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Technical Note

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Radiological effects on non-human biota - initial review

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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 i avgränsade frågor. I SSM:s Technical note-serie rapporteras resultaten från dessa konsultuppdrag.

Projektets syfte

Detta granskningsuppdrag är en del av den inledande granskningen vilken syftar till att få en bred belysning av SR-site med underreferenser för att identifiera eventuella behov av kompletteringar och förtydliganden som SKB bör tillfoga ansökningsunderlaget samt att identifiera viktiga granskningsfrågor inför huvudgranskningsfasen. Detta uppdrag behandlar SKBs redovisning av långsiktiga (efter förslutning) effekter på vilda växter och djur av det föreslagna slutförvaret med fokus på frågor kring om den använda utvärderingsmetodiken inkluderar alla relevanta transport- och ackumulationsprocesser, radionuklider och organismer, om använda parametervärden är relevanta för platsen och samstämmiga med de värden som används i övrigt inom Sr-Site, och om använda dos-effektsamband är relevanta.

Författarens sammanfattning

Fokus för denna granskning har varit SKB:s riskbedömning av stråleffekter på djur och växter (biota) inom SR-Site enligt gällande lagar, föreskrifter och riktlinjer från SSM. Granskningen utfördes av Karolina Stark vid Systemekologiska institutionen, Stockholms Universitet. Kort sammanfattat så visar denna granskning att det kan ifrågasättas om SR-Site är komplett främst vad gäller inkluderade och övervägda radionuklider och ekosystem scenarion i risk bedömningen.

Det finns också luckor i provtagning och mätdata från Forsmark, och i beräknade koncentration faktorer till biota. Utförandet av riskbedömning för människa och för biota skiljer sig även åt inom SR-Site i hur data från miljön har använts. Dessa luckor leder till att den vetenskapliga tillförlitligheten och kvaliteten kan ifrågasättas. Förtydligande behövs även i frågor kring det använda dos-verktyget ERICA tool och antaganden gjorda i detta verktyg. Övriga frågor som behöver ytterligare förtydliganden och förslag på granskningsfrågor till SSM:s huvudgranskning av SKB:s ansökan finns även listade i denna rapport.

Projektinformation

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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 on specific issues. The results from the consultants' tasks are reported in SSM's Technical Note series.

Objectives of the project
This review is part of the initial review phase with the overall goal to achieve a broad coverage of SR-Site and its supporting references and in particular identify the need for complementary information and clarifications to be delivered by SKB. Within this assignment, SKB´s assessment in SR-Site of radiological effects on non-human biota have been reviewed with focused consideration on whether the assessment methodology accounts for all relevant transport and accumulation processes, radionuclides and organisms, if parameter values used for modeling of doses to biota are relevant for the site and coherent with values used within SR-Site when modeling doses to humans and if dose-effect relationships used in order to assess the likelihood of effects are relevant.

Summary by the author
The focus of this review was SKB's assessment of radiological effects on non-human biota in SR-Site according to present regulations and guidance from SSM and it was conducted by Karolina Stark at the Department of Systems Ecology, Stockholm University. In short, the results from this review show that the completeness of the safety assessment can be questioned regarding considered radionuclides and ecosystem scenarios. In addition, there are gaps in the Forsmark site sampling and data, in calculated concentration ratios for non-human biota, and the integration of human and non-human biota dose assessment.

These gaps question the scientific soundness and quality of SR-Site. Clarifications are also needed regarding the use of the ERICA dose assessment tool and its assumptions. Other questions that need further clarification and suggestions of topics to SSM for further review of SKB's application are also provided in this technical note.

Project information
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This report was commissioned by the Swedish Radiation Safety Authority (SSM). The conclusions and viewpoints presented in the report are those of the author(s) and do not necessarily coincide with those of SSM.

Contents

1. Introduction

This review is part of SSM's Initial review phase of the Swedish Nuclear Fuel and Waste Management Company (SKB) safety assessment SR-Site for a final disposal of spent nuclear fuel at the Forsmark site. The focus of this review is SKB's assessment of radiological effects on non-human biota in SR-Site. Karolina Stark at the Department of Systems Ecology, Stockholm University, has conducted this review during a total of one man-month of work as outlined in the contract between SSM and Stockholm University (SSM 2010-1982).

For this review assignment it was specified that the reviewer should consider if the assessment methodology accounts for all relevant transport and accumulation processes, radionuclides and organisms, if parameter used for modeling of doses to biota are relevant for the site and coherent with values used within SR-Site when modeling doses to humans and if dose-effect relationships used in order to assess the likelihood of effects are relevant.

