

Additional considerations for the non-human biota dose assessment in the SR-PSU

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Abstract

The influence of size of the biosphere object on **resulting** dose rates has been discussed. Smaller alternative object delineations which are relevant to non-human biota were used. It was determined that the impact of decreasing object size on increase activity concentration of radionuclides would not pose a risk to non-human biota (NHB). An analysis of the impact of object size on dose rates indicated that object size would need to be reduced to a very small area in order to substantially increase the concentration of key dose-contributing radionuclides (i.e. C-14) to the point where they might pose a threat to populations of biota. Such a reduction in object size is unrealistic and would raise further questions as to the relevance for population- or ecosystem-level endpoints.

The potential impact of home-range and migration of NHB on dose is discussed in detail. Since the conservative assumption that all organisms are permanently resident within the site biosphere objects was applied in the SR-PSU assessment, any time spent away from the object can be considered a reducing factor for dose. The theoretical reduction of dose due to migratory habits of some biota indicates that the assessed dose rates to some types of organisms are conservative.

The ERICA tool was updated in November 2014. These changes were not included in the SR-PSU assessment as they were released after the assessment was performed. No changes in the model, i.e. the equations, occurred; the changes are limited to the parameter values. The relevance of changes in ERICA 1.2 on to the SR-PSU assessment are elaborated upon, in chapter 4.

The CR values used in the ERICA tool were updated based on updated data in the *Wildlife transfer database*. The newly available literature data on CRs will be incorporated in upcoming safety assessments. In order to assess the potential effect of updated CR values on the outcome of the assessment an updated version of CR values including newly available literature data is derived in Chapter 5. The updated CR values are compared to the CR values used in SR-PSU. In some cases, large difference in CR values was found and for these cases the dose consequence is evaluated.

It is argued here that it is not realistic for aquatic birds and mammals to be mapped as on or in sediment in freshwater or marine ecosystems; such sediment interaction is considered momentary at most. Interactions of birds and mammals with soil are considered in the assessment to be covered by the reference organisms in the terrestrial ecosystem. Despite the implausibility of this case, we investigate the occupancy of mammals and birds in aquatic sediments. The results indicate that there is no significant increase in dose rate from such organisms living within sediment.

While it had not been considered in the SR-PSU assessment, it was deemed plausible that terrestrial and freshwater Amphibian could exist in soil or in sediment. Calculations for dose rates to terrestrial Amphibian in soil and freshwater Amphibian in sediment are presented and compared to the corresponding reference organisms. It is shown that dose rates to the amphibians increased when in the soil/sediment, but as most by at most 64%, and this means that the dose rates remained over four factors of ten lower than the screening dose rate.

At present there is no clear method or model for assessing the dose to root structures of plants. There is a paucity of data with regards to uptake of radionuclides into roots, the compartmentalisation of radionuclides within the different structures of a plant, and the relative radiosensitivity of the various organs. A highly conservative solution, to map the roots as a separate organism, in soil, and simply add the dose rate to that of the reference plant is discussed and employed using unit radionuclide concentrations in media to investigate the potential for underestimation in the SR-PSU assessment. Results indicate that the increase in dose rates from including root structures would not be sufficient to increase the dose rates to a point of concern and that the assessment remains sufficiently conservative to ensure the protection of NHB at the site.

No site organisms were identified that lived in an aquatic environment (external exposure) but ate exclusively from the terrestrial ecosystem (internal exposure) and therefore such a hypothetical organism was not included in the SR-PSU assessment. However, to explore the potential underestimation to such a

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hypothetical aquatic (marine or freshwater) bird or mammal the external dose rate from aquatic ecosystem and internal dose rate from the terrestrial ecosystem were combined, the resulting total dose was contrasted with the reference Bird and Mammal from each relevant ecosystem, as well as the site-species already identified which live in multiple habitats (European otter, ruddy Turnstone, Black tern). Due to the dominance of internal exposure for NHB dose rate the dose rate hypothetical organisms closely followed that of the terrestrial reference organisms. The dose rate to reference organisms was greater than to the hypothetical Bird or Mammal. It can be concluded that this pathway of exposure is not necessary to ensure protection of biota from SFR.

1 Introduction

In the SR-PSU assessment, an extensive evaluation of dose rates to non-human biota (NHB) was performed. SSM has asked a number of questions regarding the assessment of NHB, e.g. the effect of size of the biosphere objects, effect of home range, habitat preferences, exposure to roots in plants, and the importance of tool updates and new CR values (SSM2015-725-47). In this PM, the requested information is discussed in detail whereas a short summary of the answers can be found in SKBdoc 1572152.

2 Object size and home-range

2.1 Smaller objects

Despite the confidence in the methodology for object delineation used in the assessment, some alternative delineations were considered using different criteria that resulted in smaller object sizes (SKB 2014, Figure 6-14). In one variant the open wetland area in object 157_2 was outlined. This area was dominated by wetland vegetation and the peat surface was below or just above the groundwater level. According to the hydrological simulations the area contained several interconnected shallow pools, and it was deemed to be a suitable habitat for threatened species like the fen orchid and the pool frog. The open wetland area was about 50% the size of the original object, and the concentrations calculated for surface peat and associated water are deemed relevant for NHB calculations.

Four radionuclides (C-14, Cl-36, Mo-93 and Ni-59) were chosen to represent a range of transport and accumulation behaviours of radionuclides and for their relatively long half-lives, more than 4000 years (SKB 2014, Section 10.5.1). In surface peat and surface water associated with peat, the concentrations of carbon-14 increased proportionately with decreasing object size (SKB 2014, Figure 10-31). The decrease in object size has an approximately one to one inverse-linear relationship with concentration of the C-14. This is due to the degassing of C-14, which is an export pathway for C-14 and is proportional to the object size. Thus, the activity concentration of C-14 in peat and surface water was approximately twice as high in the object delineation based on open wetland area as compared to the concentrations resulting from a release to the original outline of the object. Mo-93, Cl-36 and Ni-59 are not readily degassed to the atmosphere, and differences in environmental concentrations between the outlined areas could primarily be attributed to variation in regolith thickness and hydrological fluxes. Thus, the environmental concentrations of these radionuclides were not proportional to the object size, and the concentrations in the object delineation based on open wetland area were similar to that of the original object.

The dose from C-14 represented as much as 100% of the total maximum dose rate to the most exposed organism in some calculation cases (SKB 2015, Table 8-1). In these cases, a difference in object size could be expected to proportionately affect the overall dose-rate experienced by the most-exposed organism. The most exposed organism across all calculation cases was a freshwater organism in the Earthquake calculation case, receiving a dose of 9.2×10^{-2} $\mu\text{Gy/h}$, which was more than two factors of ten lower than the screening dose rate (10 $\mu\text{Gy/h}$). Therefore, theoretically the discharge area would have to be less than one hundredth the size of object 157_2 to concentrate the C-14 to give dose rates that approach a level where an individual organisms might be significantly affected; this reduced object size represents an area of around 1500 m^2 (i.e. less than a 40m \times 40m square)¹. SKB are not aware of any transport pathway that would channel most of the release to such a small lake or wetland ecosystem. Instead SKB's analysis of transport pathways from the SFR repositories suggest that the minimum area for a substantial fraction of the release would be on the order of 47 000 m^2 at the bedrock – biosphere interphase (SKB 2014, Section 10.8), and vertical and horizontal transport within the surface system is likely to result in dispersion to an even larger area (see further discussion in SKB 2014, Section 11.2.3).

The population of an organism type is unlikely to be confined entirely to a biosphere object. Thus, when considering organism types with a population range larger than the reference object, a further reduction of object size could be seen as a reducing factor of the dose rate to the population overall. The organisms within such a small area would represent only a small subset of a population that would rapidly exchange with, or be replaced by unexposed organisms from surrounding areas.

¹ In the base case, where calculated dose rates were lower, the release would have to be confined to an even smaller area to reach a level of concern ($\sim 120 \text{ m}^2$ for the most-exposed organism in freshwater, and $\sim 56 \text{ m}^2$ in terrestrial ecosystems).

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The largest potential risk is to rare or endangered species with very limited population range that are endemic to the site, or which have an isolated population limited to the site, such as the pool frog *Rana lessonae*. The pool frog which is found at the site is limited to some pools and small lakes in the northern Uppland region of Sweden (Lindgren et al. 2014). The local population within the SKB investigation area is presently dispersed over 11 pools, most of which are small in size (<1500 m²) (Collinder and Zachariassen 2016). If it is assumed that the future Forsmark landscape will resemble the present, a spatially confined release is likely to affect only a single pool. If one pond were to receive a high exposure from released radionuclides, which results in a reduced rate of reproduction in that pond, other ponds nearby will be unaffected. Thus, even in a worst case scenario only a small fraction (<10%) of the population would be affected, and the affected sub-population would be within migration distance from several unaffected pools nearby.

In summary, SKB have no indications that there exists any pathways that can transport a significant fraction of the total release from SFR to a confined habitat that is of such a small size that an individual organism would be at risk. Moreover, even in a worst case scenario where the release is hypothetically confined to a small habitat, only a limited fraction of the local population would be affected. Therefore, SKB conclude that a concentrated release into a very small area does not pose a risk of having a significant impact on populations of non-human biota (NHB).

2.2 Influence of migration and home-range on dose rates

In the SR-PSU assessment of dose rate to NHB, it is conservatively assumed that the organisms reside permanently at the site, i.e. within a biosphere object. While dose rates are calculated to an individual, it is also conservatively assumed that the population of organisms all receive the same dose as the modelled individual. A biosphere object is defined as an area in the present and/or future landscape that potentially, at any time during the assessment period, could receive radionuclide-containing groundwater or surface water originating from the repositories.

The assessment assumes a homogeneous distribution of radionuclides within each biosphere object. However, outside of the biosphere objects, no radionuclide exposure is predicted. Therefore, the total dose rate to an organism depends entirely on the time where the organism is present in a biosphere object, at the Forsmark site. In SR-PSU, the organisms are effectively static, remaining in the exposure area and receiving 100% of the potential dose rate. Biosphere objects at the site range from ~100, 000 m² to just under 1.5 million m² (SKB 2014). The largest of the objects represents an area with dimensions (length, width) in the order of approximately a kilometre. For most mobile organisms that do not migrate, this represents an area that would contain the organisms, however for those organisms that have larger home-ranges or have intra- or international migratory behaviours, these areas represent just a fraction of their range.

