonable attempt to make best use of the data. Why was this not considered for the derivation of wild species CR_{wo} values?
- To estimate the transfer of radionuclides to the meat of wild herbivores eaten by humans TR-10-07 uses kinetic-allometric models. Such models are also used in wildlife assessments (Beresford & Vives i Batlle 2013) and it would appear that the models in TR-10-07, cited as coming from Avila (2006; TR-06-08), are derived from wildlife assessment models. Whilst it is uncertain that these kinetic-allometric models would give any 'better estimate' than a CR_{wo} value, given the assumptions made on dietary intake and the parameterisation of transfer to dietary components (see TR-10-07), again the question is raised why adopt different approaches in the human and non-human assessments?
- There appear to be differences in the treatment of measurements below detection limits in the non-human and human assessment. For the non-human assessment such data appear not to have been used: '*For some of the elements of interest, measurements were made, but were discarded since the values were below detection limits*' (p43 of TR-10-08). Whereas to derived CR values for the human foodchain an approach appear to have been adopted to make use of such data (see subsection starting p15 of TR-10-07). A further approach appears to have been used in the derivation of background dose rates to non-human biota (see section A4.4 of TR-10-08).

Inadequacies in the estimation of organism activity concentrations

A considerable proportion of TR-10-08 is dedicated to the selection of organisms to be considered, derivation of geometries and hence DCC values for them, and the derivation of site specific CR_{wo} values for these organism. However, these organisms are not completely assessed, rather dose rates, and risk quotients, are derived only for those radionuclides for which organism specific CR_{wo} values are available. In our view, as presented, the results for the Representative Species and Average Organisms are of little value, and potentially misleading. If the complete set of CR_{wo} values had been presented and put into context with the ERICA default values including the inadequacies of the latter then some purpose may have been served.

Even for the ERICA Reference Organisms not all radionuclides are assessed (^{126}Sn, ^{227}Ac, ^{231}Pa and ^{107}Pd). As discussed above these omissions are highly unlikely to alter the conclusion of SKB, but they do impact on the confidence in the assessment and its transparency.

2.4.7. Screening benchmark dose rate and background exposure rates

The default ERICA generic screening dose rate of 10 µGy h^{-1} is not a 'limit' it is intended as a benchmark to screen out sites which do not require further assessment with a high degree of confidence when used within a conservative assessment. Other benchmarks have been proposed (Howard et al., 2010) , for instance, the USDOE

Graded Approach (2002) uses values of 1 mGy d^{-1} for terrestrial and 10 mGy d^{-1} for terrestrial plants and aquatic animals.

The ICRP (2008) have proposed a set of derived consideration levels (DCRLs) for their Reference Animals and Plants (RAPs). The DCRLs are order of magnitude bands of dose rate and the ICRP suggested that '*These bands can then be put into perspective by, at one extreme, noting the effects of very high levels of dose that are unlikely to be encountered in the environment and, at the other, by noting what might be expected in terms of natural background*.' Subsequently, the ICRP (in-press) suggested that for planned exposure situations the lower boundary of a DCRL could be used as the appropriate starting point for optimisations of environmental exposures to animals and plants which is in-effect the same as others have suggested the screening dose rate benchmark be used (Andersson et al., 2009). However, it should be acknowledged that the ICRP documentation available to SKB at the time of their assessment was not clear on the proposed application of the DCRLs. An acknowledged problem of applying a single generic screening dose rate is that it in-effect identifies the most exposed organism which may not necessarily be the most at risk organism given different radiosensitivities (Beresford et al., 2010). The DCRLs vary for the different RAPs:

- Reference Rat, Deer, Pine Tree, Duck - 0.1-1 mGy d^{-1}
- Reference Trout, Flatfish, Frog, Brown Seaweed[6], Wild Grass - 1-10 mGy d^{-1}
- Reference Crab, Bee, Earthworm - 10-100 mGy d^{-1}

If the DCRLs had been used as a benchmark in the SKB assessment then some risk quotients would increase but only by a factor of *c.* 2.5 (0.1 mGy $d^{-1} \approx 4$ μGy h^{-1}). Conversely, other risk quotients would have reduced by factors of 4 to 40.