In addition, in the general guidelines from SSM for the Initial Review phase all external experts should consider:

- Completeness of the safety assessment
- Scientific soundness and quality of the SR-Site
- Adequacy of relevant models, data and safety functions
- Handling of uncertainties
- Safety significance
- Quality in terms of transparency and traceability of information in SR-Site and in the associated references
- Feasibility of manufacturing, construction, testing, implementation and operation of repository and engineered barrier components (if relevant)

This technical note includes a summary of Karolina Stark's findings, suggestions and conclusions within the review assignment.

1.1. Regulations

The aim of this review was to review SKB's assessment of radiological effects on non-human biota in regard of the regulations in the Environmental Code, the Nuclear Activity Act, and SSM FS 2008:37 sections 6 and 7. In SSM FS 2008:37 the sections 6 and 7 states:

- **Section 6: "**The final management of spent nuclear fuel and nuclear waste shall be implemented so that biodiversity and the sustainable use of biological resources are protected against the harmful effects of ionising radiation."
- **Section 7 "**Biological effects of ionising radiation in the habitats and ecosystems concerned shall be described. The report shall be based on available knowledge on the ecosystems concerned and shall take particular account of the existence of genetically distinctive populations such as isolated populations, endemic species and species threatened with extinction and in general any organisms worth protecting."

1.2. SKB's assessment methods

SKB assess possible harmful effects of ionizing radiation on the environment from possible future radionuclide releases from a final repository for nuclear waste by calculating radiation dose rates to non-human biota. The calculations are based on modelled activity concentrations in water and sediment in freshwater and marine ecosystems and in peat and air in wetland ecosystems from the central corrosion case. SKB use a software program, the ERICA tool, for calculating the dose rates to non-human biota and start at tier 2 (of 3 possible).

Radiation dose rates are calculated to *representative organisms* (site-specific) as far as there is input data. Where data of activity concentration is lacking for included radionuclides a set of *average organisms* were constructed by compiling data from related species. In addition, dose rates to *reference organisms* in the ERICA tool were calculated to cover all protected species in Europe and also red-listed organisms at the site.

Finally, the calculated dose rates for each organism are compared to the screening dose rate value of 10 $\mu Gy\ h^{-1}$.

Furthermore, background dose rates to organisms were calculated to evaluate if total dose rates from natural background and the possible release from a repository would results in dose rates exceeding the screening value of 10 $\mu Gy\ h^{-1}$.

2. Review findings

Here follows a summary of the review findings by Karolina Stark. They have been divided into findings related to completeness of the safety assessment, scientific soundness and quality of the SR-Site, and other review questions.

2.1. Completeness of the safety assessment

The completeness of the safety assessment can be questioned regarding radionuclides and ecosystems included as described in the following sections 2.1.1 and 2.1.2.

2.1.1. Radionuclides

Regarding completeness of the safety assessment there are some gaps in SKB's assessment concerning radionuclides included in the dose rate calculations for non-human biota. In a comparison between table 9-2 and table 11-1 in the SKB report TR-10-09 it was found that the radionuclide isotopes Ac-227, Am-242m, Cd-113m, Eu-152, H-3, Mo-93, Nb-93m, Pa-231, Pd-107, Pu-238, and Sn-121m were not included in the dose assessment for non-human biota but considered in the dose assessment for humans. In the SKB report TR-10-08 it is explained that Ac-227, Pa-231, and Pd-107 where not included in the dose assessment for non-human biota because of a lack of data.

There is a need for further explanation from SKB why the radionuclides listed above where not included in the assessment and also possibly a more extended literature search by SKB for additional data for the missing radionuclides. Last year the Wildlife Transfer Database was published online with concentration ratios (CRs) compiled by ICRP and IAEA and at least Ac can be found in the list of included elements.

2.1.2. Ecosystems

Regarding ecosystems considered in the assessment SKB have included activity concentrations in water and sediment in Freshwater and Marine ecosystems, and activity concentrations in peat and air in Wetland ecosystem in the dose rate calculations. However, activity concentrations in soil and water in other types of terrestrial ecosystems such as forest where not included. In the SKB report R-06-82 section 8.1.4 it is described that the activity concentrations in a river could be 10 times higher than in a lake and section 5.3.1 describes how flooding of streams in the Forsmark area could result in a significant accumulation of radionuclides in riparian wetlands. However, scenarios with ecosystems such as a flooding river and a floodplain/riparian wetland were not included in the dose assessment for non-human biota.