Organisms with a home-range and/or a migratory range that is larger than the dimensions of the relevant biosphere object, can be expected to be absent from the afflicted area for a period of time and thus will receive a reduced radioactive exposure. The distance travelled away from the site will be a factor in determining the proportion of the organism's life that is spent within a biosphere object and thus the proportion of exposure it will receive. The distance travelled from the site, and thus the proportion of time spent outside of a biosphere object, could be considered a reducing factor when determining dose or dose rate. An organism that spends only 50% of its time in the biosphere object could be considered to receive half of the dose rate, overall.

Long-distance migrating organism types, such as seasonally migrating birds, may spend a majority of each year away from the site and resident in a biosphere object at the site for only a few months or weeks. Therefore, the relative proportion of radiation exposure of such organisms will be reduced accordingly. The reduction of dose rates will decrease the relative risk to populations of these migrating organism types. Therefore, in an assessment where dose rates to NHB are higher than the screening dose rate by a small margin, consideration of the migration habits of some organisms may reduce the exposure to levels of no concern. However, in such circumstances there would still be less-mobile or immobile organisms

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that remain at the site, the individual organisms of such species would undergo the full dose. The effective dose to populations of organisms with limited mobility thus depends on the proportion of the population that exist within the exposed object (as described in section 2.1).

2.2.1 Freshwater organisms

Organisms associated with lakes are often dependant on the lake and will not travel far from the lake system. Sedentary biota, such as plants and some immobile animals, will be entirely confined to the lake within which they were propagated. Other organisms, by their aquatic nature and/or low mobility will also remain in a single lake. Such static or low-mobility organisms will experience the full exposure from radionuclides in the biosphere object. However, the population will span several such lakes and individuals may cross over during flood events, etc., therefore exposure to organisms in a single lake will impact only a proportion of the total population. Some organisms, such as mammals or amphibians, may be able to cross short distances out of the lake to reach an adjacent waterbody, therefore they may be able to leave the biosphere object for some time.

Migrating birds such as the black tern (*Chlidonias niger*) will be present at the site for the summer months during their breeding season, but will be absent for the remaining part of the year.

2.2.2 Marine organisms

Marine ecosystems are not defined within any biosphere object, but are assessed as being associated with relevant coastal basins. The marine ecosystem is connected to the wider Baltic Sea and no geographic boundaries apply, therefore communities of organisms are not confined to the site. Only immobile benthic organisms will remain permanently in a biosphere object. Organisms with low mobility and small home-ranges may remain in a biosphere object.

Migrating birds such as the ruddy turnstone (*Arenaria interpres*) will be present at the site for the summer months during their breeding season, but will be absent for the remaining part of the year.

Movement of planktonic organisms will follow water currents and will remain at the site until the water is exchanged; this could be as little as a few days or up to 100 days (Karlsson et al. 2010) (Phytoplankton or Zooplankton).

Marine pelagic fish such as the Baltic herring, (*Clupea harengus membras*) migrate seasonally as well as diurnally, following shoals of baitfish or the planktonic bloom, but also migrating vertically, as the water warms and cools. Such fish have no specific territory and may only briefly be present at the site. If juvenile life-stages are considered, the residence time would be longer, with one study observing a four-month occupancy of herring larvae within a basin after hatching (Bradford and Iles 1993).

Marine mammals such as the ringed seal (*Pusa hispida*), may follow shoals of fish along the coast, and would therefore be present at the site as the prey passes the site. "Resident" mammals would be situated more permanently at the site, but would still have a home range larger than the object, the resultant occupancy would still be reduced relative to those modelled in the assessment.

2.2.3 Terrestrial organism

Migrating birds such as the spotted crake (*Porzana porzana*) will be present at the site for the summer months during their breeding season, but will be absent for the remaining part of the year.

Terrestrial mammals such as the Moose (*Alces alces*) may embark on migrations of a few tens of kilometres, in relation to the advancing snowpack (Ball et al. 2001).

3 Updated inventory of Mo-93

The inventory of Mo-93 was updated at a late stage of the SR-PSU project, after the initial assessment was completed. In the initial assessment, the best estimate of the Mo-93 inventory was 1.78×10^{10} Bq. In the updated inventory, this increased to 2.93×10^{10} Bq (an increase of 64%). The “high inventory calculation case” was used as a bounding case to account for uncertainties in the inventory and included an already high inventory of Mo-93 of 9.55×10^{10} Bq. In the updated inventory for the “high inventory calculation case”, the uncertainties related to the Mo-93 inventory decreased (see Table 3-1), and the resulting inventory was actually lower than in the original assessment (by 62%). The decrease in inventory of Mo-93 in the high inventory calculation case will reduce the total dose rate in each organism, thus lowering the risk to biota for this calculation case.

In the original base case calculation, Mo-93 was a minor contributor to total dose rates in NHB; the greatest dose rates from Mo-93 were several orders of magnitude lower than the most contributing radionuclide(s). Thus, the small increase in inventory of Mo-93 in the base case in the updated version will have a negligible impact on the total dose rate to NHB. Furthermore, as the total doses to organisms will remain several orders of magnitude lower than the screening dose rate, the updated inventory will not change the conclusions of the risk assessment.

Table 3-1. Original and updated Mo-93 inventory for the base case and the high inventory calculation case.

	Original Mo-93 inventory	Updated Mo-93 inventory
Base case	1.78×10^{10} Bq	2.93×10^{10} Bq
High inventory calculation case	9.55×10^{10} Bq	5.95×10^{10} Bq

4 Changes in ERICA 1.2

The ERICA version released in 2007 was used in SR-SPU assessment, incorporated into the Ecolego modelling platform. The assessment was included in SKB (2015), submitted to SSM in December 2014. As the report was submitted just one month after the release of ERICA version 1.2 in November 2014 the new version was not included in the SR-PSU assessment.

A full list of changes to the ERICA tool with the updated version (version 1.2) can be found on the website (<http://project.facilia.se/erica-users/release-notes/Updates%20to%20the%20ERICA%20tool%20v1.2.pdf>) and a description can also be found in Brown et al. (2016). No changes in the model, i.e. the equations, occurred; the changes are limited to the parameter values. The relevance of changes in ERICA 1.2 on to the SR-PSU assessment are elaborated upon, below.

4.1 Reference organisms

Freshwater Reptile was added to the list of reference organisms in the ERICA tool. No freshwater reptiles are relevant at the Forsmark site now or in the future. The European pond turtle (*Emys orbicularis*) has a reported historical range that might have extended as far as Southern Sweden, but this would not extend as far north as Forsmark. In future assessments, the Freshwater Reptile may be included, but due to its middling geometry and its habitat on sediment, the changes are unlikely to result in dose rates higher than those found in other freshwater biota.

The terrestrial reference organism Bird Egg was removed from the list. This organism was the most exposed terrestrial organism in three calculation cases, the Earthquake calculation case, Loss of barrier function calculation case – no sorption in the repository, and the Loss of barrier function calculation case – high water flows in the repository. The removal of this organism from the assessment would mean that the next highest organism would become the most exposed in the terrestrial ecosystem of each calculation case. This would have no impact on conclusions drawn for the assessment.

The change from having two types of Marine ‘Sea anemones or true corals’ to one type in ERICA 1.2 would have no impact on the SR-PSU assessment, as none of these types were relevant to the site now or in the future.

The increase in size of the Marine Macroalgae and both Marine and Freshwater variants of Phytoplankton in ERICA 1.2 might impact the resulting dose rate calculated relative to the assessment in SR-PSU the dose rate may be slightly increased, but likely not more than other, larger reference organism types in the same habitat. Sensitivity to size was investigated in Torudd (2010) and Jaeschke et al. (2013) and was shown to have a low impact on resulting dose rates, and thus no significant impact on the conclusions from the assessment are expected. It was posited that the very small size of phytoplankton in the assessment led to dose rates significantly lower than other biota in the same environment and thus increasing the size would likely increase the resulting dose rates to levels similar to those of other organism types.

An improved naming structure was incorporated with the changes in ERICA v.1.2, however this does not affect the list of organisms tested, the dose rates calculated, or the outcome of the assessment.

4.2 DCC for Lichen and Bryophytes

Dose conversion coefficients (DCCs) for exposure of the terrestrial organism Lichen and Bryophytes were recalculated due to the change in geometry (now larger). As this organism was the most exposed organism type in the terrestrial environment in many calculation cases, such changes in DCCs are not of negligible concern. An analysis of the updated DCCs indicates that DCCs for internal irradiation (alpha, low-energy beta and high-energy beta/gamma) for many radionuclides increased slightly (Appendix A; Tables A-1b-d) and by as much as 33% for C-14. The external on soil high-energy beta/gamma DCCs increased

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significantly for all radionuclides except Ni-59 (Appendix A; Table A-1a); the highest increase in DCC was for U-238 by over 100 000 times. However, U-238 had a very small effect on the total dose rate, relative to the other radionuclides, in the original assessment, and the relative effect from U-238 remained small with the increased DCC value. Further analysis indicates that the effect from these changes in external DCCs (due to the larger geometry) increases the total dose rate (at the time of highest exposure: 7000 AD) by about 1%, compared to the SR-PSU assessment, predominantly from increases in external dose from U-235. The changes to internal DCCs had a negligible impact on total dose rate (~0.023% increase compared to SR-PSU), and therefore we can determine that the total dose rate that would result from using ERICA 1.2 parameter data for Lichen and bryophytes would be an increase of about one percent. Such an increase would not influence the overall conclusion that populations of these organisms are not at significant risk.

4.3 Occupancy factors

The updated ERICA tool now treats terrestrial Amphibian and Reptiles as “in soil”. In SR-PSU, these organisms were treated as “on soil”. Somewhat increased dose rates would be expected in these organisms from ERICA 1.2. Using Amphibian as an example, the impact of this is investigated further in section 6.

4.4 Default radionuclides

Ba-140, Ca-45, Cr-51, Cf-252, Ir-192, La-140, Pa-231 and Zn-65 have been added to the default list within the ERICA Tool. Of these, only the radionuclide Pa-231 was used in the assessment.