Screening dose rate benchmarks are for the assessment of incremental, not total (i.e. including background), dose rates. However, there is merit in putting the results of an assessment into context with local background exposures rates and SKB do this within the appendix to TR-10-08. Background dose rates were estimated taking into account natural and existing anthropogenic radionuclides. The estimates are comparable to those estimated in recent reviews (Beresford et al. 2008b; Hosseini et al. 2010) of natural background exposure of wild species. Potassium-40 was an important contributor to total background exposure rates in these two reviews. This radionuclide was not included in the estimation of background dose rates for Forsmark which may therefore be underestimated.

2.4.8. Radiation weighting factors

To estimate the reported weighted dose rates SKB used the ERICA Tool default values of 10 for alpha radiation, 3 for low energy (<10 keV) beta and 1 for high energy beta and gamma radiation. However, there is no international agreement on radiation weighting factors to use for non-human species. Alternative approaches to the ERICA Tool use an alpha weighting factor of 20 (Copplestone et al. 2001; USDOE 2004) and a weighting factor for all beta emissions of 1 (USDOE 2004).

[6] ICRP (2008) is somewhat contradictory as to if Brown Seaweed is proposed to have a DCRL of 1-10 mGy d^{-1} or 10-100 mGy d^{-1}; ICRP (in-press) confirms it should be 1-10 mGy d^{-1}.

Application of an alpha radiation weighting factor of 20 in the Forsmark assessment would result in dose rates approximately twice as high as those presented in Table 3 above (for an assumption of 100% soil dry weight). Reducing the low energy beta weighting factor would have negligible impact on the estimated dose rates.

As for other variables considered above altering the radiation weighting factors used within reasonable bounds would not alter the conclusion reached on the assessment by SKB. Furthermore, an alpha weighting factor of 10 appears to be in agreement with the current thinking of the ICRP working group considering this matter (Higley et al. 2012).

3. Conclusions

A key protection goal of the assessment, as defined by SSM, relates to the value of certain types of species. There appears to have been little 'special attention' paid to the identified red-list, functional key or economically important species. The ERICA Integrated Approach discusses the needs for, and mechanisms of, consultation with stakeholders when defining the protection goal and priorities for the assessment. The SKB reports considered do not give any information about the views of stakeholders, other than SSM, regarding the assessment of non-human biota.

Independent evaluation of the non-human biota assessment is challenging because key relevant information is contained within a number of additional and large reports and is often difficult to locate. The balance in the level of detail provided for different parts of the assessment is inconsistent with their relative importance.

Elements of the non-human assessment conducted by SKB are conservative. Given the uncertainties in making predictions over the long time periods considered in the assessment adopting conservative assumptions is a justified approach. For a conservative approach it would have been more appropriate to consider the scenario resulting in the highest predicted media activity concentrations (see section 2.4.2). However, the alternative scenario SKB quote (section 13.5.7 of TR-11-01) would not have altered the overall conclusion that the '*study gives no reason to assume that any of the species would be harmfully affected* ......' (page 3 of TR-10-08). We note that Stark (2012) in an initial assessment of the SKB non-human radiological assessment states that an earlier assessment (SR-Can) resulted in risk quotients in excess of 1 (i.e. dose rate >10μSv h^{-1}). This is because the source term has changed considerably between the SR-Can and SR-Site assessments. We are aware that SSM are currently reviewing the source term as part of the overall SR-Site review process. The evaluation in this report is based on SR-Site, if the source term were to change markedly then conclusions reached here would need to be re-evaluated.

With the aim of conducting a conservative assessment which tries to account for the uncertainties involved in such long-term predictions we feel that it is not appropriate to exclude some of the default ERICA Tool Reference Organisms. Furthermore, the exclusion from the non-human biota assessment of some radionuclides considered within SR-Site is not justified (at least not by the report as presented currently).

A considerable proportion of TR-10-08 is devoted to the selection of Representative Species and Average Organisms with the stated aim of increasing confidence. However, this is of little value as incomplete assessments are conducted for these organisms and hence confidence is not increased. The lack of information on the CR_{wo} values actually used does not help transparency.

A number of aspects of the SKB assessment are incomplete and/or lack transparency. Assuming the source term scenario is realistic and the appropriate one has been chosen for the assessment, by addressing these issues and/or using credible alternative parameters we have demonstrated that they are unlikely to affect the conclusion reached by SKB.

4. References

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. J. Environ. Radioact. 100, 1100-1108. http://dx.doi.org/10.1016/j.jenvrad.2009.05.010

Avila, R. 2006. The ecosystem models used for dose assessments in SR-Can. SKB R-06-81, 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.

