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Authors: Nicholas Beresford
Patrick Boyer
Brenda Howard

Technical Note

2014:32

Assessment of the derivation and use of distribution coefficients (K_d) and concentration ratios (CR)

Main Review Phase

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

Projektets syfte

Det övergripande syftet med projektet är att ta fram synpunkter på SKB:s säkerhetsanalys SR-Site för den långsiktiga strålsäkerheten hos det planerade slutförvaret i Forsmark. Den specifika målsättningen med detta externa granskningsprojekt är att granska hur SKB tagit fram, och använt, värden på distributionskoefficienter (Kd-värden) och överföringsfaktorer från omgivning till organismer (CR-värden), samt bedöma om andra relevanta angreppssätt skulle kunna ge avsevärt annorlunda värden med betydelse för SKB:s slutsatser angående konsekvenser av utsläpp av radionuklider i miljön från det planerade slutförvaret.

Författarnas sammanfattning

Denna rapport utgör en granskning av de angreppssätt och databaser som SKB använts sig av för att ta fram värden på överföringsfaktorer (CR-värden) och distributionskoefficienter (Kd-värden) i syfte att bedöma om dessa värden är välgrundade och tillämpliga. Relevanta alternativ diskuteras också. Granskningen fokuserar på SKB rapporterna R-10-28 och TR-10-07 vilka beskriver tillgängliga områdesspecifika data och det följande framtagandet av CR- och Kd-värden som används inom konsekvensanalysen i SR-Site.

SKB använder en Bayesiansk metod som kombinerar litteraturdata med områdesspecifika data för att få bästa nytta av de ofta fåtaliga områdesdata som finns. Detta är ett inom radioekologin ganska nytt sätt att använda en etablerad statistisk metod. SKB har också försökt utnyttja områdesdata genom att beakta mätresultat under detektionsgränsen.

Även om det finns alternativa metoder att välja ut data är det svårt att avgöra om dessa metoder skulle ge mer tillförlitliga resultat eftersom den höga variabiliteten i Kd- och CR-värden innebär att det är viktigt med ett konservativt angreppssätt både i framtagandet och användandet av värden. Att bestämma vad som är konservativt är bara möjligt om man har tillräcklig förståelse för vilken inverkan parametervärdena har för slutresultaten vid olika överförings- och exponeringsvägar. Om man till exempel ansätter ett lågt Kd-värde för suspenderat material i akvatisk miljö, så är det konservativt vad gäller exponeringsvägar kopplade till vattenmassan, medan motsatsen gäller för exponeringsvägar kopplade till sediment.

SKB har utvecklat en konceptuell modell inom SR-Site som inkluderar ett antal olika födoslag från land-, sötvatten- och havsvattenekosystem. Provtagningsstrategin verkar dock inte vara väl kopplad till denna konceptuella modell.

De CR-värden, baserade på bästa bedömning (best estimate, BE) som används inom SR-Site resulterar ofta i mindre konservativa utvärderingar jämfört med om litteraturdata hade använts. I många fall är dock litteraturdata baserade på få data, och fokuseringen på att använda områdesspecifika data är i linje med SSM:s tidigare rekommendation. Det framstår som att SKB inte tillämpat ett konservativt angreppsätt när kunskap om analoga ämnen har använts för att ta fram CR-värden för de ämnen som ingår i utvärderingen. Det hade kanske varit mer relevant att använda ett konservativt angreppsätt än att påpeka att värden som sannolikt undervärderar överföringen har använts (t.ex. för phytoplankton i sötvatten).

En jämförelse mellan SKB:s Kd-värden (BE och GSD) och litteraturvärden visar att Kd-värden för ”Regolith Low” och ”Regolith MidUp” systematiskt är lika med eller högre än Kd-värden i litteraturen. Höga Kd-värden i dessa miljöer ökar transporttiden från geosfären till biosfären. SKB:s GSD-värden är ofta lägre än motsvarande i litteraturen vilket möjligen inte är konservativt när probabilistiska utvärderingar genomförs.

Ett flertal BE Kd-värden är troligen för höga, såsom för Ag i ”regolith MidUp”, för Am i marina sediment, för Cs i ”regolith Low” och ”regolith MidUp” och för I i ”regolithMidUp” . Tvärtom så verkar värdena för Pu i akvatiska sediment vara låga. Flera motsägelsefulla Kd-värden observerades vilket hör ihop med grupperingen av ”regolith Mid” och ”regolith Up”.

Litteraturvärden används i framtagandet av ett stort antal CR- och Kd-värden, endera direkt eller genom Bayesiansk uppdatering. Emellertid har endast relativt få källor utnyttjats med stort beroende av tre publicerade sammanställningar. Vissa av de använda värdena är ganska gamla och gäller i vissa fall, om de kan spåras, inte för det ämnen som de används för. I sådana fall borde istället nyare data använts, endera för ämnet självt eller för tillämpliga analoga ämnen.

Vikten av att förfina användandet av litteraturdata eller nödvändigheten att ta fram ämnesspecifika data om de saknas, beror på den förväntade dosen från den specifika radionukliden. Känslighetsanalyser och alternativa modelleringar med starkt konservativa värden torde möjliggöra välavvägda beslut om sådana insatser är motiverade.

Projektinformation

Kontaktperson på SSM: Pål Andersson
Diarienummer avtal: SSM2013-3686
Aktivitetsnummer: 3030012-4111

SSM perspective

Background

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

Objectives of the project

The general objective of the project is to provide review comments on SKB's postclosure safety analysis, SR-Site, for the proposed repository at Forsmark. The specific objective of the work presented in this report is to perform an in-depth review of the SKB method and databases from which Kd and CR values are derived in order to judge whether used parameter values are robustly derived and fit for purpose, and whether a credible alternative approach could lead to significantly different parameter values.

Summary by the authors

This report presents a review of the approaches and databases which SKB have used to derive concentration ratios (CRs) and distribution coefficients (Kds) to consider if they are robustly derived and fit for purpose. Credible alternative approaches are also considered. The focus of this review are SKB reports R-10-28 and TR-10-07 which describe the available site specific data and the subsequent derivation of CR and Kd values respectively for application in human assessment.

The method applied by SKB to derive the CR and Kd values are based on a Bayesian approach that combines literature values with in-situ, on site data. Whilst the numbers of site data were often limited the authors have tried to make best use of these data in combination with literature data by using Bayesian updating. This is a relatively novel application of an established statistical approach to radioecology. Similarly, the authors have attempted to make best use of all their site samples by taking into account results below the limits of detection.

Although alternative methods to select values exist, it is difficult to identify whether these methods would give more reliable assessment outcomes because the high variability of Kd and CR values means that it is important to use conservative criteria in both their selection, and in how they are used in an assessment. The determination of these conservative criteria is only possible if we adequately understand their impact on the outcome of the model as a function of the different transfer and exposure pathways. For example, the use of a low Kd value derived for suspended particulate matter in aquatic systems will be conservative for pathways linked to water, but the reverse is true for pathways linked to sediments.

SKB have defined a conceptual model for application in SR-Site which includes a variety of terrestrial, freshwater and marine foodstuffs. However, their sampling strategy does not reflect their conceptual model.

The best estimate (BE) CR values used in SR-Site will often result in less conservative assessments than if the literature data had been used. However, in many instances the literature values are based on few data and a focus on site specific values is compatible with the SSM recommendation (to use site specific data). There does not appear to have been consideration given to deriving conservative values when analogue approaches are used. Derivation of conservative analogue values may have been more appropriate than acknowledging that values likely to under predict have been selected (e.g. freshwater phytoplankton).

Comparisons of SKB Kd values (BE and GSD) with literature data showed that Kd values in the ‘Regolith Low’ and ‘Regolith MidUp’ are systematically equal to, or higher, than Kd values in literature. Such high Kd values in these compartments will increase the transfer times from the geosphere to the biosphere. Also BE values are often accompanied by GSD values which are lower than literature data which may not be a conservative approach when the probability distribution functions are used. Several BE Kd values are probably too high: notably in regolith MidUp for Ag, in marine sediments for Am, in regolith Low and MidUp for Cs and in Regolith MidUp for I. Conversely, BE value in aquatic sediments (limnic and marine) seem low for Pu. Several inconsistencies in Kd selection were observed and are associated with the grouping of the regolith Mid and Up compartments.

Literature values are used to provide a large number of the CR and Kd values, either directly or via Bayesian updating. However, relatively few literature sources have been used with a reliance on three published reviews. Some of the literature values used are rather old and, if they can be traced back, are sometimes not for the actual element the value is being used for. In these circumstances, more recent data should have been identified, either for the element itself or appropriate analogues.

The importance of improving the literature values used, or the need to acquire actual data for the element in their absence, depends on the anticipated doses for the particular radioisotope. Sensitivity analysis or assuming highly conservative values and running the model should allow a sensible decision to be made as to whether this is justified.

Project information
Contact person at SSM: Pål Andersson

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myndigheten

Swedish Radiation Safety Authority

Author: Nicholas Beresford[1], Patrick Boyer[2] and Brenda Howard[1]

[1]NERC's Centre for Ecology & Hydrology, Lancaster, United Kingdom;

[2]Institut de Radioprotection et de Süreté Nucléaire,
CE-Cadarache-13115, St. Paul lez Durance, France

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Contents

1. Introduction

Radioactive waste and spent nuclear fuel from Swedish nuclear power plants are managed by the Swedish Nuclear Fuel and Waste Management Co (SKB). Between 2002 and 2007, SKB performed site investigations with the intention of finding a suitable location for a geological repository for spent fuel arising from the Swedish nuclear power programme. Studies were focused on two different sites along the eastern coast of southern Sweden; Forsmark in the municipality of Östhammar and Laxemar-Simpevarp in the municipality of Oskarshamn. Based on the conclusions of these initial site studies, SKB selected the Forsmark site as the site for the repository.

According to the regulations of the Swedish Radiation Safety Authority (SSM), a safety assessment focused on potential developments that may lead to the release of radionuclides of the planned repository has to be performed before the construction of the repository can commence. SKB launched the project SR-Site (SKB 2011; report TR-11-01)[1] to conduct the required safety assessment which focused on three major areas of investigation: performance of the repository, the geosphere and the biosphere.

This report presents a review of the approaches and databases which SKB have used to derive concentration ratios (CR values) and distribution coefficients (K_d values) to consider if they are robustly derived and fit for purpose. Credible alternative approaches are also considered. The focus of this review are SKB reports R-10-28 (Tröjbom & Nordén 2010) and TR-10-07 (Nordén et al. 2010) which describe the available site specific data and the subsequent derivation of CR and K_d values respectively for application in human assessment.

The contract specification included the consideration of transfer parameters for application in SKBs non-human assessment (Torudd 2010; report TR-10-08). However, after consultation with SSM it was agreed that this should be included within our overall review of SKBs assessment of the long-term radiological effects on plants and animals of a deep geological repository (reported in Howard & Beresford 2014).

[1] SKB reports will be referred to by report number after they are initially mentioned within the text.

2. Assessment of the derivation and use of Kd and CR values

2.1. SKB's presentation

The biosphere assessments of SKB provide estimates of human exposure to radioactivity from a unit release, expressed in the form of landscape dose conversion factors (LDFs) (Avila et al. 2010; report TR-10-06). Multiplying these factors with modelled release rates from the geosphere to the biosphere gives estimates of annual doses to human which are then used to assess compliance with the relevant regulatory risk criterion. To accomplish this, the transport and accumulation of radionuclides in the biosphere throughout a full glacial cycle has been described using a radionuclide model for the biosphere (SKB 2010; report TR-10-09). The biological uptake of radionuclides by potential food sources for humans has been estimated from predicted radionuclide activity concentrations in the environment (air, soil and water) using various parameter values. The radionuclide model needs distribution coefficients (K_d) to describe the partitioning between the dissolved and sorbed phases of an element (in terrestrial and aquatic ecosystems) and concentration ratios (CR) to model the uptake of radionuclide by organisms. For each radionuclide Landscape Dose Conversion Factors (LDF) defined as the annual effective dose to a representative (human) individual from the most exposed group resulting from a constant unit release rate of a radionuclide to the biosphere are derived (Sv a^{-1} per Bq a^{-1})

To avoid using the high upper limit in the range of reported K_d values given for many radionuclides in data compilations, SSM recommended SKB to use site-specific data in an review of an earlier assessment (referred to as SR-Can) (Xu et al. 2008). TR-10-07 derives CR and K_d values for application in the SR-Site assessment. In many instances, SKB have used Bayesian statistics to utilise both the site and literature data to derive parameter values and associated Probability Density Functions (PDF).

Tröjbom & Nordén (R-10-28) describes the various studies which have been conducted in marine, freshwater and marine ecosystems in the vicinity of Forsmark and Laxemar-Simpevarp to determine elemental concentrations in biota, regolith (largely soils), surface water, ground water and pore water. The studies reviewed are largely from other SKB reports, although data sources (e.g. HELCOM-MORS) are also included. An overview of sampling and analytical methods used in each study is presented. The data resulting from these studies are assessed in terms of its suitability to derive site specific CR and K_d values. An explorative analysis of the data is presented considering, for instance, if there are differences in elemental concentrations between the two sites or different biota types. Assumptions and considerations made during the selection of site specific data are presented although the resultant values are not presented within the report; these are presented in TR-10-07. For both terrestrial and aquatic animals all the studies reviewed presented concentrations in muscle.

2.2. Motivation of the assessment

The objective of this review was to conduct an assessment of the methodology and data used by SKB to derive K_d and CR values. The aim was to judge if the parameters were robust and fit for purpose or if alternative approaches and values could have been used.

2.3. The consultant's assessment

To evaluate if the derived parameter values are fit for purpose we have taken differing approaches for K_d and CR values.

The K_d values derived by SKB were compared against internationally 'recommended' value (from IAEA reports). Then, the K_d values for the different compartments are compared to check how consistent they are. The CR values are often sourced from one of three reviews including the recent international compilation of data in IAEA (2010). Therefore, unlike the K_d values we have little additional information with which to compare the values used by SKB. Consequently, we have evaluated how these CR values from the review literature were originally derived and how they have been used by SKB.

In the following sections we consider generic issues associated with data availability, conceptual models, statistical analyses and data selection. Subsequently, we consider issues associated with K_d and CR values (and other approaches used to determine activity concentrations in foodstuffs) separately.

2.3.1. Data availability and conceptual models

SKB report R-10-28 compiles site specific data available for Forsmark and Laxemar. These data are subsequent used in TR-10-07 to provide K_d and CR values. The conceptual models considered by SKB for the potential transfer of radionuclides to humans have a relatively limited number of foodstuffs:

1. Terrestrial: crops (cereals, root crops and vegetables), pasturage, mushrooms, berries, milk (cow), meat (beef), game animals
2. Freshwater: fish and crustaceans
3. Marine: fish

Numbers of derived CR and K_d values from site data are ≤ 10 for most element-sample type combinations; exceptions are CR values for terrestrial primary producers (n=19 for some elements) and K_d values for organic soil (n=11-28).