The SKB report TR-10-08 describes how the activity concentrations included in the assessment originate from ecosystems at the site such as wetland, watercourses, lakes, and sea (brackish water). These ecosystems were then assigned one of the ERICA tools three ecosystems (terrestrial, freshwater, and marine). It is also described that agricultural ecosystems are not included because they will originate from drained wetlands and be productive for 100 years. In turn they are disregarded

as biota habitat because of the assumption that individuals in agricultural landscape belong to large and stable populations from surrounding areas. First, it is surprising that SKB assumes that the drained wetland (mire with peat) will be a productive area because historically this type of soil was regarded as "light" and not very productive. Second, there are biotas (several plant species and animal species as birds) that are dependent on agricultural ecosystems and it is possible that a contaminated area could develop in to a "sink" for nearby populations draining it of genetically important individuals.

Concerning exposure pathways and habitats SKB has included those covered in the ERICA tool as described in the SKB report TR-10-08.

However, there is a possible scaling problem in SKB's dose assessment that leads to the question: How large area has a biosphere/landscape object in the radionuclide model? This model was not reviewed in this assignment. Can these landscape objects be applied to, for example, the genetically unique Pool frog breeding pond habitat at the site? Or are these types of habitats disregarded as being too small and the modeled activity concentrations averaged over a larger landscape object?

2.2. Scientific soundness and quality of the SR-Site

The scientific soundness and quality of the SR-Site can be questioned regarding site data, concentration ratios for non-human biota, and the integration of human and non-human biota dose assessment as described further in the section 2.2.1, 2.2.2, and 2.2.3.

2.2.1. Site data

The scientific soundness and quality can be questioned concerning site data for the SR-Site. In the dose assessment for non-human biota site data are missing for the major dose contributing radionuclides Ra-226, Np-237, and Po-210. Both the previous assessment in SR-Can and a BIOPROTA report from 2010 pointed out these radionuclides as key radionuclides. These data gaps have not been filled in SR-Site.

Moreover, there has been a lack of consistency over time in the sampling and measurements from the site Forsmark as was pointed out in the SKB report TR-10-08.

2.2.2. Concentration ratios for non-human biota

In the dose rate calculations for non-human biota SKB use concentration ratios (CRs) calculated to estimate internal exposure from radionuclides to organisms. Too few samples were collected from the site to enable a comparison of site CRs with the default CR values included in the ERICA tool. This is unfortunate because the ERICA tool database is not complete and consists of several data gaps that have been filled with a number of extrapolation methods. Also, in the SKB report TR-10-08 it was found that for CRs where the ERICA database has few data points the difference from site data was larger. Moreover, the calculated CRs from collected samples from the site show a tendency to be lower than in the ERICA tool for

terrestrial and freshwater biota. This is an issue that SKB should investigate further to understand what characteristics at the Forsmark site that can influence these results for the CR values.

Further, in the dose assessment for non-human biota it is assumed that the ERICA marine ecosystem CRs are adequate for the Baltic Sea/brackish biota from the Forsmark site. This is not a convincing assumption because these two ecosystems can have different biochemistry and in the Wildlife Transfer Database the data for marine and estuarine/brackish ecosystems were placed in two separate groups.

2.2.3. Integration human and non-human biota assessment

There are some scientific soundness questions regarding SKB's integration of human and non-human biota dose assessment in SR-Site. The SKB report TR-10-07 presents the Best Estimate (BE) values and Probability Distribution Functions (PDFs) of CRs for different types of terrestrial and aquatic biota used in the derivation of Landscape Dose Factors (LDFs) applied in dose assessments for humans. The report also describes a kinetic-allometric model that was applied for deriving values of CR for terrestrial herbivores in cases when data for an element were missing. This presentation leads to the question: Are these values also used in the dose assessment for non-human biota? If not, why not?

Furthermore, in comparison with the CR values used in the dose assessment for humans as described in, for example, the SKB report TR-10-07 the CRs for humans have been normalized to the carbon content of organisms. What are the advantages of this approach, and further, why was this approach not applied for CRs for non-human biota?

Moreover, what is SKB's reasoning behind developing a new dose assessment model called the Landscape dose factors (LDFs) for humans but not for biota dose assessment in SR-Site? These issues need to be further motivated and clarified by SKB.

2.3. Other review questions

This section describes review findings related to a previous dose assessment called SR-Can by SKB and to dose assessment assumptions and results in SR-Site.