Barnett, C.L., Beresford, N.A., Self, P.L., Howard, B.J., Frankland, J.C., Fulker, M.J., Dodd, B.A., Marriott, J.V.R. 1999. Radiocaesium activity concentrations in the fruit-bodies of macrofungi in Great Britain and an assessment of dietary intake habits, Science of The Total Environment, 231, 67-83. http://dx.doi.org/10.1016/S0048-9697(99)00085-6.

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

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

Beresford, N.A., Barnett, C.L., Jones, D.G., Wood, M.D., Appleton, J.D., Breward, N., Copplestone D. 2008b. Background exposure rates of terrestrial wildlife in England and Wales. J. Environ. Radioact., 99, 1430-1439. http://dx.doi.org/10.1016/j.jenvrad.2008.03.003

Beresford, N.A., Barnett, C.L., Beaugelin-Seiller, K., Brown, J.E., Cheng, J-J., Copplestone, D., Gaschak, S., Hingston, J.L., Horyna, J., Hosseini, A., Howard, B.J., Kamboj, S., Kryshev, A., Nedveckaite, T., Olyslaegers, G., Sazykina, T., Smith, J.T., Telleria, D., Vives i Batlle, J., Yankovich, T.L., Heling, R., Wood, M.D., Yu, C. 2009. Findings and recommendations from an international comparison of models and approaches for the estimation of radiological exposure to non-human biota, Radioprotection 44, 565–570. http://dx.doi.org/10.1051/radiopro/20095104

Beresford N.A. 2010. The transfer of radionuclides to wildlife (Editorial). Radiation Environ Biophys., 49, 505-508. http://dx.doi.org/10.1007/s00411-010-0325-x

Beresford, N. A., Hosseini, A., Brown, J. E., Cailes, C., Beaugelin-Seiller, K., Barnett, C. L., Copplestone. D. 2010. Assessment of risk to wildlife from ionising radiation: can initial screening tiers be used with a high level of confidence? J. Radiol. Prot., 30 , 265-284. http://dx.doi.org/10.1088/0952-4746/30/2/S04

Beresford, N.A., Vives I Batlle, J. 2013. Estimating the biological half-life for radionuclides in homoeothermic vertebrates: A simplified allometric approach. Rad. Environ. Biophys. 52, 505-511. http://dx.doi.org/10.1007/s00411-013-0481-x

Beresford, N.A., Boyer, P., Howard, B.J. 2013. Assessment of the derivation and use of Kd and CR values. Report to SSM (contract number SSM2013-3686).

Bergstrom, K., Nordinder, U. 1990. Individual radiation doses from unit releases of long lived radionuclides. SKB TR 90-09, Svensk Kärnbränslehantering AB.

Brown J.E, Beresford N.A. Hosseini A. 2013. Approaches to providing missing transfer parameter values in the ERICA Tool - How well do they work? J. Environ. Radioact. 126, 399-411. http://dx.doi.org/10.1016/j.jenvrad.2012.05.005

Brown, J.E., Alfonso, B., Avila, R., Beresford, N.A., Copplestone, D., Pröhl, G., Ulanovsky A. 2008. The ERICA Tool. J. Environ. Radioact., 99, 1371-1383. http://dx.doi.org/10.1016/j.jenvrad.2008.01.008

Copplestone ,D., Hingston J.L., Real, A. 2008. The development and purpose of the FREDERICA radiation effects database. J. Environ. Radioact. 99 1456-1463.

Copplestone, D., Beresford, N.A., Howard, B.J. 2010. EDITORIAL: Protection of the Environment from Ionising Radiation: developing criteria and evaluating approaches for use in regulation. J. Radiol. Prot., 30, 191-194. http://dx.doi.org/10.1088/0952-4746/30/2/E03

EU (2003) Technical Guidance Document in support of Commission Directive 93/67/EEC on Risk Assessment for new notified substances, Commission Regulation (EC) No 1488/94 on Risk Assessment for existing substances and Directive 98/8/EC of the European Parliament and of the Council concerning the placing of biocidal products on the market. (Luxembourg: Office for Official Publication of the European Commission). Available from: http://ecb.jrc.ec.europa.eu/tgd/

Davis, P.A., Zach, R., Stephens, N.E., Amiro, B.D., Reid, J.A.K., Sheppard, M.I., Sheppard, S.C. Stephenson, M. 1993. The disposal of Canada's Nuclear Fuel Waste: The Biosphere Model, BIOTRAC, for Postclosure Assessment. AECL 10720, COG-93-10. AECL Research, Whiteshell Laboratories, Pinawa, Manitoba

Frissel, M., Koster, J. 1989. Uncertainties of predicted soil-to-plant transfer factors because of averaging the impact of space, time, local conditions and crop variety. In: Experiences with radioecological assessment models, comparisons between predictions and observations. Proc. of a workshop, Neuherberg, November 1986. Leising, C.,Wirth, E. (Eds), pp. 16–27 (JSH-Heft; 128).