The majority of site data discussed in R-10-28 originate from SKB studies. However, there does not appear to have been a focussed collection of samples specifically aimed at providing the parameter values for the radionuclides and foodstuffs considered in the SR-Site assessment and the conceptual models. Consequently, there were no site data for a number of the foodstuffs considered including: agricultural foodstuffs, berries or freshwater crustaceans. Why this partial approach to sampling was taken is unclear. For instance, whilst berry bearing plant species were sampled, berries were not even though they are considered as a food source in the model.

For agricultural animal products only cow milk and beef were considered in the SR-Site model. The transfer of radionuclides to animal derived foodstuffs has traditionally be described by the ‘transfer coefficient’ defined as the ratio of the radionuclide activity concentration in the food product (e.g. milk, meat, eggs) to the daily intake of that radionuclide. Transfer coefficients vary between animal species. TR-10-07 acknowledges this, but also states that the concentration ratio between the radionuclide activity concentration in an animal product and the diet of the animal tends to be relatively constant between species. TR-10-07 therefore proposes that the activity concentration in meats other than beef would be similar to those predicted in beef. This is a reasonable suggestion and IAEA (2010) presents dietary CR values on the basis that they are more generic across animal species than transfer coefficients. However, the activity concentration in meat will obviously be dependent upon the activity concentration in the diet which may not be consistent across species. TR-10-07 does not consider the milk of animals other than cows on the basis that this is the only milk currently produced in the area. However, the same argument as used with respect to the meat of different animals would be valid for milk if, in the future, other dairy animals are farmed in the area.

All site data used to derive K_d and CR values originate from stable element analyses of the collected samples. Consequently, there are no site data for those elements which were not detectable using this approach (e.g. actinide elements). Whilst it is unlikely that many of the radionuclides considered in SR-Site and excluded using this approach would be detectable/present in the environment it is probable that site data for some could have been obtained (e.g. radioisotopes of Pu, Po, Ra).

Selection of CR and K_d values

R-10-28 presents data for both Forsmark and Laxemar and in TR-10-07 these data are combined and used as the ‘site specific data’. SR-Site uses deterministic simulations to derive the LDFs and probabilistic simulations for uncertainty and sensitivity analysis. Therefore, both best estimate (BE) parameter values and PDFs (GM and GSD) were required. In selecting CR and K_d values for application in SR-Site SKB have used both site specific and literature data as follows:

1. If both site-specific and literature data were available, the parameter values were combined and Bayesian inference methods used to derive the BE and PDF
2. If site-specific data were not available, but representative literature data could be found, the BE and PDF were derived from the literature data.
3. If site-specific data were available, but representative literature data could not be found, the BE and PDF were derived from the site data
4. If neither site-specific or literature data were available data for analogues or, in the case of game animals, kinetic-allometric models were used.

It is possible to identify how the CR values have been derived from the tables and appendices of TR-10-07. Consideration of the literature was largely restricted to IAEA 2010, Beresford et al. (2007), Karlsson & Bergström (2002, SKB R-02-28) and Sheppard et al. (2009, SKB-09-27). Beresford et al. (2007) is the ERICA Integrated approach and does not report the CR values used by the ERICA Tool. However, it is a commonly used reference for the Tool.

Bayesian updating
The application of Bayesian updating represents an approach which takes into account all of the available information including the largely limited site data and literature data. Alternative approaches would be to either ignore the site data where it is limited (the suggestion of Sheppard (2005) could be interpreted in this way) or to simply pool the two data sets. The application of Bayesian updating represents a credible attempt to make better use of the information available. Where site-specific data had at least 5 samples and there were 10 values or more from the literature the 'prior from population' method was used. This approach is biased towards the site specific data. Where prior from population was not used the updating approach applied was 'prior from sub-population'. This assumed that both the site and literature data belonged to the same sub-population and the resultant, or posterior, distribution is a compromise between the site and literature data.

In selecting best estimate CR and K_d values when the prior from population approach was used the GM of the *posterior distribution* was taken as the BE. However, when the prior from sub-population approach was used, and the number of site data was at least 10, the GM of the *site data* was used as the BE; this again weighted towards the site data. Where site data were <10 the GM of the posterior distribution is cited as being used, however, this does not always appear to have been the case (e.g. see U and Th CR values for mushroom in Table D-6 of TR-10-07).

In some instances, (e.g. K_d values for Ag, Cl, Th and U for 'Ter_reoUp') the prior from population was used as the prior from sub-population gave 'unrealistically' high GSD values.

Given the relatively low number of site specific data the bias towards these values when using Bayesian updating may at first raise concerns. However, in the case of CR values the majority of the selected BE values are within an order of magnitude of the literature values which are themselves often based on limited data. For terrestrial primary producers, freshwater macrophytes, freshwater fish and marine fish the majority of the BE values are lower than the corresponding literature values. However, in only five cases (freshwater fish Nb and marine fish Cl, Mo, Sr and U) the BE was more than an order of magnitude lower than the literature values. However, again some of these literature values were themselves based on few data.

As the sources of literature considered did not include CR values for microphytobenthos (Table 5-3 of TR-10-07) and for many elements only one site measurement was available, Bayesian updating was not possible. Consequently, for 16 elements for this category the CR value used in SR-Site is based upon one measurement only.

There was often greater difference between the BE K_d values and those from the cited literature than for the CR values. Therefore, a more detailed evaluation of the K_d values used in SR-Site compared with those in the literature is presented in section 2.1.2.

Analogues
Where no data were available from either the site or literature to derive a specific CR analogues were used. TR-10-07 states the first analogue was the use of stable isotope data. However, as all of the usable site data were based on stable element measurements this option was in-effect the default choice rather than a decision on which analogue to use when data were lacking.

The second analogue applied was to use data for the same element for a different biota type. For instance, as noted above, mollusc data were used from freshwater crustaceans. However, this appears to be the result of the sampling strategy. TR-10-07 suggests that this approach (using site data for a different organism) introduces errors which are 'acceptable and less severe' than those associated with using literature data for the same organism (page 22). Evidence to support this suggestion would have been appropriate.

For some CR values data for the same organism in a different ecosystem were used (e.g. marine CR values were used for freshwater plants (n=4) and fish (n=5)). In some instances combinations of analogues were used, for instance, marine plant CR values from the literature were applied to freshwater microphytobenthos for some elements. R-10-28 provides a comparison of element concentrations in the freshwater and marine biota sampled from Forsmark and Laxemar. It would have been more useful if this (and other) analyses were conducted on the derived CR values from the site data as this could then have been used to help select analogue values.

For some organisms CR values of a similar element have been assumed (e.g. a number of CR values for Ca assume the same value as available data for Sr).

The application of such analogue approaches when data are lacking is similar to approaches used in other compilations of transfer values in human and wildlife assessments (e.g. IAEA 2004; Beresford et al. 2008; ICRP 2009). Given the uncertainties associated with such approaches previously the most conservative option (i.e. highest CR) from a range of analogues has been favoured (e.g. Beresford et al. 2008). TR-10-07 makes no comment on whether the analogue derived values have been selected to be conservative or not. To the contrary, for freshwater phytoplankton site specific data for freshwater macrophytes are used to provide 19 of the 29 required CR values even though the text acknowledges that the approach may result in a 'slight underestimation' based upon a comparison of some CR values derived from site specific macrophyte date with literature data for freshwater phytoplankton (three of the comparisons show the macrophyte CR values to be at least two-orders of magnitude lower than the literature values for phytoplankton) (page 45 of TR-10-07). There were between only four and nine site specific CR values for freshwater macrophytes.

Treatment of data below limits of detection
In TR-10-07 SKB outline an approach they have used to take into account values below the detection limits. It is good that there has been an attempt to use these many data rather than ignore them. However, it is not clear which CR or K_d values have been derived using data below the limits of detection or the extent of use of such data (for both the numerator and denominator of the CR and K_d equations) for a specific CR or K_d value. Table A1-2 of R-10-28 does gives a percentage of values below limits of detection, but this is difficult to use and relies on an understanding of the coding in the SKB database.

2.3.2. K_d values

Because the assessments performed by SKB are based on best estimate values, the consideration of K_d values presented in this report is mainly dedicated to the analysis of the statistical methods used by SKB and to checking the coherence between the parameter values. Therefore, the main objective has been to provide a global analysis rather than an individual analysis of each value. For K_d our approach included two steps: (i) a global comparison (including all elements) between SKB values and referenced values in literature and (ii) identification of inconsistencies for each element by considering the parameter values used by SKB in the different ecosystem compartments.

The analysis of K_d values focuses on the best estimate (BE) values and geometric standard deviations (GSD) selected by SKB. Here, we outline the basic concepts behind the use of K_d and comments on how these concepts are applied in the model. Then, an evaluation is given of all of the BE and GSD values presented by SKB for K_d. A generic analysis initially compares the K_d values with data referenced in the literature for the different ecosystems and compartments considered in SR-Site. Thereafter, a synthesis of the analysis is provided for each element included in the assessment.

The K_d concept

Many mechanisms (such as sorption, desorption, precipitation) determine the distribution of radionuclides between their dissolved and particulate forms. For assessments, the state of the art does not currently provide an operational, mechanistic approach to model each of these mechanisms. For this reason, integrated approaches to quantifying these distributions are generally applied and the most commonly used (as it is the case here) is that based on the coefficient K_d. This coefficient is based on the hypothesis that the exchanges between the dissolved and the particulate forms are reversible and instantaneously equilibrated. For an element X, it is described as follow:

$$Kd(X) = {[X]_{solid}} \big/ {[X]_{solution}}$$

Where X is the radionuclide, $[X]_{solid}$ (Bq kg^{-1} dry weight) is the radionuclide activity concentration of the solid (soil, sediment, suspended particulate matter (SPM)),$[X]_{solution}$ (Bq m^{-3}) is the radionuclide activity concentration in the solution.

For modelling application, there are two main sources of uncertainty linked to the use of K_d:

1. Kd is dependent on the radionuclide, properties of the particles (nature, size etc.) and chemical conditions (pH, redox conditions etc.) and currently its determination is highly empirical. Without in-situ calibration the best that can be done is to use best estimated values or, preferably, assess uncertainty by using probability functions of Kd such as those provided by the IAEA for soil, freshwater and marine ecosystems (IAEA 2004;2010).
2. Kd is not appropriate to take into account irreversible phases. This point is highlighted by the differences between Kd values determined by sorption or desorption experiments. If irreversible phases are present then Kd_sorption is lower than Kd_desorption. In practice, the main risk is of overestimating the rate of depuration from particulate matter.

SKB approach

The assessments performed by SKB are based on a compartmental model of the biosphere described with different layers and components. The source of radionuclides is situated in the deeper layer (‘Regolith Low’) and transfer to other layers is due to water fluxes, particle fluxes and gas fluxes. As K_d is needed to quantify the transfer of radionuclides by water fluxes, the model requires K_d values for each radionuclide in each of the components shown in Figure 1.

Grouping of K_d values

SKB consider K_d in four type of soils/sediments as follows:

1. Lower layer of the regolith (kD_regoLow)
2. Organic deposit layers of both the terrestrial and aquatic ecosystems, namely all the Regolith up and Regolith Mid compartments (termed here kD_regoMidUp)
3. SPM in lakes (Lake_kD_PM)
4. SPM in marine systems (Sea_kD_PM)

The parameter codes as used by SKB are shown in parenthesis.

To assess the relevance of this selection, we consider the properties attributed by SKB to these components.

- <u>Regolith Low:</u> The lower part of the regolith is an inorganic layer overlying the bedrock, primarily composed of coarsely graded and heterogeneous sediments of glacial origin (glacial till). It is common to both terrestrial and aquatic systems.

- <u>LakeRegolith Mid, MarineRegolith Mid:</u> The middle part of the regolith in the aquatic part of the biosphere, usually consisting of glacial and postglacial clays, gyttja and finer sediments which originate mainly from the period after the retreat of the last glacial ice sheet.

- <u>LakeRegolith Up, MarineRegolith Up:</u> The part of the aquatic regolith with the highest biological activity, comprising approximately 5–10 cm of the upper aquatic sediments where resuspension and bioturbation can maintain an oxidizing ecosystems.

- <u>TerRegolith Mid:</u> The middle part of the terrestrial regolith, containing glacial and postglacial fine material, namely former sediments from the seabed/lake bottoms. This part, composed of organogenic soil, is supposedly oxidized, compacted and composed of a mixture between agricultural soil and glacial and postglacial deposits.

- <u>TerRegolith Up:</u> The upper part of the terrestrial regolith which has the highest biological activity, such as the peat in a mire, or the ploughed layer in agricultural land.

- <u>Lake PM and Marine PM:</u> The surface water (stream, lake, or water).

	Lake SPM	Marine SPM
TerRegolith Up	LakeRegolith Up	MarineRegolith Up
TerRegolith Mid	LakeRegolith Mid	MarineRegolith Mid
Regolith Low		

Figure 1: Biosphere compartments where K_d values are required

However, for K_d in regolith, it is explained in TR-10-07 (p25) that two different values are considered: one for Regolith Low and one for all other regoliths. The choice is based on (i) a separation between inorganic (low) and organic (other) layers and (ii) the necessity to group enough data to build the PDF functions.

The categorization of the different parts of the soil/sediment means that Regoliths Up and Mid correspond respectively to surface layers which are in contact with atmosphere for soils and water for aquatic environments and to a deeper layers located between surface and lower layers. SKB attributes the same K_d, value to all Mid and Up compartments. This decision merits further consideration and justification, especially for Regolith Up which are interfaced to different environments namely soil, marine and limnic waters that do not have the same properties and different interfaces. As Regolith Mid is probably more homogeneous (which should be demonstrated) the assumption is probably less inappropriate for these layers.

In aquatic systems, Regolith Up corresponds to the upper layer of bottom sediments. For large temporal scales, this layer can be assumed to be equilibrated with SPM because oxidizing conditions are similar and exchanges between surface sediment and water column are greater and faster than between Regolith Mid and Regolith Up. The differences between the K_d values of SPM and surface sediments are mainly due to particle size segregation. The K_d of SPM is generally higher than those of surface sediments because the size of the particles is lower in suspension than in the sediment, and therefore they have a higher surface area. Conversely, differences between Regolith Up and Regolith Mid arise from differences between the prevailing chemical conditions which are determined by vertical gradients in oxidizing conditions produced by the reduction of organic matter by bacterial activity. Therefore, for aquatic systems it would be more realistic and appropriate to distinguish between K_d values for mid and up layers.

In TR-10-07 (p24) the text queries the representativeness of K_d values for bottom sediments as they are obtained from the ratio between sediment concentration and water concentration and not between sediment and pore water concentrations. This is a valid point. To improve the data set for surface sediment, an alternative method may be to use the K_d for SPM, but divided by a factor ranging between 1and 10 to represent the decrease due to the particle size segregation (IAEA, 2001).

Generic comparison of BE and GSD values with literature data

This section aims to compare BE and GSD values selected for use in SR-Site by SKB with the generic values given by the IAEA (2010; 2004). The IAEA reports can be considered as the key current international reference sources. These comparisons are made for each group of K_d (inorganic deposits, organic deposits, Marine SPM and lake SPM) and they are discussed relative to conservatism criteria relevant to the assessment. These criteria are essentially justified by the difficulty to appreciate how BE and GSD values determined today can be representative of their real variability and of their potential evolution over many centuries. In this context, the following analysis are based on the comparison of the SKB values with the IAEA values to appreciate the levels of conservatism associated to the BE and GSD values used by SKB.