2.3.1. A comparison with SR-Can

In a previous dose assessment for a final repository by SKB called SR-Can dose rate calculations for non-human biota in the advection/corrosion case resulted in risk quotients above 1 for the radionuclides Po-210 and Ra-226. This leads to the question: What has changed in SR-Sites dose rate calculations to result in no risk quotients above 1 for non-human biota?

In the dose assessment for non-human biota in SR-Site the activity concentrations used for biota are from the central corrosion case. Is this the same case as used in previous assessment called SR-Can or has something changed?

2.3.2. Dose assessment tool assumptions and results

In the dose rate calculations for non-human biota SKB use peat as input in the ERICA tool. In the ERICA tool it is possible to change, for example, the percent dry weight of soil for the input activity concentrations. How did SKB consider the soil density and water content of the peat activity concentrations used as input? How many percent dry weight was assumed in the ERICA tool calculations?

Further, the internal exposure by intake of water by terrestrial biota was not considered. This might be particularly important because SKB chose the terrestrial ecosystem in the ERICA tool to represent a wetland. The dose assessment tool RESRAD-BIOTA considers this exposure pathway. Would SKB's dose rate results for non-human biota be different if the RESRAD-BIOTA tool was used in the assessment instead of the ERICA tool?

In the SKB report TR-11-01, Page 842, in section 15.7.5 it is stated that "The methodology used to evaluate dose to non-human biota needs further development to fully utilize site data". Is SKB referring to using the ERICA tool to assess doses to non-human biota? What developments does SKB mean would be necessary and what has SKB done to develop and implement them?

For which reference organism size in the ERICA tool is skin and fur assumed to be shielding? How does this affect the dose rate results in SKB's dose assessment?

In the SKB report TR-10-08 on Page 39 it was pointed out that how to estimate radiation doses to mushrooms with their complicated morphology needs further study. How was this issue handled in SR-Site?

In the dose assessment for non-human biota are plants assumed to be ellipsoids, as well as mushroom? If so is this a representative shape of a plants/mushroom? Would the dose results differ if plants were to be represented by a cylinder? This could be tested with a more detailed model than the ERICA tool such as the TADPOLE model.

In SKB report TR-10-08 on page 41-42 it is unclear whether the highest mean doses are compared or the maximum (95^{th} percentile) doses as in a worst case scenario. In the text they are discussed as the highest total doses. This needs further clarification by SKB.

In SKB report TR-10-08 on Page 42, Ra-226, Np-237, and Po-210 contributed the most to the radiation dose to non-human biota. This is not further discussed in the report. Was this expected? What characteristics of these isotopes or the release material result in the highest radiation doses from these isotopes?

In SKB report TR-10-08, Figure 3-2 habitat 10 should be "freshwater in sediment".

In SKB report TR-11-01 on page 681, Table 13-8, it is stated that the mean release was used, as given in the probabilistic central case, to calculate dose rates to non-human biota. Why were not maximum releases used in the dose rate calculation to non-human biota?

In SKB report TR-11-01, Page 626, Section 13.2, it is stated that "If harmful effects at the level of the individual organisms can be excluded, then this also ensures the sustainability of populations and of ecosystem functions**"**. This may not be true

when it comes to effects on populations and ecosystem functions. In the STAR network WP 5 population effects have been modeled from effects on individuals and it was found that population effects occur at a lower dose rates than the individual effects. In addition, there may be an effect on an ecosystem function without a harmful effect on an individual. Stressed organism may accumulate less energy and nutrient that may lead to decreased food quality for higher trophic levels in for example the aquatic food chain (starting with phytoplankton) and in the terrestrial ecosystem with stressed insects accumulating less nutrients which decrease the decomposition rates and effects the nutrient cycling in the whole ecosystem.

Finally, because long term radiological effects are assessed it can be interesting to explore if lifetime radiation doses may differ for organisms compared to radiation dose rates. If lifetime doses were to be calculated to non-human biota instead of dose rates which organisms would be the most exposed from a possible future release of radionuclides in a deep repository? These results could complement SKB's results from the dose rate calculations.

APPENDIX 1

Coverage of SKB reports

Table 1: SKB reports reviewed in this review assignment of SR-Site for radiological effects on non-human biota.