Garnier-Laplace, J., Copplestone, D., Gilbin, R., Alonzo, F., Ciffroy, P., Gilek, M., Aguero, A., Bjork, M., Oughton, D., Jaworsk, A., Larsson C.M., Hingston, J. 2008. Issues and practices in the use of effects data from FREDERICA in the ERICA integrated approach. J. Environ. Radioact. 99, 1474-1483

Garnier-Laplace, J., Della-Vedova, C., Andersson, P., Copplestone, D., Cailes, C., Beresford, N.A., Howard, B.J., Howe, P., Whitehouse, P. 2010. A multi-criteria weight of evidence approach for deriving ecological benchmarks for radioactive substances. J. Radiol. Prot., 30, 215-233. http://dx.doi.org/10.1088/0952-4746/30/2/S02

Gillett, A.G. Crout N.M.J. 2000. A review of ^{137}Cs transfer to fungi and consequences for modelling environmental transfer, Journal of Environmental Radioactivity, 48, 95-121.http://dx.doi.org/10.1016/S0265-931X(99)00060-0.

Hosseini, A., Beresford N.A., Brown, J.E., Jones, D.G., Phaneuf, M., Thørring H., Yankovich, T. 2010. Background dose-rates to reference animals and plants arising from exposure to naturally occurring radionuclides in aquatic environments J. Radiol. Prot., 30, 235-264. http://dx.doi.org/10.1088/0952-4746/30/2/S03

Howard, B.J., Larsson, C-M. 2008. The ERICA Integrated Approach and its contribution to protection of the environment from ionising radiation. J. Environ. Radioact., 99, 1361-1363. http://dx.doi.org/10.1016/j.jenvrad.2008.04.013

Howard, B.J., Beresford, N.A., Andersson, P., Brown, J.E., Copplestone, D., Beaugelin-Seiller, K., Garnier-Laplace, J., Howe, P. Oughton, D., Whitehouse, P. 2010. Protection of the environment from ionising radiation in a regulatory context – an overview of the PROTECT coordinated action project. J. Radiol. Prot., 30, 195-214. http://dx.doi.org/10.1088/0952-4746/30/2/S01

Howard, B.J. 2013a. A new IAEA handbook quantifying the transfer of radionuclides to wildlife for assessment tools J. Environ. Radioact. 126, 284-287. http://dx.doi.org/10.1016/j.jenvrad.2013.11.002

Howard, B.J., Beresford, N.A., Copplestone, D., Telleria, D., Proehl, G., Fesenko, S., Jeffree, R., Yankovich, T., Brown, J., Higley, K., Johansen, M., Mulye, H., Vandenhove, H., Gashchak, S., Wood, M.D., Takata, H., Andersson, P., Dale, P., Ryan, J., Bollhöfer, A., Doering, C., Barnett, C.L., and Wells, C. 2013b. The IAEA Handbook on Radionuclide Transfer to Wildlife. J. Environ. Radioact. 121, 55–74 http://dx.doi.org/10.1016/j.jenvrad.2012.01.027

Higley, K.A., Kocher, D.C., Real, A.G., Chambers, D.C., 2012. Relative biological effectiveness and radiation weighting factors in the context of animals and plants. Ann. ICRP 42(3/4), 233-245.

Higley KA, Domotor SL, Antonio EJ, 2003. A kinetic-allometric approach to predicting tissue radionuclide concentrations for biota, Journal of Environmental Radioactivity, 66, 61–74.

IAEA, 2001. Literature models for use in assessing the impact of discharges of radioactive substances to the environment. IAEA Safety Reports Series 19, International Atomic Energy Agency, Vienna.

IAEA, 2004. Sediment distribution coefficients and concentration factors for biota in the marine environment. IAEA Technical Reports Series 422, International Atomic Energy Agency, Vienna.

IAEA 1994. Handbook of parameter values for the prediction of radionuclide transfer in temperate environments. Technical Reports Series No. 364. International Atomic Energy Agency, Vienna.