TR-10-07 (p9) implies that GSD values are only used to analyze the sensitivity of the model. However, it seems that SKB determines the sensitivity directly from the

Table 1: BE and GSD values for K_d of inorganic deposit (Regolith Low) from SKB TR-10-07 and IAEA (2010) referred to as TRS 472

Element	SKB BE	SKB GM	SKB GSD	SKB Method	TRS472 BE	TRS472 GSD	TRS472 Type
Ac	1.2E+0	1.2E+0	2	TRS472	1.2E+0	2.4	Mineral
Ag	1.4E-1	1.4E-1	3	TRS472	1.4E-1	3	Mineral
Am*	2.6E+0	2.6E+0	6	TRS472	2.6E+0	6.1	All soils
Ca	3.4E-2	3.4E-2	1.7	Prior fr. Pop.	7.0E-3	3.2	Mineral
Cd	2.4E-1	2.4E-1	8.4	Prior fr. Pop.	1.1E-1	8.1	Mineral
Cl	4.4E-4	4.4E-4	4.7	Prior	3.0E-4	3	All soils
Cm*	9.3E+0	9.3E+0	4	TRS472	9.3E+0	3.8	All soils
Cs	3.6E+1	3.6E+1	4.1	Prior fr. Pop.	1.2E+0	7	All soils
Eu	1.1E+1	1.1E+1	5.5	Prior fr. Pop.	-	-	-
Ho	5.2E+0	5.2E+0	9.7	Prior	6.3E-1	2.4	Mineral
I	7.1E-3	7.1E-3	5.1	Prior	7.0E-3	5.2	Mineral
Mo	1.5E-1	1.5E-1	3.3	Prior fr. Pop.	4.0E-2	2.8	All soils
Nb	1.9E+0	1.9E+0	5.3	Prior	1.5E+0	3.7	All soils
Ni	3.1E-1	1.8E+0	4	Prior fr. Pop.	2.8E-1	7	All soils
Np	2.0E-2	2.0E-2	4	TRS472	2.0E-2	3.6	Mineral
Pa	1.4E+0	1.4E+0	2	TRS472	1.4E+0	2.3	Mineral
Pb	7.7E+0	7.7E+0	5.4	Prior fr. Pop.	2.0E+0	9.9	All soils
Pd	1.4E-1	1.4E-1	2	TRS472	1.4E-1	2	Mineral
Po	2.1E-1	1.9E-1	5	TRS472	1.9E-1	5.1	Mineral
Pu*	7.4E-1	7.4E-1	4	TRS472	7.4E-1	4	All soils
Ra	7.3E+0	7.3E+0	2.2	Site-specific	2.5E+0	13	All soils
Se	2.2E-2	2.2E-2	2.6	Prior fr. Pop.	2.0E-1	3.3	All soils
Sm	5.0E+0	5.0E+0	13	Prior	6.3E-1	2.4	Mineral
Sn	2.9E-1	2.9E-1	2	TRS472	2.8E-1	2.2	Mineral
Sr	3.2E-1	3.2E-1	2.9	Prior fr. Pop.	5.2E-2	5.9	All soils
Tc	6.0E-5	6.0E-5	4	TRS472	6.3E-5	3.7	Mineral
Th	3.2E+1	3.2E+1	15	Prior fr. Pop.	2.6E+0	10	Mineral
U	1.5E+0	1.5E+0	3.3	Prior fr. Pop.	7.1E-2	11	pH<5
Zr	4.7E-1	4.7E-1	1.6	Prior fr. Pop.	4.1E-1	21	All soils

*SKB comment – all soils; $^{+}$Prior from population

probabilistic distributions characterized by the BE and GSD values. In that case the sensitivity to a parameter is more or less proportional to the variability of the parameter which is determined by its GSD. Hence, a low GSD value reduces the sensitivity of the model and can lead to the conclusion that the parameter is not relatively important.

BE and GSD values for inorganic deposits

In Regolith Low, K_d values have a direct impact on residence times: an increase in K_d resulting in an increased residence time. Table 1 presents the BE and GSD values used by SKB for the K_d values of Regolith Low. The SKB method refers to the derivations described above , Table 1 also includes values published by the IAEA (IAEA 2010) for mineral soil when available, or for 'all soils' when mineral soil is not given; the exception is U where K_ds are not categorized by this approach. As explained above, this choice is motivated by conservative considerations about the residence times in the Regolith Low compartment.

In Table 1, the values presented by SKB are only derived from site specific studies for Ra. The values are from TRS 472 for Ac, Am, Cm, Np, Pa, Po, Pu, and Tc; the remainder are derived using Bayesian methods combined site and literature data. For a number of elements, the values derived by the Bayesian method using "prior from subpopulation" are similar to those given by TRS 472. Figure 2 presents the ratios between the BE values used by SKB and those given by the IAEA (2010). All BE values used by SKB are equal to, or higher than, IAEA values, except for Se (this is noted in TR-10-07).

Figure 3 presents a similar comparison for the GSDs. The greatest differences between SKB and IAEA are observed for the GSDs of Ho, Ra, Sm, U and Zr. For Cl, Ho, Sm and Th, the GSDs used by SKB are higher than those of IAEA. This is appropriate from a conservative point of view. Conversely, the lower GSD applied to Ca, Cs, Ni, Pb, Ra, Sr, U and Zr does not provide the same degree of conservatism. This is all the more questionable given that BE values for these elements are higher than the IAEA values.

To complete this analysis, Figure 4 compares the ratios BE/GSD between SKB and IAEA. The greatest differences between SKB and IAEA values occur for Ca, Cs, Pb, Ra, Sr, Th, U and Zr where SKB ratios are higher than the IAEA ratios. This suggests a tendency not to be conservative as whilst the SKB K_d values are higher than the IAEA values their variability is reduced. It is suggested that improved higher values of GSD for these elements should be adopted. Two simple methods can be proposed: 1) use IAEA GSD values because they have been obtained from a larger data set, 2) adjust the GSD to obtain the same BE/GSD ratio as that of the IAEA.

This suggestion is particularly important for Ca, Cs, Pb, Ra, Sr and U, because the SKB BE values for these elements are several times higher than those of the IAEA which will lead to predicted long residence times in Regolith Low. The impact is lower for Ra, Ni, Sr and Zr because their SKB BE values are nearer to the IAEA values.

BE and GSD values for organic deposits
Organic deposits are considered as representative of Regolith Mid and Regolith Up for both the terrestrial, limnic and marine ecosystems. As for the Regolith Low, K_d values of organic deposit have a direct impact on the residence times in these compartments. Residence times increase when K_d values increase. Thus, conservatism in the SKB values is also considered by comparing the BE and GSD values with IAEA (2010). Table 2 presents the BE and the GSD values applied by SKB to characterise the K_d values of the organic deposits. As for inorganic deposit, the table also gives the values provided by IAEA (2010) for organic soil, when available, or for all soils when the value of organic soil is not given, and for a pH ranging between 5 and 8 if the two previous are unknown because this range corresponds to the average pH range of organic soils (Brady, 1984).

The BE values used by SKB for Ac, Am, Cm, Np, Pa, Pd, Po, Pu and Tc come from TRS 472. For Ag, Ca, Cd, Cl, Ho, I, Mo, Ni, Pb, Se, Sm, Th and U, the BE values are obtained from site specific data while GM and GSM come from Bayesian methods (which includes TRS values). For Eu and Ra, only site specific data have been used.

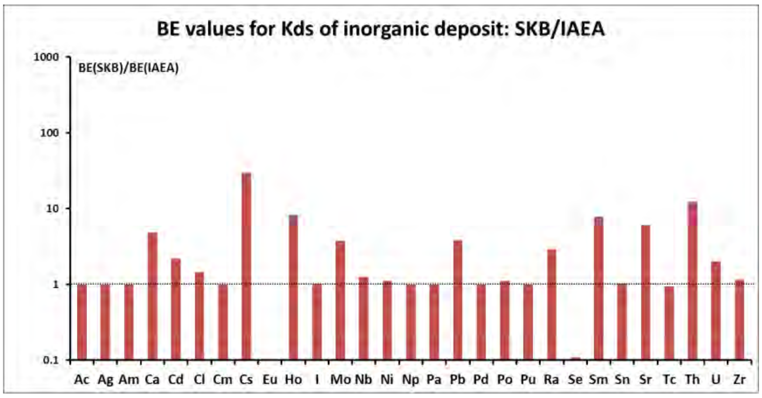

Figure 2: Ratio between BE values for Kd of inorganic deposits (Kd(SKB)/Kd(IAEA))

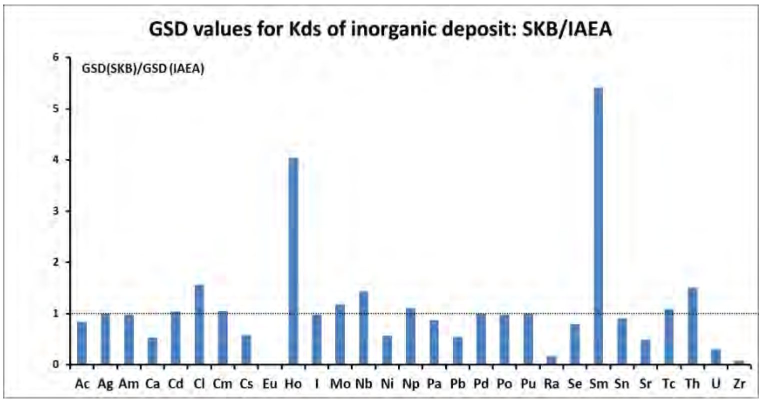

Figure 3: Ratio of GSD values for Kd of inorganic deposit (GSD(SKB)/GSD(IAEA))

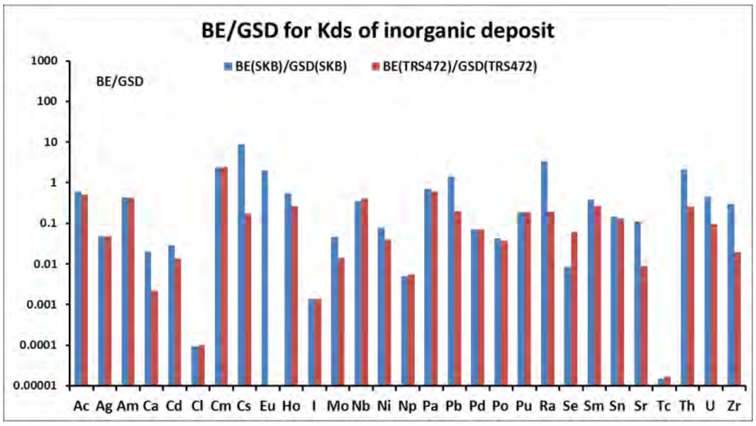

Figure 4: Ratio of BE/GSD for SKB values and IAEA Kd values for the inorganic deposit

Table 2: BE and GSD values for K_d of organic deposit (All Regolith Mid and Up)

Element	SKB BE	SKB GM	SKB GSD	SKB Method	TRS472 BE	TRS472 GSD	TRS472 Kd type
Ac*	1.7E+0	1.7E+0	3	TRS472	1.7E+0	2.8	All soils
Ag	6.2E+1	5.2E+1	3.5	Prior fr. Pop.	3.8E-1	7.1	All soils
Am#	2.5E+0	2.5E+0	5	TRS472	2.5E+0	4.6	Organic
Ca	6.3E-2	1.5E-2	5	Prior	8.0E-3	3.4	All soils
Cd	4.3E+0	2.4E+0	19	Prior	6.5E-1	6	Organic
Cl	1.0E-2	1.1E-2	3.5	Prior fr. Pop.	3.0E-4	3	All soils
Cm*	9.3E+0	9.3E+0	4	TRS472	9.3E+0	3.8	All soils
Cs	2.6E+1	2.6E+1	2.2	Prior fr. Pop.	2.7E-1	6.8	Organic
Eu	8.6E+0	8.6E+0	5.4	Site-specific			
Ho	1.2E+1	8.2E+0	4.7	Prior	9.3E-1	2.9	All soils
I	7.1E-1	2.4E-1	7.6	Prior	3.2E-2	3.3	Organic
Mo	1.1E+0	4.8E-1	8.8	Prior	4.0E-2	2.8	All soils
Nb	4.0E+1	4.0E+1	3.8	Prior fr. Pop.	1.5E+0	3.7	All soils
Ni	3.0E+0	1.9E+0	4.3	Prior	9.8E-1	2.1	Clay+Org.
Np#	8.1E-1	8.1E-1	1.3	TRS472	8.1E-1	1.4	Organic
Pa*	2.0E+0	2.0E+0	3	TRS472	2.0E+0	2.8	All soils
Pb	4.3E+1	2.8E+1	5.8	Prior	2.5E+0	2.5	Organic
Pd*	1.8E-1	1.8E-1	2	TRS472	1.8E-1	2.3	All soils
Po#, ^	6.6E+0	6.6E+0	5	TRS472	2.1E-1	5.4	All soils
Pu#	7.4E-1	7.4E-1	4	TRS472	7.6E-1	3.7	Organic
Ra*	2.3E+0	2.3E+0	2.1	Site-specific	2.5E+0	13	All soils
Se	5.3E-1	2.3E-1	3.8	Prior	2.0E-1	3.3	All soils
Sm	1.1E+1	7.8E+0	5.3	Prior	9.3E-1	2.9	All soils
Sn	8.0E+0	8.0E+0	3.6	Prior fr. Pop.	1.6E+0	6.2	All soils
Sr	1.2E-1	1.2E-1	2.7	Prior fr. Pop.	6.9E-2	5.4	Loam+Clay
Tc	3.0E-3	3.0E-3	3	TRS472	3.1E-3	2.9	Organic
Th#	4.2E+1	4.2E+1	3.7	Prior fr. Pop.	7.3E-1	44	Organic
U	6.5E+0	6.3E+0	3.4	Prior fr. Pop.	1.2E+0	6.1	Organic
Zr	5.6E+0	5.6E+0	16	Prior fr. Pop.	4.1E-1	21	All soils

*SKB comment – all soils; #organic, ^GSD all soils

From the previous table, Figure 5 presents an overall comparison between SKB and IAEA BE values.

The BE values used by SKB are consistently higher than those given in the TRS 472, with the sole exception of the site specific Ra value which is similar. The use of these higher values by SKB is most evident for organic deposit when compared with mineral deposit, and for all the elements that are not based on the literature.

The GSD values are compared in Figure 6. The GSD values obtained from site specific data by SKB for Ag, Cs, Ra, Th, U and Zr are very low compared with TRS 472 values. However, they are associated with BE values which are higher than the TRS 472 values (except for Ra) as can be seen in the comparison between the BE/GSD ratios given by SKB and IAEA shown in Figure 7.

The SKB ratios between the BE and the derived GSD are high compared with the IAEA ratios for Ag, Cs, Nb, Pb, Ra, Sn, Th and U. Because the BE values used by SKB for these elements are greater than the IAEA values it is also suggested to apply higher GSD values for these elements (for the same reasons as that for inorganic deposit). Inversely, for Ca, Cl, I, Mo, Pd, Pu, Se, and Sr, the SKB ratios are significantly lower than the IAEA ratios.