CR values used for Pa in ERICA 1.2 are based on elements analogues (in most cases Am, Pu and U) since no additional CR data for Pa are reported in ERICA 1.2. In SR-SPU element analogues based on site-specific data were used when possible. The inclusion of Pa in ERICA 1.2 would not affect the CR values used in SR-PSU since no additional CR data for Pa have been made available.

The DCC values for Pa-231 used in SR-PSU were derived using the ERICA tool, the updated DCC values now included in ERICA 1.2 as default are in most cases identical to the values derived in SR-PSU, with the exception of marine and freshwater phytoplankton where the mass has been updated in ERICA 1.2. These updated data will be included in upcoming safety assessment but the effects on the reported dose rates in SR-PSU are expected to be small and will not affect the conclusions drawn in the assessment.

4.5 Updated CR values in ERICA 1.2

The CR values from the Wildlife Transfer Database was used to update the CR values in the ERICA tool version 1.2 (Brown et al. 2016). The Wildlife Transfer Database (WTD) is a joint effort by ICRP and IAEA to create a database, where transfer factors (CRs) for wildlife are collected for assessment of radiological safety for the environment. The WTD consist of two data tables, one table reported by ICRP where CRs are derived for the reference animal and plants (RAPs) defined by ICRP, and one table reported by IAEA where data for several generic wildlife types are reported. Both tables are derived using data from the same underlying sources, the difference is how the selected data are categorised into either RAP organisms or generic wildlife groups. The database tables are updated continuously when new data have been made available. The CR data for general wildlife group from the IAEA Summary table have been used to update the ERICA 1.2 database. The WTD version from December 2013 was used to update the ERICA 1.2 tool. In comparison to the first version of the database from February 2011 17,000 CR values were added. Since a large number of new data had been made available the updated CR values in ERICA 1.2 differ largely from the CR values used in the version from 2007 in some cases.

A simplified and revised method for extrapolating concentration ratio (CR) values where empirical data was lacking has been implemented in ERICA 1.2. It had been noted that the previous methods for deriving values could lead to extreme estimates of environmental media concentration levels, especially in aquatic organisms. The recommendation to used CR values for “similar reference organisms” instead of similar

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taxonomy was made, and it also advised against the use of CR for freshwater organisms as parameter analogues for marine organisms and vice versa.

5 Updated CR values based on newly available literature data

The newly available literature data presented in WTD with around 17,000 additional CR values are an important resource for parameterisation for future safety assessments and will affect the selection of CR values in upcoming assessment. Since these newly available data were not available at the time of the parameterisation for SR-PSU, and therefore not included, the effect of the additional data will be investigated in this section.

5.1 Literature data used for CR values in SR-PSU

The CR values used for NHB calculations in SR-PSU are derived in Tröjbom et al. (2013). Site data have been used wherever available, or, if lacking, site data from an analogous organism or elements were used. Literature data have, in the majority of cases, been used as supporting data, to sense check the selected site data. But in cases where no site data were applicable, data from literature sources were implemented from three data sources: the WTD, ICRP Summary table dated to February 2011 (ICRP 2009), the database presented in ERICA Assessment Tool (Beresford et al. 2008 (terrestrial) and Hosseini et al. 2008 (aquatic)) and the data from IAEA (2009, 2010).

During the parameterisation of CR values for SR-PSU, two database tables were available at the WTD website, the ICRP summary table and the IAEA summary table, both dated to February 2011. The ICRP summary table was reported in ICRP Publication 114 (ICRP 2009) and this table was included in the SR-PSU assessment. The data from the IAEA summary table dated to February 2011 were used to produce the IAEA report TRS 479 (IAEA 2014). The IAEA report TRS 479 was published in 2014 after the parameterisation in SR-PSU safety assessment was conducted therefore these data were not included in the SR-PSU assessment.

For some elements and organism types site data were not available, and no analogues were applicable, for these cases selected CR values were based on literature data. This is true for the elements Ag, Po, Pu and Tc and for the terrestrial organisms: Detritivorous invertebrates, Flying insect, Gastropods, and Soil invertebrates. These parameter and element cases, where literature data were used in SR-PSU are shown in Table 5-1 (marked with an L in blue boxes). For these elements and parameters, it can be expected that new literature data presented in WTD will result in updated CR values. In other cases, where site data for analogues (elements and/or parameter analogues) were used, newly available literature data might replace the analogue data and result in updated CR values. These cases are marked with a A in orange boxes in the Table 5-1.

5.2 Newly available literature data in the WTD

An update of the WTD has been done in April 2015 and at the moment, two updated versions of the database files, ICRP Summary table and IAEA Summary table are available at the wildlifetransfer.org website. None of these tables are reported in any publication, here they are referred to as the WTD ICRP (2015) and WTD IAEA (2015). This means that additional updates of the WTD have been done after the update of CRs in ERICA 1.2 in December 2014.

The data from the WTD IAEA summary table from February 2011 have been compared to the WTD IAEA (2015) version; it was determined that additional data for over 300 CR cases have been added and that many additional data samples have been added to existing CR values resulting in updated values.

The WTD ICRP summary table from February 2011 and from April 2015 have been compared and it was concluded that CR values for 239 additional cases have been added to the 2015 version of the table. Many of the values were updated and additional references were used.

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Table 5-1. Cases where literature data have been used for parameterisation in SR-SPU and where the updated literature data is expected to have a direct effect on the selected CR values marked with an L in blue boxes in the table. Cases where analogues have been used for parameterisation are marked with an A in orange boxes in the table, for some of these cases the updated data can have an effects on the selected CR value.

Parameter	Ac	Ag	Am	Ba	Ca	Cd	Cl	Cm	Co	Cs	Eu	Ho	I	Mo	Nb	Ni	Np	A	Pb	Pd	Po	Pu	Ra	Se	Sm	Sn	Sr	Tc	Th	U	Zr		
cR_Lake_amph_NHB	A		A	A	L	A	A	A	A	A	A	A	A	A	A	A	A	A	L	A	A	A	A	A	A	A	A	A	A	A	A	A	
cR_Lake_bent_fish_NHB	A		A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A		A	A	A	A	A	A	A	A	A	A	A	A	A	
cR_Lake_bird_NHB	A		A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A		A	A	L	A	A	A	A	A	A	A	A	A	A	
cR_Lake_bivale_NHB	A		A					A											A		A	L	L	A			A						
cR_Lake_crust_NHB	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	L	L	L	A	A	A	A	L	A	A	A	
cR_Lake_Fish_NHB	A		A			L					A								A		A	L	L	A			A		L	L			
cR_Lake_gastr_NHB	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	L	L	L	A	A	A	A	L	A	A	A	
cR_Lake_ins_larvae_NHB	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	L	A	A	A	A	
cR_Lake_mammal_NHB	A		A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A		A	A	L	A	A	A	A	A	A	A	A	A	A	
cR_Lake_pel_fish_NHB	A		A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A		A	A	A	A	A	A	A	A	A	A	A	A	A	
cR_Lake_pp_plank_NHB	A	L	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	L	L	A	A	A	A	A	L	A	A	A	A	
cR_Lake_pp_vasc_NHB	A	L	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	L		A	A	A	A	A						
cR_Lake_zoopl_NHB	A	L	A	A	A	A	A	A	L	L	A	A	L	A	A	A	A	A	L	A	A	L	A	A	A	A	A	L	A	L	L	A	
cR_Sea_bent_fish_NHB	A	A		A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	
cR_Sea_bent_moll_NHB	A	L	A					A											A	A		L	L	L				A	L				
cR_Sea_bird_NHB	A	L	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	L	L	A	A	A	A	A	A	A	A	L	A	
cR_Sea_crust_NHB	A	L	A				L						L		L				A	A	A	L	L	L			A			L			
cR_Sea_Fish_NHB	A	L	A								A	A							A	A	A	L	L	A				L					
cR_Sea_mammal_NHB	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	L	L	L	A	A	A	A	A	L	A	L	A	
cR_Sea_pel_fish_NHB	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
cR_Sea_polych_NHB	A	L	A	A	A	L	A	A	L	L	A	A	A	A	L	A	A	A	A	A	L	L	A	L	A	A	A						
cR_Sea_pp_macro_NHB	A	L	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	L	L	A	A	A	A	A	L	A	A	A	A	
cR_Sea_pp_plank_NHB	A	L	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	L	L	A	A	A	A	A	L	A	A	A	A	
cR_Sea_pp_vasc_NHB	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
cR_Sea_zoopl_NHB	A	L	A				L												A	A	A	L	L	L			A	A	L	L	L		
cR_Ter_amph_NHB	A	L	A	A	A	L	A	A	A	L	A	A	A	A	A	A	A	A	L	A						A	L	L	A	A	A	A	
cR_Ter_bird_egg_NHB	A	A	A	A	A	A	A	A	A	L	A	A	L	A	L	A	A	A	A	A	A					A	A	A	A	L	A	L	A
cR_Ter_detr_inv_NHB		L				L	L	L	L	L	L		L		L	L	L	A	L	A	L	L	L	L			A		L	L	L	L	
cR_Ter_fl_ins_NHB	A	L	L	A	A	L	A	A	L	L	L	A	L	A	L	L	A	A	L	A	A	L	L	L	A	A	L	L	L	L	L	L	
cR_Ter_gastr_NHB	A	L	L	A	A	L	A	A	L	L	L	A	L	A	L	L	A	A	L	A	A	L	L	L	A	A	L	L	L	L	L	L	
cR_Ter_mammal_large_NHB	A	L	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	L	L	A	A	A	A	A	L	A	A	A	A	
cR_Ter_mammal_small_NHB	A	L	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A		L	A	A	A	A	A	L	A	A	A	A	
cR_Ter_pp_grass_NHB	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
cR_Ter_pp_lich_NHB	A		A					A											A	A		L	A						L				
cR_Ter_pp_shrub_NHB	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
cR_Ter_pp_tree_NHB	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
cR_Ter_soil_inv_NHB	A	L	L	A	A	L	L	A	L	L	L	A	L	A	L	L	A	A	L	A	A	L	L	L	A	A	L	L	L	L	L	L	

5.3 Updated CR based on newly available literature data in WTD

In order to assess the effect of the updated WTD data on CR values selected for SR-PSU and to prepare for upcoming safety analysis where updated CR values will be required, an updated set of CR values is derived here. The updated CR values are derived using the same assumptions and methods as in SR-PSU. The only difference is the inclusion of the newly available literature data. The assumptions and methods are described in detail in Tröjbom et al. (2013).