IAEA, 2010. Handbook of parameter values for the prediction of radionuclide transfer to humans in terrestrial and freshwater environments, Technical Reports Series 472. International Atomic Energy Agency, Vienna.

IAEA in press. Handbook of parameter values for the prediction of radionuclide transfer to wildlife. Technical Reports Series, Vienna. IAEA

ICRP, 1983. Radionuclide Transformations - Energy and Intensity of Emissions. ICRP Publication 38. Elsevier.

ICRP 2008. Environmental Protection - the Concept and Use of Reference Animals and Plants. ICRP Publication 108. Elsevier.

ICRP, 2009. Environmental Protection: Transfer Parameters for Reference Animals and Plants. ICRP Publication 114. Ann. ICRP Vol 39 (6). Strand, P. Beresford, N. Copplestone, D. Godoy, J. Jianguo, L. Saxen, R. Yankovich, T. Brown. J. Elsevier. http://www.icrp.org/publication.asp?id=ICRP%20Publication%20114

ICRP in press. Protection of the Environment under Different Exposure Situations. Elsevier.

Karlsson, S. Bergström, U. 2002. Nuclide documentation. Element-specific parameter values used in the biospheric models of the safety assessments SR 97 and SAFE. SKB R-02-28, 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 report TR-11-01. Vol. I, Svensk Kärnbränslehantering AB.

NCRP, 1996. Screening models for releases of radionuclides to atmosphere, surface water and ground. National Council on Radiation Protection and Measurements, USA. NCRP Report No. 123. Vol I.

Ng, Y. 1982. A review of transfer factors for assessing the dose from radionuclides in agricultural products, Nuclear Safety, 23, 57–71.

Ng, Y., Colsher, C.S., Quinn, D.J., Thompson, S.E. 1977. Transfer coefficients for the prediction of the dose to man via the forage-cow-milk pathway from radionuclides released to the biosphere, Lawrence Livermore Laboratory (UCRL-51939).

Ng, Y.C., Thompson, S.E., Colsher, C.S. 1982. Soil-to-plant concentration factors for radiological assessment. Lawrence Livermore National Laboratory (NUREG/CR-2975;

Nordén S, Avila R, de la Cruz I, Stenberg K, Grolander S, 2010. Element-specific and constant parameters used for dose calculations in SR-Site, SKB TR-10-07, Svensk Kärnbränslehantering AB.

Pokorny, B., Al Sayegh-Petkovšek, S., Ribarič-Lasnik, C., Vrtačnik, J., Darinka Z Doganoc, Miha Adamič, 2003. Fungi ingestion as an important factor influencing heavy metal intake in roe deer: evidence from faeces, Sci. Total Environ., 324, 223-234. http://dx.doi.org/10.1016/j.scitotenv.2003.10.027.

Robens, E., Hauschild, J., Aumann, D.C. 1988. Iodine-129 in the environment of a nuclear fuel reprocessing plant: III. Soil-to-plant concentration factors for iodine-129 and iodine-127 and their transfer factors to milk, eggs and pork, J.Environ. Radioact., 8, 37–52.

de Román , M., Boa, E., Woodward, S. 2006. Wild-gathered fungi for health and rural livelihoods, Proc. Nutr. Soc., 65, 190-197.

SKB 2010. Biosphere analyses for the safety assessment SR-Site – synthesis and summary of results SKB report 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 report TR-11-01. Vol. III, Svensk Kärnbränslehantering AB.

Sheppard, S.C., 2005. Transfer parameters: are on-site data really better?, Human and Ecological Risk Assessment. 11, 939-949.

Sheppard, S., Long, J., Sanipelli, B., Sohlenius, G. 2009. Solid/liquid partition coefficients (Kd) for selected soils and sediments at Forsmark and Laxemar-Simpevarp. SKB R-09-27, Svensk Kärnbränslehantering AB.

Sheppard, S.C., Long, J.M., Sanipelli, B. 2010. Plant/soil concentration ratios for paired field and garden crops, with emphasis on iodine and the role of soil adhesion, J.Environ. Radioact., 101, 1032-1037.

Stark , K. 2012. Radiological effects on non-human biota – initial review. Report number:2012-38. Swedish Radiation Safety Authority.

SSM, 2008. 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. Radiat. Environ. Biophys., 49, 591-601.

Xu, S., Wörman, A., Dverstorp, B., Kłos, R., Shaw, G., Marklund. L.2008. SSI's independent consequence calculations in support of the regulatory review of the SR-Can safety assessment, SSI Rapport 2008:08. Swedish Radiation Protection Authority.