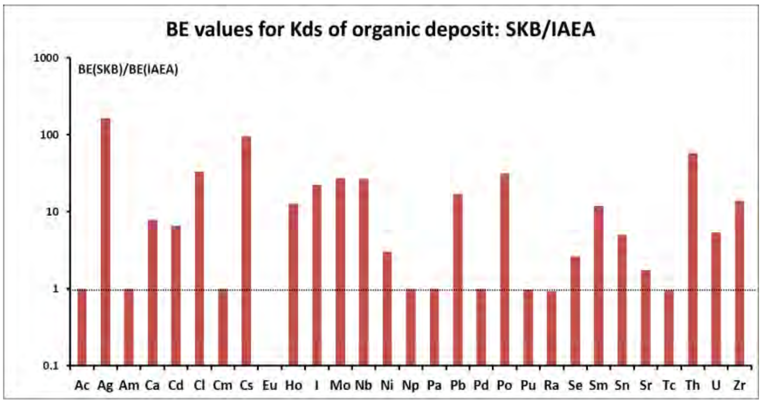

Figure 5: Ratio of BE values for K_d of organic deposit (Kd(SKB)/Kd(IAEA))

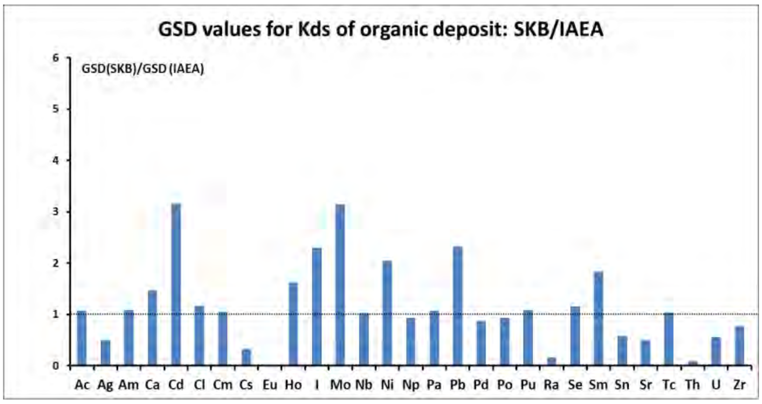

Figure 6: Ratio of GSD values for K_d of organic deposit (GSD(SKB)/GSD(IAEA))

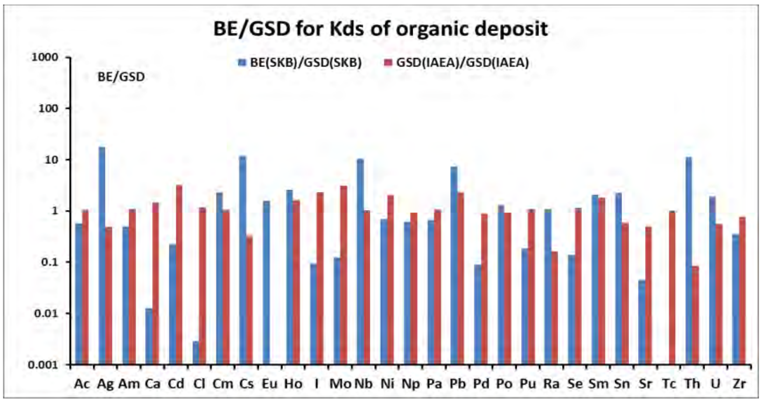

Figure 7: Ratios of BE/GSD values for K_d of organic deposit

BE and GSD values for SPM in marine ecosystems
Considering the very large time scales involved in the scenario and that the timescales of transfer in the oceans are significantly greater than in Regolith low, Mid and Up it can be assumed that the sensitivity of the model to K_d values for SPM in marine ecosystems will be less important than that to K_d values in the Regolith Low, Mid and Up. Thus, K_d values for SPM in marine ecosystem have no (or low) effect on the transfer times from the source to the biosphere. The effect of K_d for SPM is associated with pathways of contamination which are impacted by the dissolved or solid phases. For example, low K_d values will increase direct transfer to pelagic fish and high K_d values will increase transfer to benthic fish. In these circumstances, conservative criteria are closely related to the pathways applied in the model and differ depending on particular pathway being considered.

For K_d values in marine ecosystems the main source of data is TRS 422 which gives two type of BE values (open and margin ocean) and does not provide GSD. Considering the location of the Forsmark site, margin ocean values would seem more appropriate. There are no published data for Ho and Mo.

Table 3 presents these K_d values and those of SKB which are deduced from several methods and references[2]: Karlsson and Bergström (2002) for Ac and Pd, Beresford

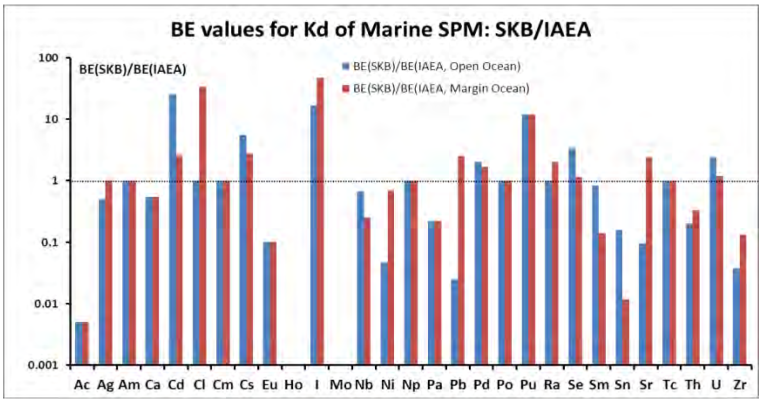

Figure 8: Ratio of BE values for K_d of SPM in marine ecosystems (K_d(SKB)/K_d(IAEA) for open and margin ocean)

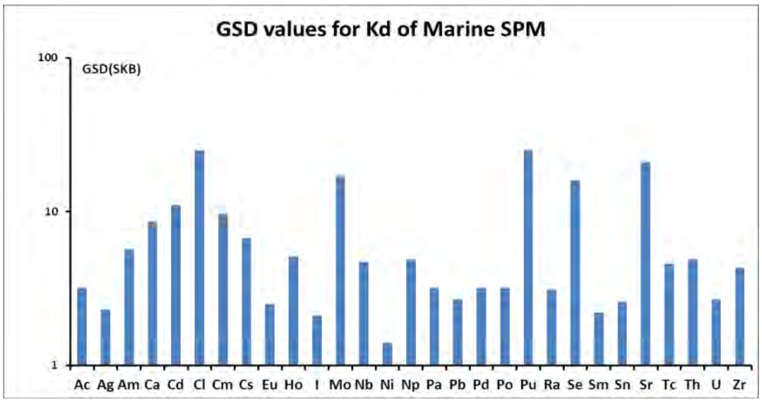

Figure 9: GSD values for K_d of marine SPM

[2]In TR-10-07 it is stated that there is no literature data for the K_d of Ca. However, values for Ca are given in TRS422 for margin and open oceans although these values are similar to the *in-situ* value obtained by SKB.

et al. (2007) for Ag, Am, Cm, Np, Po and Tc, TRS 422 for Cl and Ra and Sheppard et al. (2009) for Pa and Pu. Site specific data are used for Ca and Bayesian methods for Cd, Cs, Eu, Ho, I, Mo, Mb, Ni, Pb, Se, Sm, Sn, Sr, Th, U and Zr.

Figure 8 synthesizes the data in Table 3 by giving the ratios between the BE values used by SKB and those given in TRS 422 for both open and margin ocean. The largest differences between open and margin oceans are less than one order of magnitude. In contrast to the Regolith Low, Mid and Up there is no systematic tendency: for some radionuclides, K_d are higher than literature data whilst they are lower for others.The lack of published values for GSD in marine ecosystems means that comparison with literature data cannot be carried out for the GSD values shown in Figure 9. Further analysis of the data in these figures is presented below.

BE and GSD values for SPM in limnic ecosystems

Similarly to K_d values for SPM in marine ecosystem, K_d values in limnic ecosystems have no (low) effect on the transfer times from the source to the biosphere. Again the K_d values impact only on the pathways of contamination affected by the dissolved or solid phases.

For K_d in limnic ecosystem, Table 4 presents BE and GSD values used by SKB and those given by TRS 472. For these ecosystems, SKB used Karlsson and Bergström (2002) to allocate the BE and GSD of the K_d values of Ac, Pa, Pd, Po and Sn. The values coming from the TRS 472 are used for Am, Cm, Np, Pu, Ra and Tc. For these Bayesian methods are employed for Ag, Cd, Cs, Eu, Ho, I, Mo, Nb, Ni Sm, Sr, Th, U and Zr. For Cl, the values come from Veselý et al. (2001). The comparison between the BE values is presented in Figure 10.

The comparison does not show a consistent tendency between the K_d values used by SKB and those from the literature. The ratios are high for Eu, U and Zr and low for Ag. It is difficult to suggest an analysis of these ratios based on conservative criteria because these K_d values do not affect directly the transit times from the geosphere to the biosphere and they impact differently transfer pathways. This analysis will be completed with comparisons between the different compartments presented later.

For Lake SPM, GSD referenced values are available for Ag, Am, Cs, I, Pu, Ra, Sr and Th only. Figure 11 presents the GSD ratio for these elements. In Figure 11, Cs, I and Th are associated with the lower GSD values and their respective BE values are similar to published values.

Figure 12 compares the BE/GSD ratios for lake SPM and for the elements with other published GSD values (Ag, Am, Cs, I, Pu, Sr and Th). The differences between the SKB and IAEA ratios are small. However, for Cs, I and Th it is suggested to consider using GSD IAEA values or to determine GSD value as a function of the IAEA ratio.

Table 3. A comparison of K_d for marine ecosystems

Element	SKB BE	SKB GM	SKB GSD	SKB Method	TRS422 BE Open Ocean	TRS422 BE Ocean Margin
Ac	1.0E+1	1.0E+1	3.2	Karlsson and Bergström, 2002	2.0E+3	2.0E+3
Ag	1.0E+1	1.0E+1	2.3	Beresford et al., 2007	2.0E+1	1.0E+1
Am	2.0E+3	2.0E+3	5.7	Beresford et al., 2007	2.0E+3	2.0E+3
Ca	2.7E-1	2.7E-1	8.6	Site-specific data	5.0E-1	5.0E-1
Cd	7.7E+1	7.7E+1	11	Prior from population	3.0E+	3.0E+1
Cl	1.0E-3	1.0E-3	25	TRS 422	1.0E-3	3.0E-5
Cm@	2.0E+3	2.0E+3	9.6	Beresford et al., 2007	2.0E+3	2.0E+3
Cs	1.1E+1	1.1E+1	6.7	Prior from population	2.0E+0	4.0E+0
Eu	2.0E+2	2.0E+2	2.5	Prior from population	2.0E+3	2.0E+3
Ho	4.6E+1	4.6E+1	5.1	Prior from population		
I	3.3E+0	3.3E+0	2.1	Prior from population	2.0E-1	7.0E-2
Mo	1.6E-1	1.6E-1	17	Prior from population		
Nb	2.0E+2	2.0E+2	4.7	Prior from population	3.0E+2	8.0E+2
Ni	1.4E+1	1.4E+1	1.4	Prior from population	3.0E+2	2.0E+1
Np	1.0E+0	1.0E+0	4.9	Beresford et al., 2007	1.0E+0	1.0E+0
Pa	1.1E+3	1.1E+3	3.2	Sheppard et al., 2009	5.0E+3	5.0E+3
Pb	2.5E+2	2.5E+2	2.7	Prior from population	1.0E+4	1.0E+2
Pd	1.0E+1	1.0E+1	3.2	Karlsson and Bergström, 2002	5.0E+0	6.0E+0
Po	2.0E+4	2.0E+4	3.2	Beresford et al., 2007	2.0E+4	2.0E+4
Pu	1.2E+3	1.2E+3	25	Sheppard et al., 2009	1.0E+2	1.0E+2
Ra	4.0E+0	4.0E+0	3.1	TRS 422	4.0E+0	2.0E+0
Se	3.4E+0	3.4E+0	16	Prior from subpopulation	1.0E+0	3.0E+0
Sm	4.2E+2	4.2E+2	2.2	Prior from population	5.0E+2	3.0E+3
Sn	4.7E+1	4.7E+1	2.6	Prior from population	3.0E+2	4.0E+3
Sr	1.9E-2	1.9E-2	21	Prior from subpopulation	2.0E-1	8.0E-03
Tc	1.0E-1	1.0E-1	4.6	Beresford et al., 2007	1.0E-1	1.0E-1
Th	1.0E+3	1.0E+3	4.9	Prior from population	5.0E+3	3.0E+3
U	1.2E+0	1.2E+0	2.7	Prior from population	5.0E-1	1.0E+0
Zr	2.6E+2	2.6E+2	4.3	Prior from population	7.0E+3	2.0E+3

@GSD maximum GSD of all “Sea_kD_PM” and “Lake_kD_PM”

Table 4: A comparison of K_d for limnic ecosystems

Element	SKB BE	SKB GM	SKB GSD	SKB Method	TRS472 BE	TRS472 GSD	TRS472 Type*
Ac	1.0E+1	1.0E+1	3.2	Karlsson, Bergström, 2002			
Ag	9.3E+1	9.3E+1	2.3	Prior from subpopulation	4.4E+2	1.7	Des.
Am	1.2E+2	1.2E+2	5.7	TRS472	1.2E+2	5.7	Field
Ca	7.0E-1	7.0E-1	3.2	Site-specific data			
Cd	8.6E+1	8.6E+1	4	Prior from population			
Cl	9.8E-2	9.8E-2	25	Veselý et al. 2001			
Cm[@]	5.0E+0	5.0E+0	9.6	TRS472	5.0E+0		
Cs	9.7E+1	9.7E+1	3.2	Prior from population	2.9E+1	5.9	Field
Eu	5.8E+1	5.8E+1	2.9	Prior from population	5.0E-1		
Ho	1.6E+2	1.6E+2	2.2	Prior from population			
I	1.0E+1	1.0E+1	3.7	Prior from population	4.4E+0	14	Ads.
Mo	6.8E+0	6.8E+0	5.3	Prior from population			
Nb	2.3E+2	2.3E+2	3.2	Prior from population			
Ni	2.6E+1	2.6E+1	2.3	Prior from population			
Np	1.0E-2	1.0E-2	4.9	TRS472			
Pa	1.0E+2	1.0E+2	3.2	Karlsson, Bergström, 2002			
Pb	5.4E+2	5.4E+2	2.9	Prior from population			
Pd	2.0E+0	2.0E+0	3.2	Karlsson, Bergström, 2002			
Po	1.0E+1	1.0E+1	3.2	Karlsson, Bergström, 2002			
Pu	2.4E+2	2.4E+2	6.6	TRS472	2.4E+2	6.6	Field
Ra	7.4E+0	7.4E+0	3.1	TRS472	7.4E+0	3.1	All
Se	8.4E+0	8.4E+0	2.1	Site-specific data			
Sm	1.4E+2	1.4E+2	3.6	Prior from population			
Sn	5.0E+1	3.2E+1	1.8	Karlsson, Bergström, 2002			
Sr	1.1E+0	1.1E+	3	Prior from subpopulation	1.2E+0	2.7	Field
Tc	5.0E-3	5.0E-3	4.6	TRS472	5.0E-3		
Th	3.0E+2	3.0E+2	4.6	Prior from population	1.9E+2	21	All
U	6.3E+0	6.3E+0	9.3	Prior from population	5.0E-2		
Zr	5.7E+1	5.7E+1	4.4	Prior from population	1.0E+0		

*From adsorption (Ads.), desorption (Des.) or field measurements; [@]GSD = maximum GSD of all "Sea_kD_PM" and "Lake_kD_PM" (from TR-10-07).