In general, the latest version of the WTD data, presented in the table WTD IAEA 2015, is considered the most appropriate literature source (literature source 1, L1) where available. All the data tables reported by WTD and ERICA 1.2 derive data from the same underlying source, this means that the data are not unique entries, rather duplicates of the same underlying data, therefore a comparison between the data tables are not relevant and selection of additional literature sources (in addition to WTD IAEA 2015) not necessary.

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For limnic biota, new data were reported in the WTD for several of the organisms of interest: Bird, Crustacean, Fish, Insect, Macroalgae, Mammal, Mollusc, Phytoplankton, Zooplankton and Vascular plants. For several of these biota types, data were available for a few of the elements of interest; this means that literature data were still missing in many cases. No additional data were reported for amphibians. Data on gastropods were still missing in the WTD.

For marine biota, updated data were available for Fish, Mollusc, Bird, Crustacean, Mammal, Polychaete worms, Macroalgae, Phytoplankton and Zooplankton. For most organisms, data were available for a limited number of elements.

WTD IAEA (2015) reported updated data for terrestrial Bird, Detritivorous invertebrate, Reptile, Flying insect, Mammals, Soil invertebrates, Grass, Shrubs, Trees and Lichen and bryophytes. Data for Amphibian were not updated from the ICRP (2009) version. For Gastropod, no data were available.

The site data used in SR-PSU has not been updated which means that, for cases where site-specific data are used, the CR values were not changed.

5.3.1 Comparison between updated CR values and SR-PSU CR values

Table 5-22 shows the ratios between the updated CRs and CRs used in SR-PSU. The ratios are on a logarithmic scale, thus are positive when the updated CR value is higher than the value used in SR-PSU and negative when the updated CR value is lower than the CR value used in SR-PSU. In most cases, the updated CR values are the same as those applied in SR-PSU (marked grey in the table). For most of the cases where new CR values are selected, the new values are within one order of magnitude of the old values (marked green in the table).

In the following section, the changes made to the SR-PSU CR values are described in detail.

Detailed description of the changes in CR values

For Ag, the updated CR values are within one order of magnitude of the SR-PSU values for all parameters except limnic plankton and flying insects. In both of these cases, the updated values are lower than the SR-PSU values. In PSU literature data for Ag were used in most cases. The data for Ag were discarded in the updated version of the WTD IAEA (2015), probably due to data quality issues. Instead of using Ag data from older references, the updated CR values are based on the element analogue Cu in most cases. Cu is selected as an element analogue in the updated ERICA 1.2 database and therefore it is also selected as suitable element analogue here.

For Pu, most CR values are within one order of magnitude of the SR-PSU values, or close to this. For four of the parameters, the change exceeds one order of magnitude; in all of these cases data from WTD IAEA (2015) are used in the updated version instead of the data reported by ICRP (2009) or ERICA 1.0 that were used in SR-PSU. The CR value for marine benthic and pelagic fish increased while the CR value for freshwater vascular plant decreased. The updated Pu CR value for freshwater bird (based on WTD IAEA 2015) is three orders of magnitude larger than the value reported in ICRP (2009) (that was used in SR-PSU).

The Po CR values for nine parameters changed by more than one order of magnitude in the updated data set. For marine birds, the updated value is eight orders of magnitude higher than the value in SR-PSU. The data reported by ICRP (2009) were used in SR-PSU, and these values are not included in the updated versions of the WTD database. The values differed greatly from the values selected by ERICA 1.0 and were also low in comparison to the CR values for other elements. In the updated version, the CR value for marine fish is used instead, since no data are reported by WTD IAEA (2015). This value is considerably higher. Updated Po CR data for terrestrial amphibian, bird and mammal are almost three orders of magnitude higher than the SR-PSU values. In these cases, updated data for terrestrial mammals reported in WTD IAEA (2015) are used instead of the data for mammals reported by ERICA 1.0.

The updated CR values for Tc have changed by more than one order of magnitude in two cases; for marine mammals and terrestrial lichen and bryophytes. The updated CR value for marine mammal is

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derived from the data for crustacean as a parameter analogue since no literature data are available. In SR-PSU, the data were based on a kinetic model. No Tc literature data for lichen and bryophytes are available in WTD IAEA (2015), in SR-PSU data from ERICA 1.0 were used. In the updated version, Mo is selected as element analogue instead and site data were applied. This is considered to be a better choice than ERICA 1.2 data that is based on the highest reported data for plants.

For Ca, Cd, Pb and Th, the CR values are updated for many of the parameters. The updated values are within one order of magnitude of the SR-PSU values in most cases.

For freshwater zooplankton, no site data are available and literature data are available for only a few elements. Therefore, data for marine zooplankton were used as a parameter analogue in SR-PSU. In ERICA 1.2 it is recommended that data from different ecosystems should not be used as analogues. The marine zooplankton data are therefore replaced by freshwater bivalve mollusc site data where literature data on freshwater zooplankton are missing in the updated version. This resulted in updated values for all elements for this parameter. For 16 of the elements, the values have changed by less than one order of magnitude. 12 cases are almost two orders of magnitude (higher or lower). For Zr, the updated CR value is more than two orders of magnitude lower than the value used in SR-PSU.

For terrestrial detritivorous invertebrates (called annelid in ERICA 1.2), new literature data have been compiled for many elements. These data are used in the updated version when available and element analogues are used when data are missing. This data replaced the ERICA 1.0 data used in SR-PSU and the values changed in most cases. The differences between the SR-SPU dataset and the updated version are small in general, except for Nb where the updated value is two orders of magnitude higher than the SR-PSU value.

New data for bees (WTD ICRP 2015) are used when possible for flying insect in the updated version of the dataset. These data were not available in earlier versions of the WTD and resulted in updated values in most cases (in most cases leading to lower values). For Cd and Cm and Sn, the values have changed by two orders of magnitude, while for the other elements the differences are smaller.

WTD IAEA (2015) reported additional data on terrestrial Mollusc that are used for terrestrial Gastropod in the updated version. This resulted in updated values in comparison to the SR-PSU values for almost all elements. In general, the values only changed to a small extent, but in the cases of Eu and Nb the values changed by around two order of magnitude.

For Soil invertebrates, WTD IAEA (2015) reported new data that are used when possible in the updated version. This resulted in updated values (in most cases higher values) for almost all elements. The updated values are within one order of magnitude of the SR-PSU CR values, or close to this, for all elements except for Nb, where the values have changed by two orders of magnitude.

WTD IAEA (2015) reported additional data for a terrestrial Reptile that are used when applicable in the updated version of the dataset. These data replace site-specific mammal data that were used in SR-PSU. For Ac, Am, Cm, Eu, Ho, Np, Pa and Sm, the updated values are almost three orders of magnitude higher than those in SR-PSU. In these cases, Am data for reptiles are used instead of La site data for mammals.

The updated CRs for Ba, Eu, Mo, Nb, Pu, Ra, Se and U in freshwater bird have changed by more than two orders of magnitude from the SR-PSU values. For all of these elements except Se, the updated values are higher. In all of these cases, newly available data on birds (WTD IAEA 2015) are used in the updated version of the dataset. For parameterisation in SR-PSU, data for the parameter analogue limnic fish were used (for all except Pu, see above).

In summary, the values selected for most cases in the updated dataset are the same as used in SR-PSU. This reflects the fact that most cases relied on site-specific data, and the site-specific CR data have not been updated since SR-PSU. Where new CR values have been selected, the values are usually within one order of magnitude of the SR-PSU values. For a few cases (37 out of 1146) the values have changed by more than two orders of magnitude, and in most of these cases the updated values are higher than those in SR-PSU.

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Table 5-2 Ratio between CR values used in SR-PSU and updated CR values based on updated literature data from Wildlife Transfer Database (WTD). Positive ratios show cases where the updated CR value is higher than the value used in SR-PSU and vice versa. The ratio is on a logarithmic scale, i.e. a value of 1 means that the difference is 10 times, a value of 2 means a difference of 100 and so on. Differences (higher OR lower) of less than a factor of 10 are coloured green, between 10 and 100 are coloured yellow, and greater than a factor of 100 are coloured red.