Reviewed report	Reviewed sections	Comments
TR-10-08 Long term radiological effects on plants and animals of a deep geological repository	All sections	The main report reviewed in this assignment
TR-11-01 Long-term safety for the final repository for spent nuclear fuel at Forsmark	Relevant sections for the dose assessment for non-human biota, especially volume III sections in chapter 13 and 15.	Other volumes and chapters in this report were also quickly read through and were used for comparison between human and non-human biota assessment and text in TR-10-08
TR-10-09 Biosphere analyses for the safety assessment SR-Site – synthesis and summary of results	Relevant sections for dose assessment for non-human biota, especially chapter 11.	Other chapters in this report were also quickly read through and some tables were used for comparison between human and non-human biota assessment
TR-10-07 Element-specific and constant parameters used for dose calculations in SR-Site	Relevant section for comparison between human and non-human biota assessment	
TR-10-45 FEP report for the safety assessment SR-SIte	Summary, introduction, chapter 1 and 2. Some tables in the appendix	Read through introductory chapters to understand how the FEP report and database was built up. No thorough review conducted of the FEP list
R-06-82 The biosphere at Forsmark. Data, assumptions and models used in the SR-Can assessment	Section 5.3.1 and 8.1.4	A report included in the SR-Can assessment but relevant here for comparison with SR-SIte

APPENDIX 2

Suggested needs for complementary information from SKB

1. SKB should explain why not the same radionuclides were used in the dose assessment for humans and for non-human biota.
2. SKB should clarify why some ecosystems and scenarios where not included for biota such as a flooding river, riparian wetland, forest, and agricultural ecosystem.
3. SKB should clarify how the size of the landscape objects was chosen for the dose assessment to non-human biota. Can they be applied to, for example, important breeding habitats for a pool frog?
4. SKB should possibly complement site data for identified gaps for the dose assessment for non-human biota, especially for major dose contributing radionuclides and concentration ratios for organisms where the ERICA tool has few data points.
5. SKB should further investigate the characteristics at the Forsmark site that influence the site CR values to differ from the CR values in ERICA.
6. SKB should apply relevant CR values for brackish water organisms in the dose assessment for no-human biota.
7. SKB should clarify if and why different CR values were used in the derivation of LDFs for humans and in the dose assessment for non-human biota.
8. SKB should explain why CR values for humans were normalized to carbon content but not CR values in the dose assessment for non-human biota.
9. SKB should clarify and further motivate why a new dose assessment approach for humans was developed that perhaps better applies to possible long-term effects but no such approach was developed for non-human biota.
10. SKB should explain what has changed from SR-Can to SR-Site so that no risk quotients are now above 1 for non-human biota. Also, is the same scenario used in SR-Site as in SR-Can?
11. SKB should clarify the dose assessment assumptions such as what dry weight percentage that was used for peat activity concentrations in the ERICA tool, what shape that was used for mushrooms, and why the intake of water by wetland organisms was not included in the dose assessment for non-human biota.
12. SKB should clarify if mean releases or if maximum releases were used in the dose assessment for non-human biota. It is described differently in different reports (TR-10-08 and TR-11-01).

APPENDIX 3

Suggested review topics for SSM

1. Lifetime radiation doses to non-human biota. Is it appropriate to calculate only dose rates to biota to assess long-term effects from a possible future release from a deep repository? Or should lifetime doses also be calculated? What organisms would be the most exposed in such calculations?
2. Why are site data missing in the dose assessment for non-human biota? And why has there been no consistency in the sampling and measurements from the Forsmark site? This is particularly surprising because of the long period of preparations for SKB's application. Is this a problem for the assessment?
3. Exposure pathways, habitats, and ecosystems. Are there any more exposure pathways for non-human biota missing is the SKB dose assessment?
4. What shape sizes for plants and mushrooms where used in the dose assessment for non-human biota? Could the doses to plants and mushrooms be assessed with other shapes? Does this affect the dose results?
5. How is it possible that a future possible failure of a repository for high level nuclear waste does not result in any risk quotients above 1 for non-human biota when compared to the screening value of 10 $\mu Gy\ h^{-1}$? Is it because of retention of radionuclides in the upward transport from the deep repository, the landscape model used and the size of landscape objects, or will there be low release levels?
6. A comparison could be performed between the dose results from the ERICA tool and other dose models such as the RESRAD-BIOTA and K-BIOTA and others that, for example, participated in IAEA EMRAS I and II.
7. Does protecting individuals also protect ecosystem functions? This question could be further explored.
8. A comparison could be performed between dose results when using CR values in the ERICA tool and CR values from ICRP (more selective) and CR values from IAEA (more data included).
9. A comparison could be performed between dose results when using current grouping of CRs for reference organisms and dose results if the CRs are grouped according to the function of the species that data originate from.

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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 270 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.

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