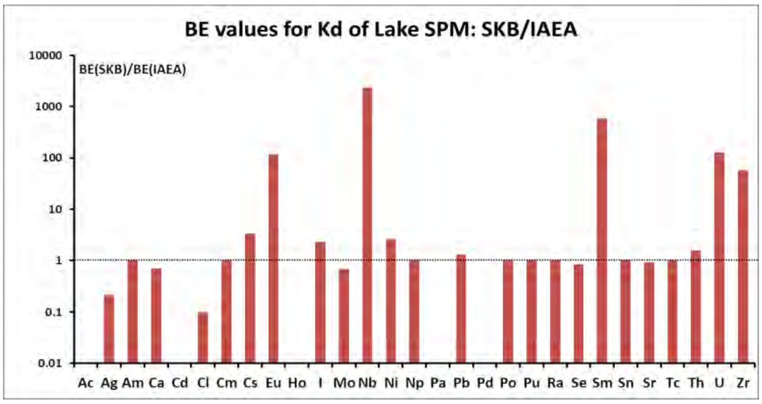

Figure 10: BE values for K_d of Lake SPM (K_d(SKB)/K_d(literature))

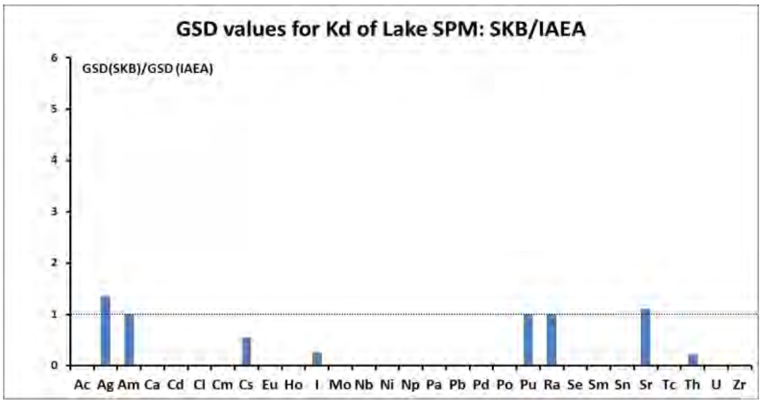

Figure 11: GSD values for K_d of Lake SPM (GSD(SKB)/GSD(IAEA))

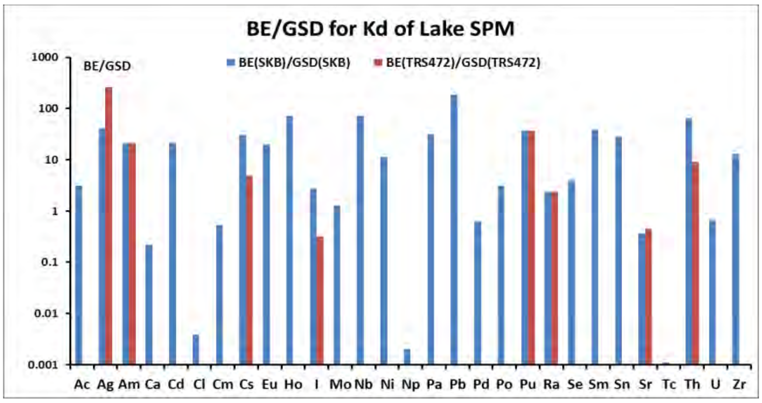

Figure 12: BE/GSD values for K_d of Lake SPM

Generic comparisons between the compartments

To complete the previous analyses, this section compares the BE and the GSD values between the compartments. Four comparisons are considered: 1) Lake SPM *vs* Regolith Up, 2) Marine SPM *vs* Regolith Up, 3) Marine SPM *vs* Lake SPM and 4) Regolith Low *vs* Regolith Up. The aim is to analyse whether the values applied by SKB in the different compartments are consistent with the general tendencies that are often observed between these compartments. The overall objective is to consider the general coherence of the SKB data set.

Lake SPM vs Regolith Up

In aquatic systems, Regolith Up corresponds to the surface layer of bottom sediments. Because particles sizes are bigger in this layer than in the suspension, it can be expected that the ratio between the K_d value for lake SPM and Regolith Up is between 1 and 10. To check this aspect, Figure 13 presents the ratios obtained with the BE values used by SKB for Lake SPM and Regolith MidUp.

In general, K_d SPM > K_d sediment and the majority of the ratios are within one order of magnitude. For Np, the K_d in SPMs is considerably lower than in sediment and well below the expected ratio and this needs to be considered further. Inversely, K_d in SPM is significantly higher, than that in sediment, and above the expected ratio, for Am, Pa, and Pu. The ratios between the GSD values are given in Figure 14. There are similar GSD between lake SPM and Regolith Up, with the exceptions of Am, Cl, Cm, Mo, Np, Pu, Tc, Th and U for which GSD values are higher for SPM than for sediments. The difference is most notable for Cl and U.

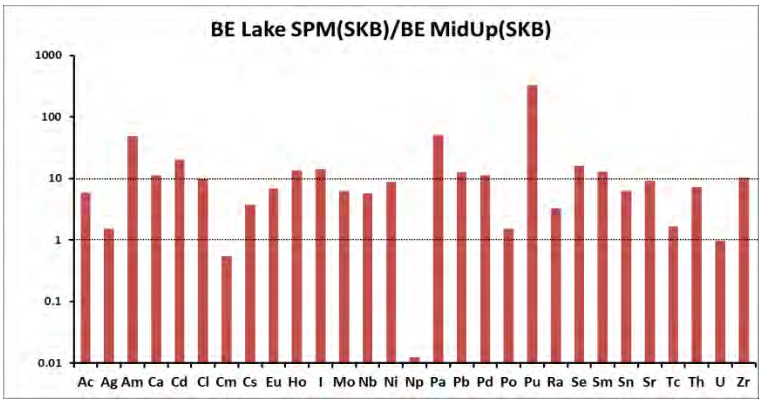

Figure 13: BE Lake SPM(SKB)/BE MidUp(SKB)

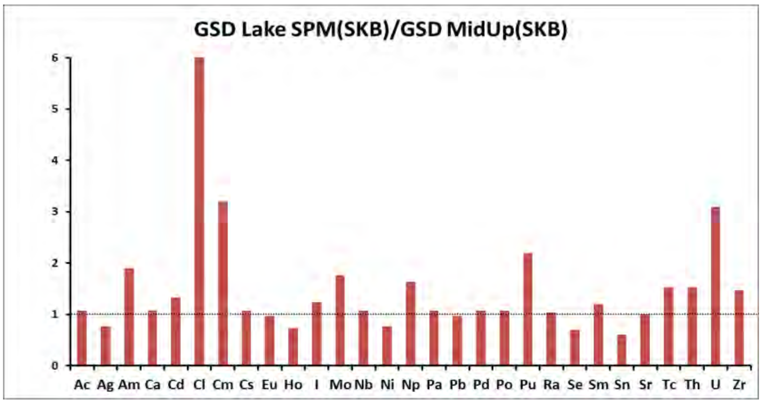

Figure 14: GSD Lake SPM(SKB)/GSD MidUp(SKB)

Marine SPM vs Regolith Up
In marine ecosystems the ratios between SPM and sediment can be higher than those in Lake because the differences between the particles sizes are more significant. Figure 15 presents the ratios used for the marine values by SKB. As expected, the results are much more heterogeneous than for Lake. K_d for Marine SPM are higher than those for sediment for Am, Cm, Pa, Pd, Po, Pu, Tc and Zr and are lower for Ag, Cs, Mo, Sr and U.

Figure 16 presents the ratios between the GSD**.** The differences between GSD values are significant and vary by several orders of magnitude. Consideration should be given to using GSD IAEA values or to determine GSD value as a function of the IAEA ratio. This is especially an issue for Ag and U because the BE and the GSD ratios of these two elements are lower than one.

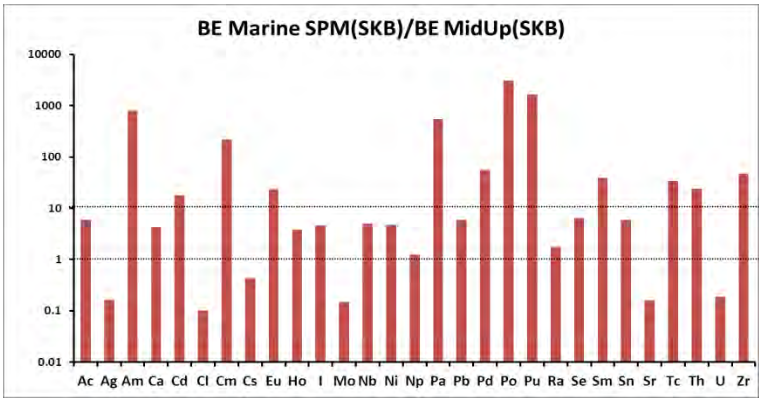

Figure 15: BE Marine SPM(SKB)/BE MidUp(SKB)

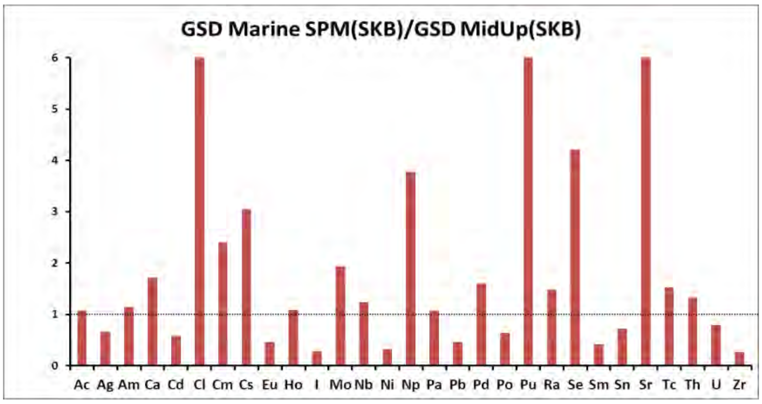

Figure 16: GSD Marine SPM(SKB)/GSD MidUp(SKB)

Marine SPM vs Lake SPM
Due to the salinity, the cationic exchanges in marine ecosystems will tend to reduce the K_d values. Conversely, the size of SPM is significantly lower in marine ecosystems and will tend to increase the K_d. Consequently, the ratios between Marine and Lake K_d depend on the balance between these two factors and do not follow a general tendency. Nevertheless, for identical particles, it can be expected that the values for the K_d of lake SPM are greater than the K_d for marine SPM and that their ratio is consequently lower than one. From this consideration, Figure 17 presents the ratios obtained with the SKB data set. The results are heterogeneous, it is suggested that when the ratio greatly exceeds 1, as is the case for Cm, Np and Po, the values used should be critically evaluated.

Figure 18 presents the ratio of the GSD. GSD for marine SPM are generally higher than those for GSD for lake SPM with some exceptions. The differences are extended by several orders of magnitude for Ca, Cd, Cl, Cm, Cs, Mo, Pu, Se and Sr.

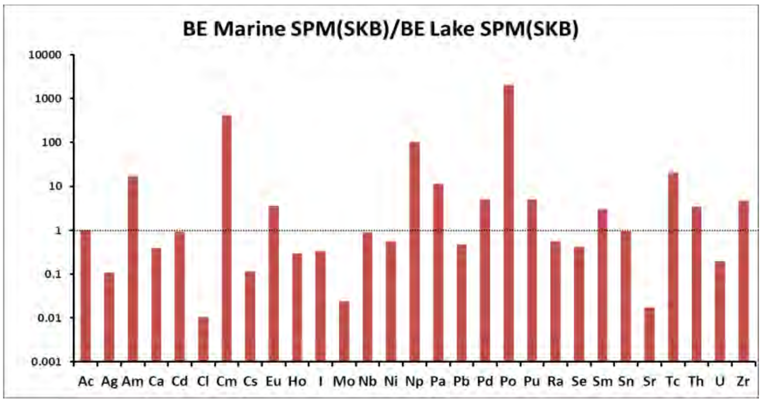

Figure 17: BE Marine SPM(SKB)/BE Lake SPM(SKB)

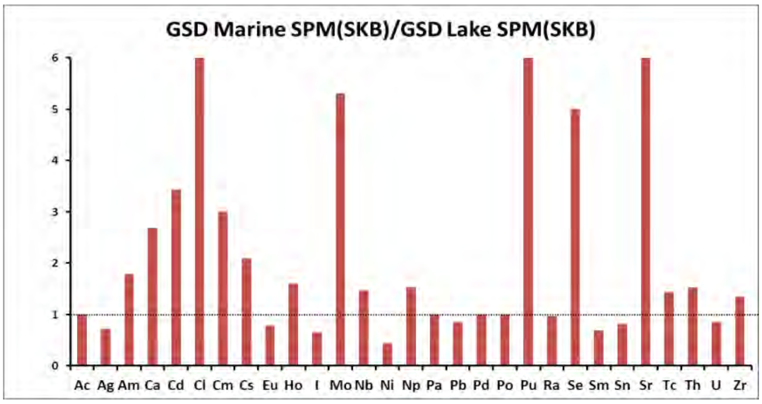

Figure 18: GSD Marine SPM(SKB)/GSD Lake SPM(SKB)

Regolith Low vs Regolith MidUp

It is well documented that the presence of organic matter increases K_d values. The aim of the comparison shown in Figure 19 is to check whether the tendency is followed when K_d values for Regolith Low (non-organic) are compared with K_d for Regolith MidUp (organic).

As expected, the majority of the ratios are less than 1, which shows good consistency between the SKB values for Regolith Low and MidUp and with established knowledge.

In Regolith variability in the amount of organic matter increases the variability of the K_d value. Consequently, the GSD values in Regolith Low should be lower than in Regolith MidUp. To test this, the ratios between GSD values in Regolith Low and Regolith MidUp (expected to be lower than 1) are presented in Figure 20. The majority of these ratios are lower or equal to one with the exception of Am, Cl, Cs, Ho, Nb, Np, Sm, Tc and Th. For these elements it is suggested to increase the variability in Regolith MidUp by adjusting their GSD values using the GSD values for Regolith Low.