Parameter	Ac	Ag	Am	Ba	Ca	Cd	Cl	Cm	Co	Cs	Eu	Ho	I	Mo	Nb	Ni	Np	Pa	Pb	Pd	Po	Pu	Ra	Se	Sm	Sn	Sr	Tc	Th	U	Zr	
cR_Lake_amph_NHB	0.0	0.5	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.9	0.0	0.0	0.0	0.0	0.4	0.2	0.0	0.0		
cR_Lake_bent_fish_NHB	0.0	0.5	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.9	0.0	0.0	0.0	0.0	0.4	0.2	0.0	0.0		
cR_Lake_bird_NHB	0.0	0.5	0.0	2.2	0.1	0.1	0.0	0.0	1.3	-0.1	3.3	0.0	-0.2	2.1	2.6	0.0	0.0	0.0	0.0	0.0	0.6	3.0	2.5	-2.0	0.0	0.0	1.8	0.4	0.2	2.5	-0.3	
cR_Lake_bivalve_NHB	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.5	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0		
cR_Lake_crust_NHB	0.0	0.0	0.0	-0.5	0.4	-0.7	0.0	0.0	-0.3	0.7	0.0	0.0	0.0	-0.3	0.0	0.0	0.0	0.0	0.0	0.0	-0.2	-0.3	-0.9	-0.8	0.0	0.5	0.5	0.7	0.0	0.7	0.6	
cR_Lake_Fish_NHB	0.0	0.5	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.9	0.0	0.0	0.0	0.0	0.4	0.2	0.0	0.0		
cR_Lake_gastr_NHB	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.9	0.5	0.7	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	
cR_Lake_ins_larvae_NHB	0.0	0.0	0.1	0.0	-0.9	0.0	0.0	-0.8	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.1	0.4	0.5	0.0	0.0	0.0	0.7	0.0	0.0	0.0		
cR_Lake_mammal_NHB	0.0	0.5	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.6	0.6	-0.2	-2.1	0.0	0.0	0.0	0.4	0.2	0.0	0.0		
cR_Lake_pel_fish_NHB	0.0	0.5	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.6	0.6	0.9	0.0	0.0	0.0	0.0	0.4	0.2	0.0	0.0		
cR_Lake_pp_plank_NHB	0.0	-1.2	0.0	0.0	-0.8	-0.5	0.0	0.0	-1.0	-1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-1.3	0.8	-0.7	0.0	0.0	0.0	-0.7	-0.2	0.9	0.0	0.4	
cR_Lake_pp_vasc_NHB	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.4	-1.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		
cR_Lake_zoopl_NHB	-1.3	-0.8	-1.3	0.6	0.0	0.3	-0.1	-1.3	0.7	-1.1	-0.4	-1.3	-0.6	-0.4	1.8	-1.0	-1.3	-1.3	-0.6	-1.0	0.6	-0.2	2.0	-0.7	-1.6	0.2	1.1	0.5	-1.3	-0.3	-2.3	
cR_Sea_bent_fish_NHB	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	1.2	0.0	0.0	0.0	0.0	0.0	-0.6	0.0	0.0	0.0	
cR_Sea_bent_moll_NHB	0.0	-0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	-0.1	0.0	0.0	0.0	
cR_Sea_bird_NHB	0.0	-0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.5	0.4	0.0	0.0	0.0	0.0	0.0	-0.6	0.0	-1.4	0.0	
cR_Sea_crust_NHB	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	-0.1	-0.2	0.0	0.0	0.0	0.0	-0.2	0.0	1.4	0.0	
cR_Sea_mammal_NHB	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.0	-0.3	-0.4	0.0	0.0	-1.6	0.0	0.0	0.0	0.0	0.0	0.0	1.9	0.9	0.6	0.1	0.3	0.0	0.0	1.8	2.6	0.0	-0.4	0.0	
cR_Sea_pel_fish_NHB	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	1.2	0.0	0.0	0.0	0.0	0.0	-0.6	0.0	0.0	0.0	
cR_Sea_polych_NHB	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.5	0.0	1.3	0.0	-0.2	0.0	0.0	0.0	-3.8	-0.2	0.0	0.0
cR_Sea_pp_macro_NHB	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	-0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
cR_Sea_pp_plank_NHB	0.0	0.1	2.7	0.0	0.0	-1.2	0.0	2.9	-0.9	-2.6	0.0	0.0	0.1	0.0	0.0	-0.7	-0.4	0.0	1.8	0.0	0.3	0.0	-0.9	0.2	0.0	0.0	0.0	0.2	0.9	0.2	-0.3	
cR_Sea_pp_vasc_NHB	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	-0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
cR_Sea_zoopl_NHB	0.0	-0.7	0.0	0.0	0.0	0.0	-0.9	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	-0.1	-0.3	0.0	0.0	0.0	-0.8	-1.4	0.0	-1.1	0.0	
cR_Ter_amph_NHB	0.0	-0.5	0.0	-0.1	-0.1	0.0	0.0	0.0	0.0	-0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	2.8	-0.7	0.0	0.0	0.0	0.0	-0.1	-0.1	0.0	0.0	0.0	
cR_Ter_bird_NHB	0.0	-0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.8	-1.0	-0.4	0.0	0.0	0.0	0.7	0.0	0.0	0.2	0.0	
cR_Ter_detr_inv_NHB	-1.1	-0.3	0.3	-0.9	0.3	0.0	0.0	-0.1	0.7	-0.1	0.9	0.3	0.0	-0.2	2.4	0.3	-0.2	-1.1	-0.3	0.3	0.0	0.0	-0.9	0.3	0.3	1.3	-0.1	-0.2	-0.1	0.5	1.2	
cR_Ter_fl_ins_NHB	-1.9	-1.5	-1.9	-0.9	0.1	-2.9	0.0	-2.5	0.1	-0.5	-0.3	-1.9	0.0	-0.4	0.3	-0.1	-1.9	-1.9	-1.3	-0.5	0.0	0.3	-0.4	-1.2	-1.9	2.2	-0.8	-0.4	-1.3	-1.0	1.1	
cR_Ter_gastr_NHB	-0.2	-0.3	-0.2	-0.4	0.0	0.0	0.0	-0.1	0.5	0.0	2.1	-0.2	0.0	0.0	2.4	0.0	0.2	-0.2	0.0	0.0	0.0	0.0	0.0	0.0	-0.2	1.2	0.0	-0.2	-0.1	0.5	1.2	
cR_Ter_mammal_large_NHB	0.0	-0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.8	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
cR_Ter_mammal_small_NHB	0.0	-0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	-0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
cR_Ter_pp_grass_NHB	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
cR_Ter_pp_lich_NHB	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.5	0.7	0.0	0.0	0.0	0.0	-2.5	0.0	0.0	0.0	
cR_Ter_pp_shrub_NHB	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
cR_Ter_pp_tree_NHB	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
cR_Ter_rept_NHB	2.9	-0.5	2.9	0.0	1.2	0.0	0.0	2.9	0.0	0.4	2.9	2.9	0.0	0.0	0.0	1.6	2.9	2.9	-0.1	1.6	1.7	-0.7	0.0	0.0	2.4	0.0	1.8	0.0	-0.1	1.0	0.0	
cR_Ter_soil_inv_NHB	0.1	-0.3	0.1	0.7	1.3	0.2	0.0	-0.1	0.5	-0.1	0.9	0.1	0.0	-0.2	2.4	0.0	0.1	0.1	1.2	-0.6	0.0	0.0	-0.3	0.3	-1.1	1.3	0.9	0.0	-0.1	0.5	1.2	

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5.4 Consequents on dose rates due to updated CR values

The updated CR values will result in both higher and lower dose rates if implemented in the dose rate assessment. Without re-doing the full analysis it's impossible to produce updated total dose rates. However, to evaluate if the updated CR values could result in any significant increase in dose rates, the cases where the updated CRs were more than two orders of magnitude greater than in SR-PSU (27 out of the 1146 cases) were investigated. For each radionuclide of the corresponding elements investigated, the maximum internal dose over the SR-PSU assessment period are used for the comparison. The results are presented in Table 5-33. No increase in internal dose rate are found that approached a level of concern ($10 \mu\text{Gy h}^{-1}$) for any of the investigated cases. Even for Po in marine Bird, where the CR value increased by eight orders of magnitude (as discussed above), the resulting internal dose rates did not increase to a level that would impact the total dose rate, and therefore no significant increase in risk would occur.

In addition, it is concluded that the dose rates would not increase significantly for the dose-dominating radionuclides (Pa-231 and U-238), or for the organisms receiving the highest doses (freshwater bird, marine wading bird, terrestrial lichen and bryophytes and detritivorous insect).

Therefore, it can be concluded, that while the dose rates would be affected to some extent by the updates in CRs, the effect will not increase the dose rates to above the screening dose rate and therefore the overall conclusions from the assessment would remain unchanged, that populations of NHB would not be negatively impacted from radioactive releases from SFR.

Table 5-3. Comparison of internal dose rate in organisms resulting from CRs used in SR-PSU and resulting from updated CR values. Results are reported only for radionuclides with an increase in CR value of more than two orders of magnitude, relative to the CR values in SR-PSU. For the comparison, the maximum internal dose rate for each radionuclide over the SR-PSU assessment period were taken.

Ecosystem	Organism	Radionuclide	CR increase by a factor of	Internal dose rate ($\mu\text{Gy /h}$)	
				SR-PSU CR	Updated CR
Freshwater	Bird	Ba-133	1.7E+2	0	0
"	"	Eu-152	2.2E+3	0	0
"	"	Mo-93	1.3E+2	2.0E-7	2.6E-5
"	"	Nb-93m	4.2E+2	1.8E-7	7.7E-5
"	"	Nb-94	4.2E+2	3.3E-10	1.4E-7
"	"	Pu-238	1.1E+3	3.5E-13	3.7E-10
"	"	Pu-239	1.1E+3	8.7E-8	9.3E-5
"	"	Pu-240	1.1E+3	1.2E-8	1.2E-5
"	"	Pu-241	1.1E+3	5.0E-16	5.3E-13
"	"	Pu-242	1.1E+3	4.6E-9	4.9E-6
"	"	Ra-226	3.1E+2	1.2E-6	3.6E-4
"	"	Ra-228	3.1E+2	9.6E-17	3.0E-14
"	"	U-232	3.1E+2	0	0
"	"	U-233	3.1E+2	2.4E-9	7.3E-7
"	"	U-234	3.1E+2	2.5E-8	7.7E-6
"	"	U-235	3.1E+2	5.6E-7	1.7E-4
"	"	U-236	3.1E+2	4.8E-10	1.5E-7
"	"	U-238	3.1E+2	1.3E-6	4.0E-4
Marine	(Wading) bird	Po-210	3.2E+8	9.8E-19	3.2E-10
"	Mammal	Tc-99	4.4E+2	2.2E-12	9.5E-10
"	Phytoplankton	Am-241	5.1E+2	3.7E-11	1.9E-8

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Ecosystem	Organism	Radionuclide	CR increase by a factor of	Internal dose rate ($\mu\text{Gy} / \text{h}$)	
				SR-PSU CR	Updated CR
"	"	Am-242m	5.1E+2	0	0
"	"	Am-243	7.2E+2	7.4E-12	5.4E-9
"	"	Cm-242	7.2E+2	0	0
"	"	Cm-243	7.2E+2	0	0
"	"	Cm-244	7.2E+2	0	0
"	"	Cm-245	7.2E+2	7.5E-14	5.4E-11
"	"	Cm-246	7.2E+2	1.5E-12	1.1E-9
Terrestrial	Amphibian	Po-210	5.7E+2	6.3E-8	3.6E-5
"	Bird	Po-210	5.7E+2	6.3E-8	3.6E-5
"	Detritivorous invertebrate	Nb-93m	2.7E+2	2.9E-5	7.9E-3
"	"	Nb-94	2.7E+2	4.6E-8	1.2E-5
"	Flying insect	Sn-126	1.6E+2	8.6E-11	1.3E-8
"	Gastropod	Eu-152	1.3E+2	0	0
"	"	Nb-93m	2.7E+2	7.4E-8	2.0E-5
"	"	Nb-94	2.7E+2	6.0E-11	1.7E-8
"	Mammal (deer)	Po-210	5.7E+2	6.3E-8	3.6E-5
"	Mammal (rat)	Po-210	5.7E+2	6.3E-8	3.6E-5
"	Reptile	Ac-227	8.1E+2	9.9E-10	8.1E-7
"	"	Am-241	8.1E+2	4.0E-12	3.3E-9
"	"	Am-242m	8.1E+2	0	0
"	"	Am-243	8.1E+2	9.2E-11	7.5E-8
"	"	Cm-242	8.1E+2	0	0
"	"	Cm-243	8.1E+2	0	0
"	"	Cm-244	8.1E+2	0	0
"	"	Cm-245	8.1E+2	6.5E-13	5.3E-10
"	"	Cm-246	8.1E+2	5.3E-14	4.3E-11
"	"	Eu-152	8.1E+2	0	0
"	"	Ho-166m	8.1E+2	2.2E-14	1.8E-11
"	"	Np-237	8.1E+2	1.1E-9	8.9E-7
"	"	Pa-231	8.1E+2	7.1E-8	5.8E-5
"	"	Sm-151	2.3E+2	0	0
"	Soil Invertebrate (worm)	Nb-93m	2.7E+2	7.4E-8	2.0E-5
"	"	Nb-94	2.7E+2	6.0E-11	1.7E-8