Torudd, J. 2010. Long term radiological effects on plants and animals of a deep geological repository, SR-Site Biosphere, SKB TR-10-08, 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.

U.S. Department of Energy (DOE) 2002. A Graded Approach for Evaluating Radiation Doses to Aquatic and Terrestrial Biota. DOE-STD-1153-2002.

USDOE, 2004. RESRAD user manual http://web.ead.anl.gov/resrad/documents/RESRAD-BIOTA_Manual_Version_1.pdf

Veselý, J., Majer, V., Kučera, J., Havránek, V. 2001. Solid-water partitioning of elements in Czech freshwaters, Applied Geochemistry, 16, 437–450.

Williams, C. 2004. Framework for assessment of environmental impact (FASSET) of ionising radiation in European ecosystems. J. Radiol. Prot., 24(4A).

Wood, M.D., Beresford, N.A., Howard, B.J., Copplestone, D. 2013. Evaluating summarised radionuclide concentration ratio datasets for wildlife J. Environ. Radioact. 126, 314-325. http://dx.doi.org/10.1016/j.jenvrad.2013.07.022

Yankovich, T.L., Beresford, N.A., Wood, M., Aono, T., Andersson, P., Barnett, C.L., Bennett, P., Brown, J., Fesenko, S.,Hosseini, A., Howard, B.J., Johansen, M., Phaneuf, M., Tagami, K., Takata, H., Twining, J., Uchida, S. 2010. Whole-body to tissue concentration ratios for use in biota dose assessments for animals. Radiation Environ Biophys., 49, 549-565. http://dx.doi.org/10.1007/s00411-010-0323-z

Yankovich, T., Beresford, N.A., Fesenko S., Fesenko, J., Phaneuf, M., Dagher, E., Outola, I., Andersson, P., Thiessen, K., Ryan, J., Wood, M.D., Bollhöfer, A., Barnett, C.L., Copplestone, D. 2013. Establishing a database of radionuclide transfer parameters for freshwater wildlife. J. Environ. Radioact. 126, 299-313. http://dx.doi.org/10.1016/j.jenvrad.2012.07.014

Zinger, I., Copplestone, D., Howard B.J. 2008. Decision-making in environmental radiation protection: using the ERICA Integrated Approach. J. Environ. Radioact., 99, 1510-1518. http://dx.doi.org/10.1016/j.jenvrad.2008.01.021

Coverage of SKB reports

Reviewed report*	Reviewed sections	Comments
TR-10-08	All	Main focus of this review
TR-10-07	All	CR values for human assess – use same data as for wildlife CR derivation
R-10-28	All	Description of available site data
TR-11-01vol3	13	Different release scenarios
TR-06-08	3	Investigate derivation of allometric models in TR-10-07
R-02-28	Sections on Ac, Pa, Pd	Source of CR values for Ac, Pa and Pd in TR-10-7
TR-10-06	All	-
TR-10-09	Various	For overview of SR-Site

*See References above for full details of reports

2014:17

The Swedish Radiation Safety Authority has a comprehensive responsibility to ensure that society is safe from the effects of radiation. The Authority works to achieve radiation safety in a number of areas: nuclear power, medical care as well as commercial products and services. The Authority also works to achieve protection from natural radiation and to increase the level of radiation safety internationally.

The Swedish Radiation Safety Authority works proactively and preventively to protect people and the environment from the harmful effects of radiation, now and in the future. The Authority issues regulations and supervises compliance, while also supporting research, providing training and information, and issuing advice. Often, activities involving radiation require licences issued by the Authority. The Swedish Radiation Safety Authority maintains emergency preparedness around the clock with the aim of limiting the aftermath of radiation accidents and the unintentional spreading of radioactive substances. The Authority participates in international co-operation in order to promote radiation safety and finances projects aiming to raise the level of radiation safety in certain Eastern European countries.

The Authority reports to the Ministry of the Environment and has around 315 employees with competencies in the fields of engineering, natural and behavioural sciences, law, economics and communications. We have received quality, environmental and working environment certification.

Strålsäkerhetsmyndigheten
Swedish Radiation Safety Authority

SE-171 16 Stockholm
Solna strandväg 96

Tel: +46 8 799 40 00
Fax: +46 8 799 40 10

E-mail: registrator@ssm.se
Web: stralsakerhetsmyndigheten.se