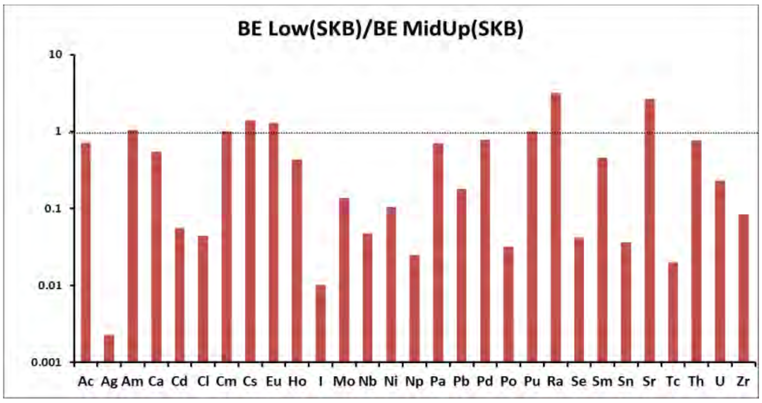

Figure 19: BE low(SKB)/BE MidUp(SKB)

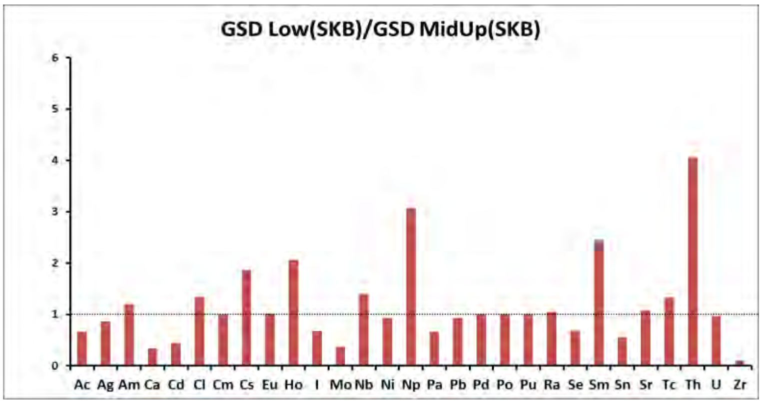

Figure 20: GSD low(SKB)/GSD MidUp(SKB)

Synthesis of comparison for each element

The tables below synthesise the results for each element; these tables are divided into two parts:

1. Gives the method used by SKB to determine the BE and GSD values and presents the tendencies of their ratios compared with relevant literature values, ie. (BE(SKB)/BE(Reference) and GSD(SKB)/GSD(Reference). The aim is to compare the values with a reference value.

2. Presents the ratios of the BE and GSD values between different compartments. The aim is to check the consistency between the values considered by SKB in the different compartments for the four following ratios:

Lake SPM/Reg. MidUp and Marine SPM/Reg. MidUp: In aquatic systems Regolith Up corresponds to the surface layer of bottom sediment. This layer is generally oxygenated and, for the same type of particle (size and nature), the K_d values (particulate activity/interstitial water activity) are similar to the K_d values of SPM. Due to the particle size segregation between the suspended particulate matter and the deposits, the particle size is finest in the SPM and the global K_d is several times greater than in the surface sediment (one to ten times on average). This behaviour cannot be extended for deep lake where surface sediment should be anoxic (in this case, Regolith Mid and Regolith Up can be aggregated). The criterion is: 1 < and < 10.

Marine SPM/Lake SPM: The cationic charge of sea water tends to decrease the capacity of adsorption of SPM. Therefore, it can be expected that K_d values in marine ecosystems are lower than in freshwater ecosystems. Conversely, the particle size of SPM is lower in sea water than in freshwater and so it can be expected that the K_d values are greater in sea water than in freshwater. Although there is not a clear tendency for the ratio between sea water and freshwater K_d values, mainly because of these two antagonist behaviours, it is considered here that the main tendency of this ratio is to be less than one. The criterion is: < 1.

Reg. Low/Reg. MidUp: The presence of organic matter, which has a high capacity to adsorb radionuclides, increases the K_d values and it can be expected that K_d values in Regolith MidUp are greater than in Regolith Low. The criterion is < 1.

Ac

BE and GSD values *vs* referenced data			
Compartment	**Origin**	**BE(SKB)/BE(Ref.)**	**GSD(SKB)/GSD(Ref.)**
Reg. Low	TRS472	= 1	≈ 1
Reg. MidUp	TRS472	= 1	= 1
Marine SPM	Karlsson& Bergstrom (2002)	<< 1	No referenced data
Lake SPM	Karlsson& Bergstrom (2002)	No referenced data	No referenced data
Ratios between compartments		**BE(C1)/BE(C2)**	**GSD(C1)/GSD(C2)**
Lake SPM/Reg. MidUp		1< and <10	≈ 1
Marine SPM/Reg. MidUp		1< and <10	≈1
Marine SPM/Lake SPM		= 1	= 1
Reg. Low/Reg. MidUp		<≈1	< 1
Comments			
no comments			

Ag

BE and GSD values *vs* referenced data			
Compartment	**Origin**	**BE(SKB)/BE(Ref.)**	**GSD(SKB)/GSD(Ref.)**
Reg. Low	TRS472	= 1	= 1
Reg. MidUp	Prior fr.Pop.	>> 1	<< 1
Marine SPM	Beresford et al. (2007)	<≈ 1	> 1
Lake SPM	Prior fr.Sub	< 1	>≈ 1
Ratios between compartments		**BE(C1)/BE(C2)**	**GSD(C1)/GSD(C2)**
Lake SPM/Reg. MidUp		1< and <10	<≈ 1
Marine SPM/Reg. MidUp		<< 1	<≈ 1
Marine SPM/Lake SPM		< 1	<≈ 1
Reg. Low/Reg. MidUp		<< 1	<≈ 1
Comments			
Compared with literature data, the values for Regolith MidUp are not conservative because the BE is very high while the GSD is very low. At the same time, the ratio between Marine SPM and Regolith MidUp is much lower than 1 confirming an overestimation of the Kd value for Regolith MidUp.			

Am

BE and GSD values *vs* referenced data			
Compartment	**Origin**	**BE(SKB)/BE(Ref.)**	**GSD(SKB)/GSD(Ref.)**
Reg. Low	TRS472	= 1	= 1
Reg. MidUp	TRS472	= 1	= 1
Marine SPM	Beresford et al. (2007)	= 1	No referenced data
Lake SPM	TRS472	= 1	= 1
Ratios between compartments		**BE(C1)/BE(C2)**	**GSD(C1)/GSD(C2)**
Lake SPM/Reg. MidUp		> 10	> 1
Marine SPM/Reg. MidUp		>> 10	≈ 1
Marine SPM/Lake SPM		≈ 10	> 1
Reg. Low/Reg. MidUp		= 1	≈ 1
Comments			
The very high ratio between the BE of Marine SPM and Regolith MidUp suggests that the BE is underestimated for surface sediments of marine ecosystems. This point is reinforced by the value being slightly higher than 1 for the ratio between Regolith Low and Regolith Up.			

Ca

BE and GSD values *vs* referenced data			
Compartment	**Origin**	**BE(SKB)/BE(Ref.)**	**GSD(SKB)/GSD(Ref.)**
Reg. Low	Prior fr.Pop.	> 1	< 1
Reg. MidUp	Prior fr.Sub	> 1	> 1
Marine SPM	Site Specific	<≈ 1	No referenced data
Lake SPM	Site Specific	<≈ 1	No referenced data
Ratios between compartments		**BE(C1)/BE(C2)**	**GSD(C1)/GSD(C2)**
Lake SPM/Reg. MidUp		≈ 10	≈ 1
Marine SPM/Reg. MidUp		1< and <10	> 1
Marine SPM/Lake SPM		< 1	> 1
Reg. Low/Reg. MidUp		<≈ 1	<< 1
Comments			
In Regolith MidUp, the SKB values are not conservative because the BE value is higher than data from the literature, while the value of the GSD is lower.			

Cd

BE and GSD values *vs* referenced data			
Compartment	**Origin**	**BE(SKB)/BE(Ref.)**	**GSD(SKB)/GSD(Ref.)**
Reg. Low	Prior fr. Pop.	> 1	= 1
Reg. MidUp	Prior fr. Sub.	> 1	> 1
Marine SPM	Prior fr. Pop.	> 1	No referenced data
Lake SPM	Prior fr. Pop.	No referenced data	No referenced data
Ratios between compartments		**BE(C1)/BE(C2)**	**GSD(C1)/GSD(C2)**
Lake SPM/Reg. MidUp		>≈ 10	>≈ 1
Marine SPM/Reg. MidUp		>≈ 10	< 1
Marine SPM/Lake SPM		≈ 1	> 1
Reg. Low/Reg. MidUp		< 1	< 1
Comments			
No comments			

Cl

BE and GSD values *vs* referenced data			
Compartment	**Origin**	**BE(SKB)/BE(Ref.)**	**GSD(SKB)/GSD(Ref.)**
Reg. Low	Prior fr. Sub.	> 10	> 1
Reg. MidUp	Prior fr. Pop.	> 1	>≈ 1
Marine SPM	TRS422	= 1	No referenced data
Lake SPM	Vesely et al (2001)	< 1	No referenced data
Ratios between compartments		**BE(C1)/BE(C2)**	**GSD(C1)/GSD(C2)**
Lake SPM/Reg. MidUp		= 10	>> 1
Marine SPM/Reg. MidUp		< 1	>> 1
Marine SPM/Lake SPM		<< 1	>> 1
Reg. Low/Reg. MidUp		< 1	> 1
Comments			
No comments			

Cm

BE and GSD values *vs* referenced data			
Compartment	**Origin**	**BE(SKB)/BE(Ref.)**	**GSD(SKB)/GSD(Ref.)**
Reg. Low	TRS472	= 1	= 1
Reg. MidUp	TRS472	= 1	= 1
Marine SPM	Beresford et al. (2007)	= 1	No referenced data
Lake SPM	TRS472	= 1	No referenced data
Ratios between compartments		**BE(C1)/BE(C2)**	**GSD(C1)/GSD(C2)**
Lake SPM/Reg. MidUp		< 1	> 1
Marine SPM/Reg. MidUp		>> 1	> 1
Marine SPM/Lake SPM		>> 1	> 1
Reg. Low/Reg. MidUp		= 1	= 1
Comments			
No comments because all data are based on literature			

Cs

BE and GSD values *vs* referenced data			
Compartment	**Origin**	**BE(SKB)/BE(Ref.)**	**GSD(SKB)/GSD(Ref.)**
Reg. Low	Prior fr. Pop.	> 1	< 1
Reg. MidUp	Prior fr. Pop.	>> 1	<< 1
Marine SPM	Prior fr. Pop.	> 1	No referenced data
Lake SPM	Prior fr. Pop.	> 1	< 1
Ratios between compartments		**BE(C1)/BE(C2)**	**GSD(C1)/GSD(C2)**
Lake SPM/Reg. MidUp		1< and <10	= 1
Marine SPM/Reg. MidUp		< 1	> 1
Marine SPM/Lake SPM		< 1	> 1
Reg. Low/Reg. MidUp		>≈ 1	> 1
Comments			
The values for Regolith Low and MidUp are not conservative because BE are higher than literature data and GSD are lower. The ratio between the BE values for Marine SPM and for Regolith MidUp is lower than 1 and suggests that the BE value for surface marine sediments is overestimated.			

Eu

BE and GSD values *vs* referenced data			
Compartment	**Origin**	**BE(SKB)/BE(Ref.)**	**GSD(SKB)/GSD(Ref.)**
Reg. Low	Prior fr. Pop.	No referenced data	No referenced data
Reg. MidUp	Site Specific	No referenced data	No referenced data
Marine SPM	Prior fr. Pop.	< 1	No referenced data
Lake SPM	Prior fr. Pop.	>> 1	No referenced data
Ratios between compartments		**BE(C1)/BE(C2)**	**GSD(C1)/GSD(C2)**
Lake SPM/Reg. MidUp		1< and <10	= 1
Marine SPM/Reg. MidUp		> 10	< 1
Marine SPM/Lake SPM		> 1	< 1
Reg. Low/Reg. MidUp		>≈ 1	= 1
Comments			
No comments			

Ho

BE and GSD values *vs* referenced data			
Compartment	**Origin**	**BE(SKB)/BE(Ref.)**	**GSD(SKB)/GSD(Ref.)**
Reg. Low	Prior fr. Sub.	> 1	>> 1
Reg. MidUp	Prior fr. Sub.	> 1	> 1
Marine SPM	Prior fr. Pop.	No referenced data	No referenced data
Lake SPM	Prior fr. Sub.	No referenced data	No referenced data
Ratios between compartments		**BE(C1)/BE(C2)**	**GSD(C1)/GSD(C2)**
Lake SPM/Reg. MidUp		>≈ 10	< 1
Marine SPM/Reg. MidUp		1< and <10	= 1
Marine SPM/Lake SPM		< 1	< 1
Reg. Low/Reg. MidUp		>≈ 1	> 1
Comments			
No comments			

I

BE and GSD values *vs* referenced data			
Compartment	**Origin**	**BE(SKB)/BE(Ref.)**	**GSD(SKB)/GSD(Ref.)**
Reg. Low	Prior fr. Sub.	= 1	= 1
Reg. MidUp	Prior fr. Sub.	> 1	> 1
Marine SPM	Prior fr. Pop.	> 1	No referenced data
Lake SPM	Prior fr. Pop.	>≈ 1	< 1
Ratios between compartments		**BE(C1)/BE(C2)**	**GSD(C1)/GSD(C2)**
Lake SPM/Reg. MidUp		>≈ 10	>≈ 1
Marine SPM/Reg. MidUp		<< 1	<< 1
Marine SPM/Lake SPM		< 1	< 1
Reg. Low/Reg. MidUp		<< 1	< 1
Comments			
For BE values, the two ratios Marine SPM/Reg and Reg. Low/Reg are significantly lower than 1. This suggests an overestimation of the BE value in Regolith MidUp.			

Mo

BE and GSD values *vs* referenced data			
Compartment	**Origin**	**BE(SKB)/BE(Ref.)**	**GSD(SKB)/GSD(Ref.)**
Reg. Low	Prior fr. Pop.	> 1	>≈ 1
Reg. MidUp	Prior fr. Sub.	> 1	> 1
Marine SPM	Prior fr. Pop.	No referenced data	No referenced data
Lake SPM	Prior fr. Pop.	<≈ 1	No referenced data
Ratios between compartments		**BE(C1)/BE(C2)**	**GSD(C1)/GSD(C2)**
Lake SPM/Reg. MidUp		1< and <10	> 1
Marine SPM/Reg. MidUp		< 1	> 1
Marine SPM/Lake SPM		<< 1	>> 1
Reg. Low/Reg. MidUp		< 1	< 1
Comments			
No comments			

Nb

BE and GSD values *vs* referenced data			
Compartment	**Origin**	**BE(SKB)/BE(Ref.)**	**GSD(SKB)/GSD(Ref.)**
Reg. Low	Prior fr. Sub.	>≈ 1	>≈ 1
Reg. MidUp	Prior fr. Pop.	> 1	= 1
Marine SPM	Prior fr. Pop.	< 1	No referenced data
Lake SPM	Prior fr. Pop.	>> 1	No referenced data
Ratios between compartments		**BE(C1)/BE(C2)**	**GSD(C1)/GSD(C2)**
Lake SPM/Reg. MidUp		1< and <10	= 1
Marine SPM/Reg. MidUp		1< and <10	>≈ 1
Marine SPM/Lake SPM		<≈ 1	> 1
Reg. Low/Reg. MidUp		< 1	> 1
Comments			
No comments			

Pa

BE and GSD values *vs* referenced data			
Compartment	**Origin**	**BE(SKB)/BE(Ref.)**	**GSD(SKB)/GSD(Ref.)**
Reg. Low	TRS472	= 1	= 1
Reg. MidUp	TRS472	= 1	= 1
Marine SPM	Sheppard & al. (2009)	< 1	No referenced data
Lake SPM	Karlsson& Bergstrom (2002)	No referenced data	No referenced data
Ratios between compartments		**BE(C1)/BE(C2)**	**GSD(C1)/GSD(C2)**
Lake SPM/Reg. MidUp		> 10	= 1
Marine SPM/Reg. MidUp		>> 10	= 1
Marine SPM/Lake SPM		> 1	= 1
Reg. Low/Reg. MidUp		<≈ 1	< 1
Comments			
No comments			

Pb

BE and GSD values *vs* referenced data			
Compartment	**Origin**	**BE(SKB)/BE(Ref.)**	**GSD(SKB)/GSD(Ref.)**
Reg. Low	Prior fr. Pop.	> 1	< 1
Reg. MidUp	Prior fr. Sub.	> 1	> 1
Marine SPM	Prior fr. Pop.	>≈ 1 (Margin)	No referenced data
Lake SPM	Prior fr. Pop.	= 1	No referenced data
Ratios between compartments		**BE(C1)/BE(C2)**	**GSD(C1)/GSD(C2)**
Lake SPM/Reg. MidUp		>≈ 10	= 1
Marine SPM/Reg. MidUp		1< and <10	< 1
Marine SPM/Lake SPM		< 1	< 1
Reg. Low/Reg. MidUp		< 1	<≈ 10
Comments			
No comments.			