6 Bias towards soil/sediment

Freshwater and marine mammals and birds were not mapped to be on or in sediment as this was not deemed reasonable or representative of such organisms at the site. It is not expected that aquatic mammals or birds will spend any significant time in contact with sediment *while submerged* (i.e. the only contact 'on sediment' would be momentary). Extended contact with the ground while not submerged was deemed in the assessment to be covered by the terrestrial exposure pathways. The assessment went further to test such a pathway by simulating organisms that are exposed from multiple habitats, living in contact with soils (in the terrestrial ecosystem) while ingesting all their food from their respective aquatic habitats (SKB 2015, Section 8.4.1). The European otter was included in the assessment as a site-specific species in order to test multiple-habitat exposure, whereby a mammal lives within a terrestrial ecosystem while eating from the marine ecosystem, receiving an external dose from terrestrial sources while receiving internal dose exclusively from the marine ecosystem. The external source term was taken to be that from the terrestrial reference organism, the small mammal (rat) which is mapped as in soil, thus is already biased as much as possible to soil exposure.

Despite the implausibility of this circumstance, to illustrate the impact, we present here data for marine and freshwater mammals and birds living within their respective sediments, while submerged. This could be seen as a highly conservative bounding case, or a calculation case that conservatively represents a situation where such biota inhabits aquatic sediments that have emerged (i.e. limnic sediment from lakes that have dried out, or marine sediments along a receding coastline). Figure 6-1. shows the dose rates to marine (Figure 6-1.a) and freshwater (Figure 6-1.b) mammals and birds which live in sediment. The organisms living in sediment received dose rates slightly higher than the in water dwelling reference organisms in both ecosystems; however, this increase was very limited, with a ~17% increase at the most (freshwater in sediment bird vs. reference Bird at 52,500 AD). The dose rates in all organisms and occupancies remained several factors of ten below the screening dose rate. Therefore, we can conclude that the proximity of birds and mammals to aquatic sediments does not have a significant influence on dose rate to organisms in the assessment.

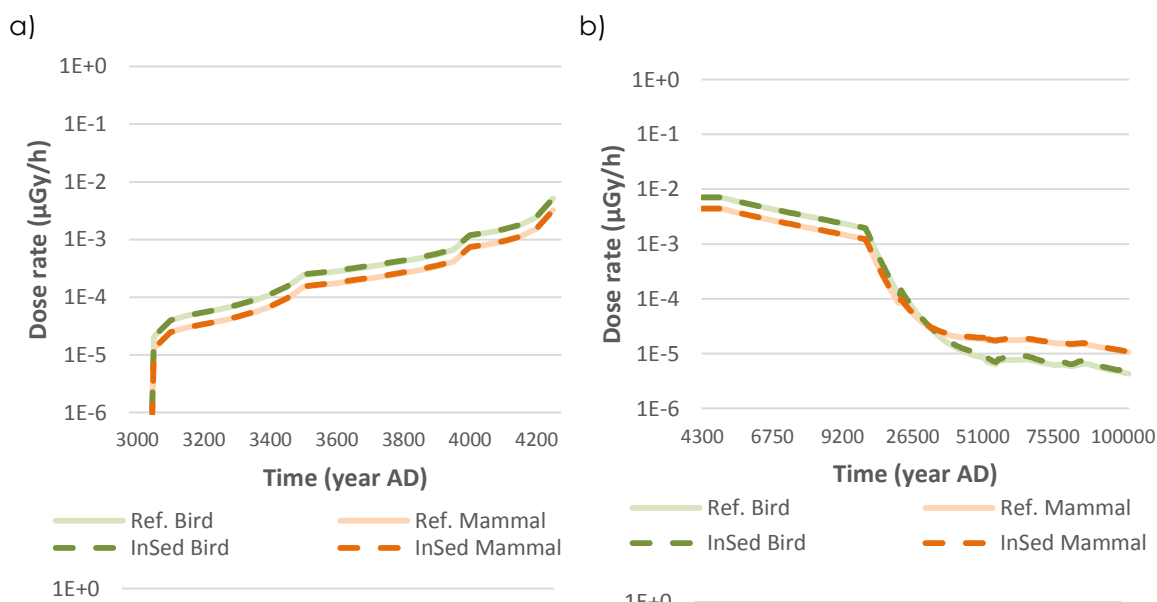


Figure 6-1. Impact on total dose rate to mammals and birds from living (a) in sediments in the marine ecosystem or (b) the freshwater ecosystem, compared to the corresponding reference organisms living in water

The terrestrial reference Amphibian was mapped as on soil and that was deemed sufficient in the assessment. However, it is feasible that a terrestrial Amphibian could spend a proportion of its time in soil,

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in burrows. Freshwater reference Amphibian was mapped as in water; occupancy in or on sediment (while submerged) had not been considered, but is plausible. We present here a basic analysis of the Amphibian living in soil (terrestrial; Figure 6-2.a) and in sediment (freshwater; Figure 6-2.b). The results indicate an increase in dose rate from in soil and in sediment occupancy compared to the original assessed organism. The maximum dose rate to each organism living in the soil/sediment was higher than that to the corresponding reference Amphibian, with an increase of ~64% in the terrestrial organism but an increase of just 1% in the freshwater organism. While the bias towards soil/sediment increases the overall dose rate, it remains lower than the highest dose rate of the most exposed organisms within the calculation case, and several factors of ten lower than the screening dose rate. Accordingly, the consideration of bias towards sediment can be considered a minor influence on dose rate.

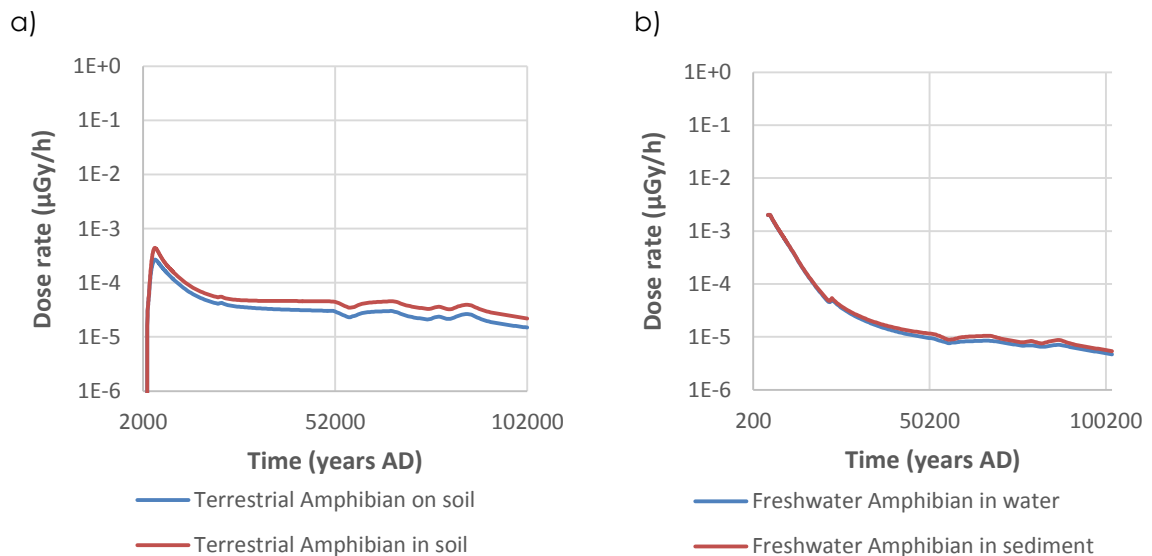


Figure 6-2. Impact on total dose rate to amphibians from occupancy (a) in soil as opposed to on soil, or b) in sediment (while submerged) as opposed to in water.

7 Plant roots

The SR-PSU assessment did not include root structures of plants in the assessment of dose rate to NHB and thus may potentially underestimate any dose rate that is associated with roots. At present there is no clear method to model such structures with much confidence. There is a demonstrable need for further research by the scientific community to elucidate the importance of root structures on the dosimetry in terrestrial plants. A combination of the lack of parameter data and uncertainties such as the sensitivity of root structures means that attempting to model root structures, at present, may raise more questions than it answers. A conservative approach is therefore preferred at this stage.

A ‘Frequently Asked Questions’ response by ERICA developer Nick Beresford (wiki.ceh.ac.uk/pages/viewpage.action?pageId=119704530) discusses the subject of modelling roots, identifying that RESRAD-BIOTA includes a geometry “deemed appropriate for plant roots” of $0.2 \times 0.2 \times 0.2$ cm with the organism modelled as ‘in soil’ but uses the same CR values as for the on soil organism. It is possible to calculate ‘root’ DCCs separately in ERICA as a new organism in a Tier 2 assessment; this approach was used by Biermans et al. (2014) to compare modelled DCCs for shoots and roots of *Arabidopsis thaliana*, with measured values. While the ERICA approach does not permit the creation of user-defined plants with occupancy of ‘in soil’, a possible stop-gap solution would be to create an analogous organism using *soil fauna/ground-living animal* and applying the appropriate parameter data from the relevant plant.

To investigate the potential for underestimation of dose rates from roots, a conservative approach was used in this complementary analysis. This was done by inclusion of roots as an additional ‘in soil’ structure, adding the exposure to that of the ‘on soil’ structure that is already considered in the assessment (i.e. the original reference organism). Additional ‘organism types’ for the roots of Grasses and herbs, Shrub and Tree were mapped (using ‘soil fauna’ due to limitations in the ERICA model). Geometries and weights for roots were mapped, as shown in Table 7-1., using the same geometry as used in RESRAD-BIOTA for Grasses and herbs and Shrub, but a larger geometry was applied for Tree root: i.e. that of the ‘on soil’ form of the ERICA reference Tree (Table 7-1.). Concentration ratios applied to each in soil “root” organism were the same as for the corresponding ‘on soil’ plant. All CRs used in the present demonstration were the generic values used in ERICA v.1.2 and are not directly comparable to those used in the SR-PSU assessment.

Table 7-1. Geometries applied to ‘plant roots’

Organism	Dimensions (m)			Mass (kg)
	Height	Width	Depth	
Grasses and Herbs	0.002	0.002	0.002	0.00262
Shrub	0.002	0.002	0.002	0.00262
Tree	1.00	0.03	0.03	471

A basic assessment was performed in the ERICA tool, using 32 radionuclides relevant to SR-PSU (Am-241, Cl-36, Cm-242, Cm-243, Cm-244, Co-60, Cs-135, Cs-137, Eu-152, I-129, Nb-94, Ni-59, Ni-63, Np-237, Pa-231, Pb-210, Po-210, Pu-238, Pu-239, Pu-240, Pu-241, Ra-226, Ra-228, Se-79, Sr-90, Tc-99, Th-228, Th-230, Th-232, U-234, U-235, U-238), and three radionuclides were specifically chosen for further discussion here: Cl-36 as it was amongst the most accumulated radionuclides in terrestrial plants in SR-PSU (SKB 2015, Figure 8-7), Pb-210 as it demonstrated the largest disparity between dose rates between root and on soil plants (see below), and Co-60 which highlights difference in accumulation in tree roots (see below). Each radionuclide was given a soil concentration of 1 Bqkg^{-1} , hereon this is termed “unit inventory”.

Results indicated that the dose rates to the ‘root’ of each organism, compared to those to the corresponding ‘on soil’ reference plant, is dependent on the radionuclide considered. In Grasses & herbs and Shrubs, the

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dose rate to roots from each radionuclide was similar to the dose rate to the corresponding on soil plant, differing by one or two percent, higher or lower. The largest increase in dose rate (2.5%) was seen from Pb-210 in Shrub roots (Table 7-2). Cl-36 in plant roots showed small decreases in dose rate, relative to the corresponding on soil plant, with the resulting dose rates approximately the same between in soil and on soil components (Table 7-2). In Tree root, small increases (<1.5%) in dose rate were calculated in some radionuclides relative to the on soil Tree (maximum increase: 1.3% from Cm-244; data not shown). However, the dose rate to Tree root from certain radionuclides such as Co-60 (see Table 7-2) were two orders of magnitude lower than to the on soil Tree.

The total dose to a hypothetical organism with both on and in soil structures is the sum of the on soil and root components (Table 7-2). For the majority of radionuclides, the resultant total dose rate is approximately double that calculated to the original (on soil) reference plant. Based on this conservative investigation, it can be expected that the inclusion of root structures would increase the dose rate to plants by little more than a factor of two. In SR-PSU, where the total dose rate to plants at the peak remained several orders of magnitude lower than the screening dose rate, the inclusion of root structures will not increase the dose rate to the point where it might exceed the screening dose rate. Thus, while it appears that the method employed in the SR-PSU assessment may underestimate the dose to plants somewhat, it is not expected that the inclusion of root structures would lead to dose rates that would represent risk to populations of terrestrial plants.

Table 7-2. Dose rates to reference plants and 'root' of plants from specific radionuclides in the complementary analysis, using a soil concentration of 1 Bqkg⁻¹ (unit inventory). The underlined values refer to the total dose rates from unit inventory of 32 radionuclides.

	Dose rate (µGy h ⁻¹)		
	Reference	Root	Total
Grasses & Herbs			
Cl-36	3.13E-3	3.11E-3	6.24E-3
Co-60	4.81E-4	4.78E-4	9.59E-4
Pb-210	2.79E-5	2.85E-5	5.64E-5
<u>Total</u>	<u>1.01E-1</u>	<u>1.02E-1</u>	<u>2.03E-1</u>
Shrub			
Cl-36	1.56E-4	1.54E-4	3.10E-4
Co-60	4.51E-4	4.52E-4	9.03E-4
Pb-210	7.34E-5	7.53E-5	1.49E-4
<u>Total</u>	<u>1.20E-1</u>	<u>1.20E-1</u>	<u>2.40E-1</u>
Tree			
Cl-36	2.27E-4	2.23E-4	4.50E-4
Co-60	3.94E-4	3.98E-6	3.98E-4
Pb-210	1.82E-5	1.79E-5	3.61E-5
<u>Total</u>	<u>1.56E-2</u>	<u>1.39E-2</u>	<u>2.94E-2</u>

8 Aquatic organisms with terrestrial CR values (ingestion from terrestrial sources)

The CR values for radionuclide accumulation in terrestrial organisms and those in freshwater/marine organisms are not directly comparable as they correspond to different media (soil in terrestrial, water in freshwater/marine ecosystems) and use different units (terrestrial: $\text{Bq kg}_{\text{FW}}^{-1}/\text{Bq kg}_{\text{DW}}^{-1}$; freshwater/marine: $\text{Bq kg}_{\text{FW}}^{-1}/\text{Bq m}^{-3}$). However, a response from SSM (SSM2015-725-47) suggested that the dose rate to aquatic organisms may be underestimated if the organism is considered to eat exclusively from the aquatic environment. Thus, it is posited that an aquatic organism may receive a higher dose rate if it ingested sources from the terrestrial ecosystem.

In SR-PSU, no species at the site that lives exclusively in an aquatic ecosystem yet feeds entirely from the terrestrial ecosystem was identified (SKB 2015), and from an assessment standpoint, it was deemed adequate that the reference terrestrial organisms would sufficiently highlight the risk from the internal exposure pathway from terrestrial sources.

Furthermore, internal exposure was shown to be the most influential component of dose to NHB across all calculation cases included in the assessment (SKB 2015, Table 8.1). Thus, the ecosystem from which an organism receives its internal exposure will be the dominant influence on the total dose experienced. In the base case, the higher activity concentration of internal dose contributing radionuclides (C-14 in particular) in the aquatic ecosystems compared to the terrestrial ecosystem led to a higher peak dose rate to aquatic organisms overall. Therefore, it is not expected that terrestrial ingestion could lead to higher dose rates than those calculated in aquatic ecosystems. However, for the sake of completeness, the effect of aquatic organisms feeding in terrestrial habitats has been investigated this further, as presented below.

Here, a hypothetical marine mammal, marine bird, and freshwater bird, were modelled to receive an external exposure exclusively from their respective aquatic environment, but receiving an internal dose entirely from the terrestrial ecosystem (Figure 8-1 a-c). These 'hypothetical organisms' are contrasted against the corresponding reference organisms, and also against the site species which inhabit terrestrial systems, but eat from aquatic sources (European otter, ruddy turnstone, black tern). As in the section dealing with multiple habitat organisms in SKB (2015, Section 8.4.1) the dose rates related to marine organisms were only assessed until 4250 AD, while a marine ecosystem is present at the site.

In all cases, the hypothetical organisms received a lower dose rate than either of their corresponding reference organisms. The results demonstrate that the dose rates to the hypothetical organisms follow closely those of the reference terrestrial organism, due to the predominance of internal exposures on total dose rate. Lower external exposures in aquatic systems relative to those in the terrestrial ecosystem led to total doses, in the hypothetical organisms, that were lower than the reference terrestrial organism. The only exception was found at the very first time point for the hypothetical marine bird eating from terrestrial sources, which had a dose rate that exceeded the terrestrial reference by less than 1×10^{-24} $\mu\text{Gy/h}$. This dose rate was still a factor of ten lower than that for the reference marine bird.

Thus it is concluded that the pathway of exposure whereby an organism receives external exposure from an aquatic environment but internal exposure from terrestrial sources will not influence the conclusion from the SR-PSU assessment that dose rates are below screening values.

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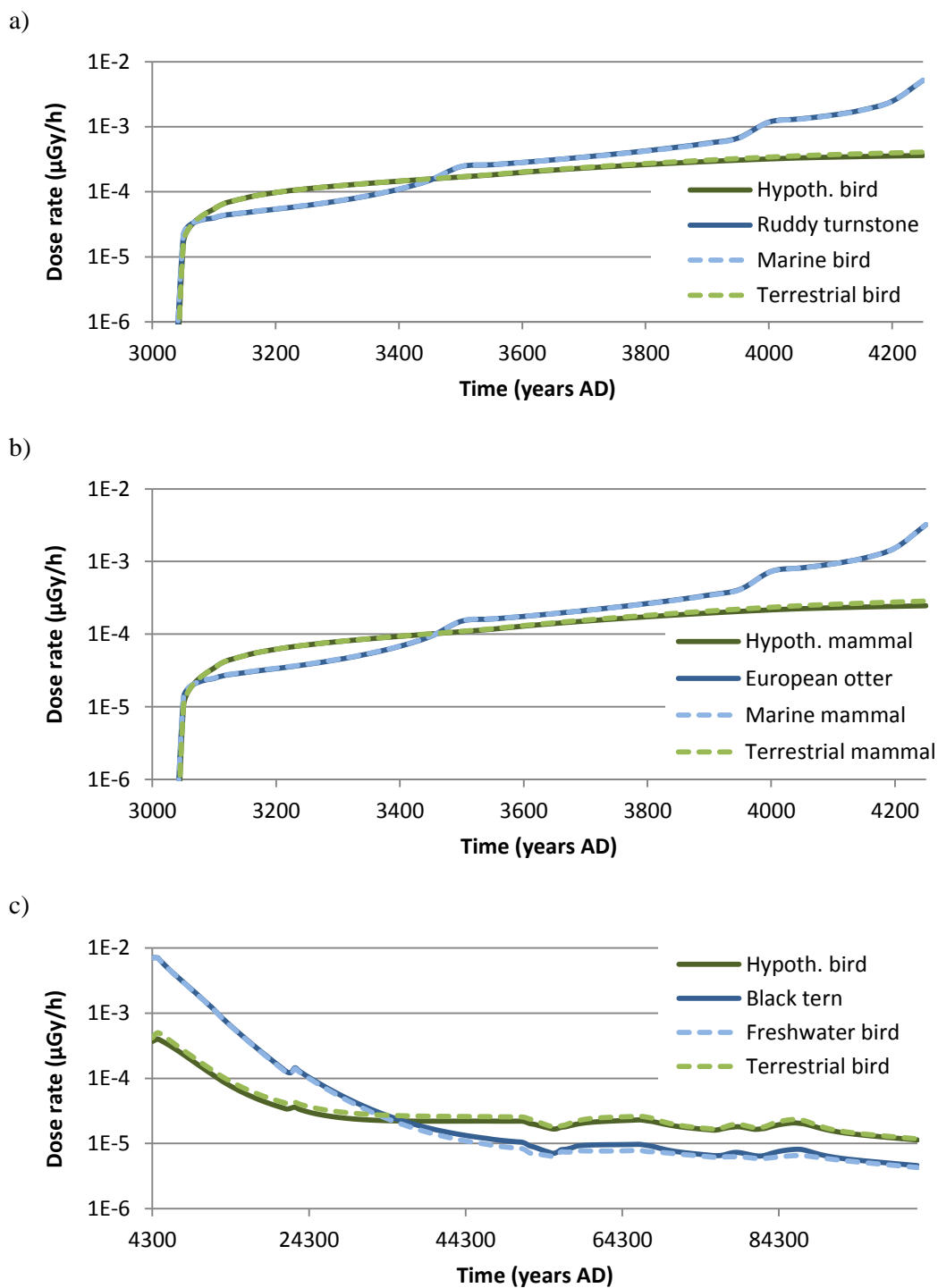