Pd

BE and GSD values *vs* referenced data			
Compartment	**Origin**	**BE(SKB)/BE(Ref.)**	**GSD(SKB)/GSD(Ref.)**
Reg. Low	TRS472	= 1	= 1
Reg. MidUp	TRS472	= 1	<≈ 1
Marine SPM	Karlsson& Bergstrom (2002)	> 1	No referenced data
Lake SPM	Karlsson& Bergstrom (2002)	No referenced data	No referenced data
Ratios between compartments		**BE(C1)/BE(C2)**	**GSD(C1)/GSD(C2)**
Lake SPM/Reg. MidUp		= 10	= 1
Marine SPM/Reg. MidUp		> 10	> 1
Marine SPM/Lake SPM		> 1	= 1
Reg. Low/Reg. MidUp		<≈ 1	= 1
Comments			
No comments			

Po

BE and GSD values *vs* referenced data			
Compartment	**Origin**	**BE(SKB)/BE(Ref.)**	**GSD(SKB)/GSD(Ref.)**
Reg. Low	TRS472	= 1	= 1
Reg. MidUp	TRS472	> 1	= 1
Marine SPM	Beresford et al. (2007)	= 1	No referenced data
Lake SPM	Karlsson& Bergstrom (2002)	= 1	No referenced data
Ratios between compartments		**BE(C1)/BE(C2)**	**GSD(C1)/GSD(C2)**
Lake SPM/Reg. MidUp		>≈ 1	= 1
Marine SPM/Reg. MidUp		>> 1	< 1
Marine SPM/Lake SPM		>> 1	= 1
Reg. Low/Reg. MidUp		< 1	= 1
Comments			
No comments.			

Pu

BE and GSD values *vs* referenced data			
Compartment	**Origin**	**BE(SKB)/BE(Ref.)**	**GSD(SKB)/GSD(Ref.)**
Reg. Low	TRS472	= 1	= 1
Reg. MidUp	TRS472	= 1	= 1
Marine SPM	Sheppard et al. (2009)	> 1	No referenced data
Lake SPM	TRS472	= 1	= 1
Ratios between compartments		**BE(C1)/BE(C2)**	**GSD(C1)/GSD(C2)**
Lake SPM/Reg. MidUp		>> 10	> 1
Marine SPM/Reg. MidUp		>> 10	>> 1
Marine SPM/Lake SPM		> 1	>> 1
Reg. Low/Reg. MidUp		= 1	= 1
Comments			
***In aquatic* systems *(marine and lake), the BE value for surface sediments seems to be underestimated. This value is equal to the BE in Regolith Low and significantly lower than the BE values for* SPM.**			

Ra

BE and GSD values *vs* referenced data			
Compartment	**Origin**	**BE(SKB)/BE(Ref.)**	**GSD(SKB)/GSD(Ref.)**
Reg. Low	Site specific	> 1	<< 1
Reg. MidUp	Site specific	= 1	<< 1
Marine SPM	TRS422	= 1	No referenced data
Lake SPM	TRS472	= 1	= 1
Ratios between compartments		**BE(C1)/BE(C2)**	**GSD(C1)/GSD(C2)**
Lake SPM/Reg. MidUp		1 < and < 10	= 1
Marine SPM/Reg. MidUp		1 < and < 10	> 1
Marine SPM/Lake SPM		< 1	= 1
Reg. Low/Reg. MidUp		> 1	= 1
Comments			
BE and GSD values for Regolith Low are not conservative. BE seems to be overestimated because its ratio with the BE value in Regolith MidUp is greater than 1 and its GSD is significantly lower than literature values.			

Se

BE and GSD values *vs* referenced data			
Compartment	**Origin**	**BE(SKB)/BE(Ref.)**	**GSD(SKB)/GSD(Ref.)**
Reg. Low	Prior fr. Pop.	<< 1	< 1
Reg. MidUp	Prior fr. Sub.	> 1	>≈ 1
Marine SPM	Prior fr. Sub.	>≈ 1	No referenced data
Lake SPM	Site Specific	<≈ 1	No referenced data
Ratios between compartments		**BE(C1)/BE(C2)**	**GSD(C1)/GSD(C2)**
Lake SPM/Reg. MidUp		>≈ 10	< 1
Marine SPM/Reg. MidUp		1 < and < 10	>> 1
Marine SPM/Lake SPM		< 1	>> 1
Reg. Low/Reg. MidUp		< 1	< 1
Comments			
BE value in Regolith Low seems very low.			

Sm

BE and GSD values *vs* referenced data			
Compartment	**Origin**	**BE(SKB)/BE(Ref.)**	**GSD(SKB)/GSD(Ref.)**
Reg. Low	Prior fr. Sub.	> 1	>> 1
Reg. MidUp	Prior fr. Sub.	> 1	> 1
Marine SPM	Prior fr. Pop.	< 1	No referenced data
Lake SPM	Prior fr. Pop.	>> 1	No referenced data
Ratios between compartments		**BE(C1)/BE(C2)**	**GSD(C1)/GSD(C2)**
Lake SPM/Reg. MidUp		>≈ 10	>≈ 1
Marine SPM/Reg. MidUp		> 10	< 1
Marine SPM/Lake SPM		> 1	< 1
Reg. Low/Reg. MidUp		< 1	> 1
Comments			
No comments			

Sn

BE and GSD values *vs* referenced data			
Compartment	**Origin**	**BE(SKB)/BE(Ref.)**	**GSD(SKB)/GSD(Ref.)**
Reg. Low	TRS472	= 1	= 1
Reg. MidUp	Prior fr. Pop.	> 1	< 1
Marine SPM	Prior fr. Pop.	< 1	No referenced data
Lake SPM	Karlsson& Bergstrom (2002)	= 1	No referenced data
Ratios between compartments		**BE(C1)/BE(C2)**	**GSD(C1)/GSD(C2)**
Lake SPM/Reg. MidUp		1 < and < 10	< 1
Marine SPM/Reg. MidUp		1 < and < 10	< 1
Marine SPM/Lake SPM		= 1	< 1
Reg. Low/Reg. MidUp		< 1	< 1
Comments			
No comments			

Sr

BE and GSD values *vs* referenced data			
Compartment	**Origin**	**BE(SKB)/BE(Ref.)**	**GSD(SKB)/GSD(Ref.)**
Reg. Low	Prior fr. Pop.	> 1	< 1
Reg. MidUp	Prior fr. Pop.	> 1	< 1
Marine SPM	Prior fr. Sub.	>≈ 1	No referenced data
Lake SPM	Prior fr. Sub.	= 1	= 1
Ratios between compartments		**BE(C1)/BE(C2)**	**GSD(C1)/GSD(C2)**
Lake SPM/Reg. MidUp		<≈ 10	= 1
Marine SPM/Reg. MidUp		<< 1	>> 1
Marine SPM/Lake SPM		<< 1	>> 1
Reg. Low/Reg. MidUp		> 1	≈ 1
Comments			
The values are not conservative in Regolith Low and MidUp because the BE values are higher than literature values and GSD values are lower. At the same time, the very low level of the ratio Marine SPM/Reg. MidUp suggests that the BE value for surface sediments in the marine environment is overestimated.			

Tc

BE and GSD values *vs* referenced data			
Compartment	**Origin**	**BE(SKB)/BE(Ref.)**	**GSD(SKB)/GSD(Ref.)**
Reg. Low	TRS472	= 1	= 1
Reg. MidUp	TRS472	= 1	= 1
Marine SPM	Beresford et al. (2007)	= 1	No referenced data
Lake SPM	TRS472	= 1	No referenced data
Ratios between compartments		**BE(C1)/BE(C2)**	**GSD(C1)/GSD(C2)**
Lake SPM/Reg. MidUp		1 < and < 10	> 1
Marine SPM/Reg. MidUp		> 10	> 1
Marine SPM/Lake SPM		> 1	> 1
Reg. Low/Reg. MidUp		<< 1	> 1
Comments			
No comments			

Th

BE and GSD values *vs* referenced data			
Compartment	**Origin**	**BE(SKB)/BE(Ref.)**	**GSD(SKB)/GSD(Ref.)**
Reg. Low	Prior fr. Pop.	> 1	> 1
Reg. MidUp	Prior fr. Pop.	>> 1	= 1
Marine SPM	Prior fr. Pop.	< 1	No referenced data
Lake SPM	Prior fr. Pop.	>≈ 1	< 1
Ratios between compartments		**BE(C1)/BE(C2)**	**GSD(C1)/GSD(C2)**
Lake SPM/Reg. MidUp		1 < and < 10	> 1
Marine SPM/Reg. MidUp		> 10	> 1
Marine SPM/Lake SPM		> 1	> 1
Reg. Low/Reg. MidUp		<≈ 1	>> 1
Comments			
No comments			

U

BE and GSD values *vs* referenced data			
Compartment	**Origin**	**BE(SKB)/BE(Ref.)**	**GSD(SKB)/GSD(Ref.)**
Reg. Low	Prior fr. Pop.	> 1	< 1
Reg. MidUp	Prior fr. Pop.	> 1	< 1
Marine SPM	Prior fr. Pop.	>≈ 1	No referenced data
Lake SPM	Prior fr. Pop.	>> 1	No referenced data
Ratios between compartments		**BE(C1)/BE(C2)**	**GSD(C1)/GSD(C2)**
Lake SPM/Reg. MidUp		= 1	> 1
Marine SPM/Reg. MidUp		<< 1	< 1
Marine SPM/Lake SPM		< 1	< 1
Reg. Low/Reg. MidUp		< 1	= 1
Comments			
The values are not conservative in Regolith Low and MidUp because the BE values are higher than literature values and GSD values are lower.			

Zr

BE and GSD values *vs* referenced data			
Compartment	**Origin**	**BE(SKB)/BE(Ref.)**	**GSD(SKB)/GSD(Ref.)**
Reg. Low	Prior fr. Pop.	= 1	<< 1
Reg. MidUp	Prior fr. Pop.	> 1	< 1
Marine SPM	Prior fr. Pop.	< 1	No referenced data
Lake SPM	Prior fr. Pop.	> 1	No referenced data
Ratios between compartments		**BE(C1)/BE(C2)**	**GSD(C1)/GSD(C2)**
Lake SPM/Reg. MidUp		= 10	> 1
Marine SPM/Reg. MidUp		> 10	< 1
Marine SPM/Lake SPM		> 1	> 1
Reg. Low/Reg. MidUp		< 1	<< 1
Comments			
The values are not conservative in Regolith Low and MidUp because the BE values are higher than, or equal to, literature values and GSD values are lower.			

2.3.3. CR values

For the compilation of CR values 29 elements are considered for 19 food/wildlife categories. However, 17 CR values are actually derived for each element as terrestrial berries, primary producers and pasturage are all assumed to have the same CR .Transfer parameters describing radionuclide transfer to foodstuffs and other organisms in TR-10-07 are normalised to carbon contents. In terms of estimating radionuclide activity concentrations in foodstuffs this has no impact. The approach is taken because productivity and human food intakes are defined in terms of carbon within SR-Site.

Two types of CR value (both normalised to C) are used in SR-Site:

1. For most organisms the CR value relates the activity concentration in edible tissues to that in the relevant environmental media (i.e. soil for terrestrial ecosystems and water for aquatic ecosystems)
2. For game animals the CR relates the activity concentration in edible (or soft) tissues to that in the assumed diet.

Although subsequently included in the consideration of CR values, the activity concentrations in milk and beef are predicted using transfer coefficients (i.e. the ratio of the activity concentration of a radionuclide in milk or meat to the daily intake of that radionuclide).

Sources of CR values used in the assessment

Whilst site data are used to derive CR values the majority of values used in SR-Site are taken from the literature or use literature values in combination with site data to derive best estimates and PDF using Bayesian inference. In the next sub-section, we focus on the sourcing of data values from the literature. Subsequently, we discuss some CR values in more detail.

Use of literature sources

The literature from which CR values were sourced was preferentially based on either IAEA (2010) or Beresford et al. (2007) depending on which had used the highest number of data to derive a CR value. If these references did not give a CR value then Karlsson & Bergström (2002, SKB R-02-28) was used. The only exceptions to the use of these three reviews were six mushroom CR values sourced from Avila (2006a; SKB report R-06-81) and two CR values for I from Robens et al (1988). No terrestrial herbivore values were derived from literature sources.

The literature source for the highest number of CR values (n=112) derived solely from the literature is the SKB review of Karlsson & Bergström (2002, R-02-28) referred to here as R-02-28. The number of CR values using this SKB review for: (i) different element and (ii) different categories is shown in Table 5. When considering the different food sources or target organism groups, R-02-28 is a key literature source for animal products and also terrestrial plants, but is not so important for aquatic CR values. It provides all the CR values for three elements: Ac, Pa and Pd. The 'original' source of the values for each element is considered individually in R-02-28 and where appropriate to values subsequently recommended in TR-10-07 these are discussed below.

Table 5: Number of CR values based solely on the review of Karlsson & Bergström (R-02-28) presented by element and foodstuff/organism. The maximum possible element n is 16 as berries, pasturage and primary producers were always assumed to have same value).

Ac	Ag	Cd	Cl	Cm	Eu	Ho	Mo	Ni
15	5	3	2	2	6	7	3	3
Np	**Pa**	**Pd**	**Po**	**Se**	**Sm**	**Sn**	**Tc**	**Th**
2	15	15	1	5	6	9	2	1

Ecosystem	Foodstuff/wildlife	n
Terrestrial	Berries / pasturage /primary producers	5
	Mushrooms*	5
	Cereals	9
	Root crops	12
	Vegetables	10
	Milk	15
	Meat	16
Freshwater	Phytoplankton	4
	Microphytobenthos	4
	Macrophytes	4
	Crustacean	3
	Fish	6
Marine	Phytoplankton	3
	Microphytobenthos	3
	Macrophytes	3
	Fish	5

* same values assumed as for berries/pasturage/primary producers .