Figure 8-1. Dose rates to hypothetical organisms that live entirely in their respective aquatic ecosystem (external exposure component), but eat exclusively from the terrestrial ecosystem (internal exposure component). Hypothetical organisms are modelled as a marine bird (a), marine mammal (b) and a freshwater bird (c).

References

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Appendix A: Dose conversion coefficient for Lichen and Bryophytes, comparison between SR-PSU and ERICA 1.2

Table A-1 Comparison of dose conversion coefficient (DCC) values for Lichen and Bryophytes between SR-PSU and ERICA 1.2 for external (on soil) high-energy beta/gamma (a), internal alpha (b), internal high-energy beta/gamma (c), and internal low-energy beta (d).

a)

	SR-PSU	ERICA 1.2	Ratio v.1.2/SR-PSU
Am-241	5.90E-11	2.59E-06	43948
C-14	0.00E+00	0.00E+00	
Cl-36	1.60E-12	3.14E-08	19605
Cm-242	6.90E-13	4.74E-08	68679
Cm-243	8.40E-10	2.23E-05	26601
Cm-244	5.90E-13	4.27E-08	72433
Co-60	3.00E-08	4.96E-04	16525
Cs-135	0.00E+00	0.00E+00	
Cs-137	6.10E-09	1.16E-04	18940
Eu-152	1.30E-08	2.26E-04	17353
H-3	0.00E+00	0.00E+00	
I-129	2.20E-11	1.15E-06	52285
Nb-94	1.80E-08	3.22E-04	17887
Ni-59	1.50E-44	0.00E+00	0
Ni-63	0.00E+00	0.00E+00	
Np-237	1.00E-10	3.61E-06	36079
Pa-231	3.85E-06	7.40E-06	2
Pb-210	4.10E-12	2.91E-07	70895
Po-210	9.60E-14	1.74E-09	18129
Pu-238	6.60E-13	6.51E-08	98704
Pu-239	6.10E-13	3.35E-08	54942
Pu-240	6.40E-13	6.22E-08	97162
Pu-241	7.70E-15	2.68E-10	34809
Ra-226	2.00E-08	3.45E-04	17268
Ra-228	1.10E-08	1.94E-04	17598
Se-79	0.00E+00	0.00E+00	
Sr-90	3.70E-16	1.63E-11	43968
Tc-99	0.00E+00	0.00E+00	
Th-228	1.80E-08	2.91E-04	16194
Th-230	1.80E-12	7.19E-08	39962
Th-232	9.00E-13	4.38E-08	48627
U-234	9.10E-13	7.17E-08	78827
U-235	1.10E-09	2.96E-05	26923
U-238	4.60E-13	5.00E-08	108605

Additional considerations for the non-human biota dose assessment in the SR-PSU

b)

	SR-PSU	ERICA 1.2	Ratio v.1.2/SR-PSU
Am-241	3.17E-03	3.16E-03	1.00
C-14	0.00E+00	0.00E+00	
Cl-36	0.00E+00	0.00E+00	
Cm-242	3.50E-03	3.52E-03	1.01
Cm-243	3.33E-03	3.34E-03	1.00
Cm-244	3.30E-03	3.34E-03	1.01
Co-60	0.00E+00	0.00E+00	
Cs-135	0.00E+00	0.00E+00	
Cs-137	0.00E+00	0.00E+00	
Eu-152	0.00E+00	0.00E+00	
H-3	0.00E+00	0.00E+00	
I-129	0.00E+00	0.00E+00	
Nb-94	0.00E+00	0.00E+00	
Ni-59	0.00E+00	0.00E+00	
Ni-63	0.00E+00	0.00E+00	
Np-237	2.77E-03	2.75E-03	0.99
Pa-231	2.87E-03	2.87E-03	1.00
Pb-210	0.00E+00	0.00E+00	0.00
Po-210	3.10E-03	3.06E-03	0.99
Pu-238	3.20E-03	3.16E-03	0.99
Pu-239	3.00E-03	2.97E-03	0.99
Pu-240	3.00E-03	2.97E-03	0.99
Pu-241	6.20E-08	6.92E-08	1.12
Ra-226	1.37E-02	1.38E-02	1.01
Ra-228	0.00E+00	0.00E+00	
Se-79	0.00E+00	0.00E+00	
Sr-90	0.00E+00	0.00E+00	
Tc-99	0.00E+00	0.00E+00	
Th-228	1.86E-02	1.85E-02	0.99
Th-230	2.70E-03	2.69E-03	1.00
Th-232	2.30E-03	2.30E-03	1.00
U-234	2.80E-03	2.74E-03	0.98
U-235	2.57E-03	2.54E-03	0.99
U-238	2.40E-03	2.41E-03	1.01

Additional considerations for the non-human biota dose assessment in the SR-PSU

c)

	SR-PSU	ERICA 1.2	Ratio v.1.2/SR-PSU
Am-241	3.20E-05	2.51E-05	0.79
C-14	2.77E-05	2.78E-05	1.00
Cl-36	1.30E-04	1.27E-04	0.98
Cm-242	0.00E+00	4.84E-06	
Cm-243	6.80E-05	6.93E-05	1.02
Cm-244	0.00E+00	4.31E-06	
Co-60	5.50E-05	5.63E-05	1.02
Cs-135	3.76E-05	3.75E-05	1.00
Cs-137	1.10E-04	1.17E-04	1.06
Eu-152	5.45E-05	5.62E-05	1.03
H-3	8.25E-07	8.09E-07	0.98
I-129	3.22E-05	3.19E-05	0.99
Nb-94	8.80E-05	8.94E-05	1.02
Ni-59	7.82E-07	8.42E-07	1.08
Ni-63	8.71E-06	8.66E-06	0.99
Np-237	2.80E-05	3.57E-05	1.27
Pa-231	3.04E-05	3.06E-05	1.01
Pb-210	1.67E-04	1.77E-04	1.06
Po-210	0.00E+00	4.96E-11	
Pu-238	0.00E+00	5.40E-06	
Pu-239	0.00E+00	2.80E-06	
Pu-240	0.00E+00	5.41E-06	
Pu-241	8.37E-07	8.36E-07	1.00
Ra-226	4.20E-04	3.39E-04	0.81
Ra-228	1.90E-04	1.97E-04	1.04
Se-79	3.17E-05	3.13E-05	0.99
Sr-90	2.90E-04	3.17E-04	1.09
Tc-99	5.40E-05	5.48E-05	1.01
Th-228	3.80E-04	3.15E-04	0.83
Th-230	0.00E+00	7.85E-06	
Th-232	0.00E+00	6.64E-06	
U-234	0.00E+00	6.96E-06	
U-235	1.08E-04	1.11E-04	1.03
U-238	0.00E+00	5.21E-06	

Additional considerations for the non-human biota dose assessment in the SR-PSU

d)

	SR-PSU	ERICA 1.2	Ratio v.1.2/SR-PSU
Am-241	0.00E+00	5.73E-06	
C-14	2.80E-07	3.73E-07	1.33
Cl-36	0.00E+00	6.91E-08	
Cm-242	0.00E+00	8.19E-07	
Cm-243	0.00E+00	7.95E-06	
Cm-244	0.00E+00	7.62E-07	
Co-60	0.00E+00	2.26E-07	
Cs-135	3.80E-07	3.05E-07	0.80
Cs-137	0.00E+00	3.71E-07	
Eu-152	3.48E-06	3.42E-06	0.98
H-3	2.48E-06	2.47E-06	1.00
I-129	4.81E-06	4.94E-06	1.03
Nb-94	0.00E+00	1.25E-07	
Ni-59	2.62E-06	2.63E-06	1.00
Ni-63	1.19E-06	1.21E-06	1.02
Np-237	0.00E+00	5.49E-06	
Pa-231	7.58E-06	7.58E-06	1.00
Pb-210	3.40E-06	4.23E-06	1.24
Po-210	0.00E+00	3.66E-13	
Pu-238	0.00E+00	8.70E-07	
Pu-239	0.00E+00	1.18E-06	
Pu-240	0.00E+00	8.28E-07	
Pu-241	2.20E-06	2.19E-06	1.00
Ra-226	0.00E+00	1.63E-06	
Ra-228	1.00E-05	9.14E-06	0.91
Se-79	3.20E-07	3.19E-07	1.00
Sr-90	0.00E+00	1.12E-07	
Tc-99	0.00E+00	1.95E-07	
Th-228	0.00E+00	3.73E-06	
Th-230	0.00E+00	6.49E-07	
Th-232	0.00E+00	6.44E-07	
U-234	0.00E+00	8.07E-07	
U-235	0.00E+00	1.23E-05	
U-238	0.00E+00	6.68E-07	