For three elements, Ac, Pa and Pd the source information in R-02-28 follows a general pattern that often occurs for elements which have received little attention in the past. Generally, the values presented are based on rather old review reports or descriptions of models where either analogue values are quoted or it is unclear whether values for analogue elements are used.

For example, for Ac, CR values for plants were based on Bergstrom & Nordlinder (1990a) which used values for Am based on chemical similarity. The Am values were based on an early version of the database used in IAEA (1994) prepared by Frissel & Koster (1989). For Ac transfer to animal products, values from NCRP (1994) were used in R-02-28. The data tables in NCRP specify (as a general footnote to the table) the data source as a set of eight reviews, none of which seems to give actual data for Ac. Furthermore, some of the values reported in the early reviews of Ng cited by NCRP (Ng 1982; Ng et al 1977, 1982) give bibliographic numbers which cannot now be traced. The authors state that the values are "in accordance with those used in Davis et al (1993)" which is not surprising for milk as this reference refers to Ng sources (Ng et al 1977; Ng 1982) mentioned above. The values for aquatic data in R-02-28 also reference general articles recommending values where it is not clear whether there is actual data for the element considered.

Table 6: Number of CR values based solely on IAEA (2010) presented by element and foodstuff/organism. The maximum possible element n is 16 as berries, pasturage and primary producers were always assumed to have same value.

Ag	Am	Ca	Cd	Cl	Cm	Cs	Eu	I	Mo	Nb	Ni
2	9	5	2	3	5	5	1	3	2	5	3
Np	**Pb**	**Po**	**Pu**	**Ra**	**Se**	**Sr**	**Tc**	**Th**	**U**	**Zr**	
5	6	5	7	5	1	5	5	5	5	5	

Ecosystem	Foodstuff/wildlife	n
Terrestrial	Berries / pasturage /primary producers	7
	Cereals	19
	Root crops	17
	Vegetables	18
	Milk	14
	Meat	13
Freshwater	Macrophytes	3
	Crustacean	3
	Fish	5

It is not possible to trace back every value used from R-02-28 as some are difficult to access, and often there are multiple steps before the actual original source is finally located. However, some general comments can be made. If an analogue value has been used in R-02-28, it would be reasonable to expect SKB to have determined if more recent data for the actual element of concern were now available or if not investigate more recent data for all potential analogues, and especially for that used for the current value adopted. For example, for Ac, the IAEA (2010) grass CR values for Am could have been used rather than the pre-1989 values for Am from by Frissel & Koster (1989). Overall, a rather more critical evaluation of whether to use the values in TR-02-28 should have been applied.

The International Atomic Energy Agency's recent human food chain document 'TRS 472' (IAEA 2010) is the second most important sources of CR values (n=108) based solely on literature values; TRS 472 does not consider the marine ecosystem. It provides some CR values in TR-10-07 for all elements except Ac, Ho, Pa, Pd, Sm and Sn. TRS 472 is considered an authoritative, internationally recognised source of transfer parameter values. However, coverage of CR values for elements is variable with most values for Am, Pu and Cm. TRS 472 provides many of the plant product CR values in TR-10-07, about half of the animal product CR values and a few freshwater values. No mushroom values were derived from this source. The latter are for aquatic plants (macrophytes) and freshwater invertebrates used for crustaceans in TR-10-07. The number of CR values using this source for (i) different element and (ii) different categories is shown in Table 6.

The I value for root crops is from sub-tropical ecosystems as there are no data for I in the temperate ecosystem data tables in TRS 472. This is the only case where such data have been used. For the other plants, Robens et al. (1998) ^{129}I data from temperate systems has been used.

Table 7. Number of CR values based solely on Beresford et al. (2007) presented by element and foodstuff/organism. The maximum possible element n is 16 as berries, pasturage and primary producers were always assumed to have same value.

Ag	Am	Cd	Cm	Np	Po	Pu	Ra	Tc	Th
4	6	1	8	8	9	8	4	8	1

Ecosystem	Foodstuff/wildlife	n
Freshwater	Phytoplankton	6
	Microphytobenthos	6
	Macrophytes	3
	Crustacean	3
	Fish	7
Marine	Phytoplankton	8
	Microphytobenthos	8
	Macrophythes	8
	Fish	8

The third most important source of CR values (n=57) in TR-10-07 is the ERICA Tool (cited as Beresford et al. 2007). The ERICA Tool values were only used for aquatic ecosystems. For both aquatic ecosystems, it provided CR values for all the nine categories considered for Am, Cm, Np, Po, Pu, Ra and Tc. The number of CR values using this source for (i) different element and (ii) different categories is shown in Table 7. As the ERICA Tool is for wildlife assessment the CR values are for the whole body of the organism. Therefore the values must be converted to edible tissue for application in human assessment. There is a footnote to the relevant table in TR-10-07 stating this has been done is given for marine fish, but not freshwater fish. If freshwater fish have not been corrected then the whole body CR values will tend to overestimate the concentrations in muscle.

In addition to the use of literature data outlined above, the literature values have also been used in the Bayesian updating. The relative importance of the literature values varies depending on the Bayesian method used. For some element-category combinations, the number of data contributing to the GM is much higher than the number of site data. This is particularly true for Cs, but also occurs for some categories for Cd, Ni, Sr, Se, I, Pb, Ca, Th and U.

Overall, it is surprising that only five reference sources were used by SKB. Although TRS 472 and the ERICA Tool are relatively recent and valuable sources, in the absence of data from these two sources, it may have been advisable to seek out other literature sources or take more samples, especially when no site data were available or where the ERICA Tool itself uses CR values which were not derived from empirical data (e.g. TR-10-07 uses CR values from the ERICA Tool for Cm and Np which were taken from IAEA (2004)).

Terrestrial primary producers, pasturage, fungi and berries

TR-10-07 presents CR values for ‘terrestrial primary producers’ which amalgamates the entire site data available for vegetation (grasses, herbs, shrubs and green tree parts) collected from forests and mires. Analyses of the site data in R-10-28 showed that chemical concentrations in the different vegetation types subsequently included in ‘terrestrial primary producers’ were similar. However, CR values for terrestrial primary producers have then been assumed for two other vegetation categories: berries (see below) and ‘pasturage’.

The derived CR values for mushroom for application in SR-Site (see Table 4-6 of TR-10-07) are based on site specific data for 8 elements only. The remaining are based upon literature data for mushrooms (R-06-81) or in 16 cases on either site specific data for green vegetation or literature review data for ‘pasturage’ (grass). Elements for which the mushroom CR values have been derived using green vegetation or pasturage include Ag and Cd. However, fungi are known to concentrate a number of heavy metals including Ag, Cd, Cu, Hg and Pb (e.g. de Román et al. 2006; Pokorny et al. 2004); this is supported by the analyses of the site data presented in R-10-28 (page 85). Consequently, the assumption of grass CR values to predict activity concentrations in mushrooms is likely to be a considerable underestimate for some elements. This will result in reduced estimated of the intake of some radionuclides not only by humans but also game animals as kinetic-allometric models which include fungi ingestion are used to make predictions for these animals (see below). It is unclear why site specific data for green vegetation have been used to derive a mushroom CR in the case of Cd as there appear to be site specific data for this element in mushrooms (see Table D-6 of TR-10-07). The site specific mushroom CR for Cd have a GM of 15 (GSD=3.1; n=9) which is circa 20-fold higher than the green vegetation CR used for mushrooms in SR-Site (GM=0.79).

Where site specific data were available for mushrooms a CR has been derived using the Bayesian methodology for Cs alone. There is a large amount of data for Cs published in refereed journals and elsewhere on the (high) transfer of Cs to fungi. Despite this, the authors have selected to use aTR-06-81 as the source of prior (literature data) which appears to consider only 10 samples. In comparison, for example, Barnett et al. (1999) presents data for *c*.300 samples from a single study whilst Gillett & Crout (2000) review >500 literature values. However, correcting for carbon, CR values derived from Barnett et al. would be similar to that applied in SR-Site; Gillett & Crout would need further manipulation as they present transfer parameters relating fungi radiocaesium activity concentration to the radiocaesium activity per metre squared but values are likely to be within an order of magnitude of that used in SR-Site.

As no site data were available for berries were available they have been assigned the same CR values as terrestrial primary producers which represent grasses, shrubs herbs and the green parts of trees). This is justified in TR-10-07 on the basis that Sheppard et al. (2010) concludes that crops tend to have similar CR values as seed crops. However, fruits in Sheppard et al. are cultivated species (apple, pepper, tomato, cucumber, zucchini and water melon) and not wild berries. IAEA (2009) suggests that the transfer of radionuclides to berries (of wild plants) is high in comparison with that for agriculturally grown crops (although transfer parameters are only reported for Cs).

Game animals

CR values for game animals have been defined as the ratio of the carbon normalised activity concentration in meat to the carbon normalised activity concentration in the diet. Two game animals are considered moose and roe deer, the diet of the former is assumed to comprise 1% mushrooms and the rest to be terrestrial primary producers (i.e. grasses, herbs, shrubs and tree leaves/needle) whilst for roe deer mushrooms are assumed to comprise 14% of the diet. As noted above, it is likely that the radionuclide intake via fungi is underestimated for some elements when the CR of terrestrial primary producers is assumed. A weighted game animal diet composition is derived by weighting for the densities of the two species in Forsmark (63% moose and 37% roe deer) resulting in an assumption of 6 % mushrooms and 94 % terrestrial primary producers. This is not a conservative assumption; TR-10-07 states that conservative model parameters were applied for game animals for several elements.

Where site specific data are used to derive CR values for game animals then the data for all herbivorous species sampled including small rodents were used because the elemental concentrations were similar. This assumption is supported by the site data and literature (e.g. Howard et al. 2009).

Where no site data are available kinetic-allometric models are used to derive CR values. These have been adapted from models originally derived for assessment of the exposure of wild animals (e.g. Higley et al. 2002) which were parameterised to estimate whole body activity concentrations. Such models have been shown to give similar results as from equilibrium CR approaches (Beresford et al. 2009) although diet selection can add some uncertainty. The CR values are manipulated from whole body to soft tissue values; this is likely to produce conservative values for elements which concentrate in no dietary tissue (e.g. I accumulation in the thyroid).

3. The Consultants' overall assessment

The method applied by SKB to derive the CR and K_d values are based on a Bayesian approach that combines literature values with *in-situ*, on site data. Whilst the numbers of site data were often limited the authors have tried to make best use of these in combination with literature data by using the Bayesian updating. This relatively novel application of an established statistical approach to radioecology should be acknowledged. Similarly, the authors have attempted to make best use of all their site samples by taking into account results below the limits of detections. However, this cannot be fully appreciated in the manner presented.

Although alternative methods to select values exist, it would be difficult to identify whether these methods give better results because the high variability of K_d and CR values (often several orders of magnitude) means that it is important to use conservative criteria in both their selection, and in how they are used in an assessment. The determination of these conservative criteria is only possible if we adequately understand their impact on the outcome of the model as a function of the different transfer and exposure pathways. For example, the use of a low K_d value derived for suspended particulate matter in aquatic systems will be conservative for pathways linked to water, but the reverse is true for pathways linked to sediments. Therefore, addressing the question "what the best value to use in this case?" we can only comment that models based on best estimate values will be necessarily limited and that models giving results in terms of probabilities and uncertainties are recommended.

SKB have defined a conceptual model for application in SR-Site which includes a variety of terrestrial, freshwater and marine foodstuffs. However, their sampling strategy does not reflect their conceptual model. If freshwater crustacean, berries, agricultural products etc. are required in the model as defined and an effort has been made to collected site specific data – why were not these included within the sampling strategy rather than in some instance organism not included in the model.

The BE CR values used in SR-Site will often result in less conservative assessments than if the literature data had been used. However, in many instances the literature values are based on few data and a focus on site specific values is in the spirit of the SSM recommendation (Xu et al. 2008). There does not appear to have been consideration given to deriving conservative values when analogue approaches are used. Derivation of conservative analogue values may have been more appropriate than acknowledging that values likely to under predict have been selected (e.g. freshwater phytoplankton).

Comparisons of SKB K_d values (BE and GSD) with literature data showed that K_d values in the Regolith Low and MidUp are systematically equal or higher than K_d values in literature. Such high K_d values in these compartments will increase the transfer times from the geosphere to the biosphere. Also BE values are often accompanied with GSD values lower than literature data. This issue concerns Ca, Cs, Pb, Ra, Sr and U in Regolith Low and Ag, Cs, Ra, Sn, Sr, Th, U and Zr in Regolith MidUp. For these different cases, the application of GSD for the IAEA values or determination of GSD values as a function of the IAEA BE/GSD ratios would be preferable.

The ratio of the K_d values used by SKB values between different compartments (Lake SPM vs Reg. MidUp; Marine SPM vs Reg. MidUp; Marine SPM vs Lake

SPM; Reg. Low vs Reg. MidUp) has been evaluated. Several BE values are probably too high: notably in Regolith MidUp for Ag, in marine sediments for Am, in Regolith Low and MidUp for Cs and in Regolith MidUp for I. Conversely, BE value in aquatic sediments (limnic and marine) seem low for Pu.

Several inconsistencies were seen associated with the grouping of the Regolith Mid and Up compartments. For example, it appears in many cases that there is a need to specifically consider organic soils and sediments for marine and limnic systems rather than attributing the same parameterization to all Regolith MidUp compartments. Organic soils, marine sediments and limnic sediments should be considered individually and not grouped in the same modeling compartment.

Literature values are used to provide a large number of the CR and K_d values, either directly or via Bayesian updating. However, relatively few literature sources have been used with a reliance on three published reviews. As highlighted above, some of the values used are now rather old and, if they can be traced back, are sometimes not for the actual element the value is being used for. In these circumstances, more recent data should have been identified, either for the element itself or appropriate analogues.

The importance of improving the literature values used, or the need to acquire actual data for the element in their absence, depends on the anticipated doses for the particular radioisotope. Sensitivity analysis or assuming highly conservative values and running the model should allow a sensible decision to be made as to whether this is justified.

4. References

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Coverage of SKB reports

Reviewed report*	Reviewed sections	Comments
TR-10-07	All	Main focus of this report with R-10-28
R-10-28	All	Main focus of this report with TR-1-07
TR-11-01vol3	13	For overview of SR-Site
TR-06-08	3	For derivation of allometric models in TR-10-07
TR-10-08	All	Non-human assessment – not considered in this report. CR values for non-human assessment are evaluated separately
R-02-28	All	Source of many parameters values reviewed
TR-10-06	-	For appreciation of LDFs
TR-10-09	Various	For overview of SR-Site

*See References above for full details of reports

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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 315 employees with competencies in the fields of engineering, natural and behavioural sciences, law, economics and communications. We have received quality, environmental and working environment certification.

Strålsäkerhetsmyndigheten
Swedish Radiation Safety Authority

SE-171 16 Stockholm
Solna strandväg 96

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

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