SKB's response to additional question from the NEA IRT

In an e-mail forwarded from SSM, dated 3 February 2012, the NEA IRT has put the following, final question to SKB as part of the on-going review of the safety assessment SR-Site:

"*Given the conservative assumptions and data SKB uses in its assessment of the performance of the proposed repository, please describe if and in what manner those conservative assumptions bias the repository system understanding and the results of the SKB performance analyses. For example, if a "best estimate" set of assumptions and data were used, would there be a difference in the dominant radionuclide(s) contributing to dose, or the relative importance of various "barriers" (e.g, bentonite buffer, bentonite backfill, copper canister, spent fuel dissolution rate, radionuclide transport through the backfill and geosphere, biosphere dose conversion factors)?*"

The following response to the IRT question has been informally reviewed by all relevant members of the SR-Site team.

Introduction

The repository system understanding emerging from the safety assessment SR-Site can be summarised as follows (quotations of two paragraphs in section 15.3.2 of the SR-Site main report):

"*The analyses in SR-Site indicate that containment is maintained even in the one million year perspective for a vast majority of canisters. Deterioration of the barrier system to the extent that containment is lost is assessed to only occur, as a statistical average, for less than one canister due to buffer erosion leading to advective conditions and enhanced corrosion. The other failure mode that could not be ruled out, that due to earthquake-induced secondary shear movements in fractures intersecting deposition holes, is even less likely and affects on average considerably less than one canister when this failure mode is evaluated statistically with a number of pessimistic assumptions. This means that containment is assessed to be maintained for the vast majority of the 6,000 canisters throughout the assessment period.*"

"*Both the failure mechanisms that could not be ruled out are of the common mode type, i.e. the canister, the buffer and the rock are all affected, either through a detrimental shear movement or through a high flow rate in the geosphere, affecting both erosion and corrosion. The causes of the failures affect also the retention properties through high flow rates and, in the case of erosion, through the absence of the buffer after failure. Hence the retarding potential of the repository is limited in these particular cases, for the canisters that have failed. Instead, safety is to a considerable extent achieved through the slow dissolution of the fuel and, to a lesser extent, through the limited corrosion rate of radionuclide-containing metallic structural parts of the fuel elements.*"

The system understanding is hence that a vast majority of canisters in a KBS-3 repository at Forsmark will maintain their integrity also in a million year perspective and that the two failure modes that could not be ruled out are of the common mode type. It is also noted that it is essentially the spatial

Svensk Kärnbränslehantering AB
Swedish Nuclear Fuel and Waste Management Co
PO Box 250, SE-101 24 Stockholm
Visiting address Blekholmstorget 30
Phone +46-8-459 84 00 Fax +46-8-579 386 10
www.skb.se
556175-2014 Seat Stockholm

variability of the natural system that causes the differences between canisters in the repository. The canisters for which failure cannot be ruled out are those located in positions where the groundwater flow rate is at the extreme high-end tail of the distribution and/or in positions intersected by the largest fractures in the stochastic discrete fracture network.

The two failure modes have been pessimistically assessed in SR-Site in order to demonstrate compliance with the regulatory risk limit with a high degree of confidence. There is, however, also a wealth of information in the SR-Site report that shows the behaviour of the system under less pessimistic assumptions. In the following, a summary of such results is given with the view of discussing the effects of the pessimistic assumptions made in the compliance demonstration.
An attempt to define a "best estimate" case, as mentioned in the IRT's question, is made for the corrosion scenario, but not for the shear load scenario since *i*) the former dominates the calculated risk and *ii*) the basis for defining a best estimate case is less developed for the latter.

System behaviour for the erosion/corrosion scenario

Buffer erosion and canister corrosion

The only situation in which canisters are assessed to fail due to corrosion is one where the buffer's protective function has been lost due to erosion. The extent of the erosion process is assessed in sections 10.3.11 and 12.2.2 of the SR-Site main report.

After consideration of all uncertainties affecting the erosion process, the assessment is summarised as three different cases: No erosion, erosion according to the SR-Site erosion model and a bounding, pessimistic case of advective conditions in all deposition positions from the time of deposition, see section 12.2.3. The latter case is used in the compliance demonstration. If a "best estimate" case were to be selected, the "middle" case where erosion occurs according to the SR-Site erosion model is deemed reasonable – motivated by the evaluation of uncertainties in section 10.3.11 sub-heading ”Identified uncertainties and their handling in the subsequent analysis" and in section 12.2 that demonstrate that both lower and higher extents of erosion are conceivable. A number of factors affect the extent of erosion calculated with this "best estimate" model. These are evaluated in section 12.2.2, subsection "Quantitative sensitivity analysis of buffer erosion/colloid release". Based on the discussion in that section, the semi-correlated base case in Figure 12-3 is deemed reasonable to use as a "best estimate" case.

Concerning the extent of enhanced corrosion when advective conditions have arisen in the deposition hole, this is controlled essentially by the hydrogeological conditions and the groundwater concentration of sulphide, as evaluated in sections 10.4.6, 10.4.9 and 12.6.2 of the SR-Site main report. In consistency with the erosion analyses, the semi-correlated hydrogeological model is deemed reasonable to use for a discussion of a best estimate case. The sulphide concentration is in SR-Site treated probabilistically and based on measured concentrations at the Forsmark site. This is seen as a reasonable approach. It is, however, noted that assuming that the concentrations vary over time such that the temporal variation at a certain position would correspond to the spatial variability over the site at repository depth today, would result in no failed canisters (second case from left in Figure 12-17 of the SR-Site main report).

The "best estimate" case selected above results in a mean value of 0.12 failed canisters in one million years as opposed to the value of 0.86 obtained for the case used in the compliance demonstration, see Figure 1 below (Figure 12-18 of the SR-Site main report). This is thus a moderate reduction of a failure rate that is already low in the more pessimistic compliance case.

Hydrogeological DFN model		Mean number of advectice positions (at 10^5 yrs)	Mean number of advectice positions at 10^6 yrs	Mean number of failed canisters (at 10^5 yrs)	Mean number of failed canisters at 10^6 yrs
Uncorrelated	Initial advection	(6000)	6000	(0.055)	1.2
	SR-Site erosion model	(1.2)	280	(0.004)	0.65
	No advection	(0)	0	(0)	0
Semicorrelated	Initial advection	(6000)	6000	(0.013)	0.18
	SR-Site erosion model	(0.6)	19	(0)	0.12
	No advection	(0)	0	(0)	0
Fully correlated	Initial advection	(6000)	6000	(0.043)	0.86
	SR-Site erosion model	(1.2)	19	(0.005)	0.57
	No advection	(0)	0	(0)	0

Figure 1. Mean number of advective deposition positions and mean number of failed canisters for the calculation cases identified as relevant for the corrosion scenario. The middle case within the ellipse may be seen as a best estimate for erosion and corrosion.

Dose consequence calculations

A number of cases of consequence calculations for the corrosion scenario are shown in Figure 13-40 of the SR-Site main report, reproduced as Figure 2 below.

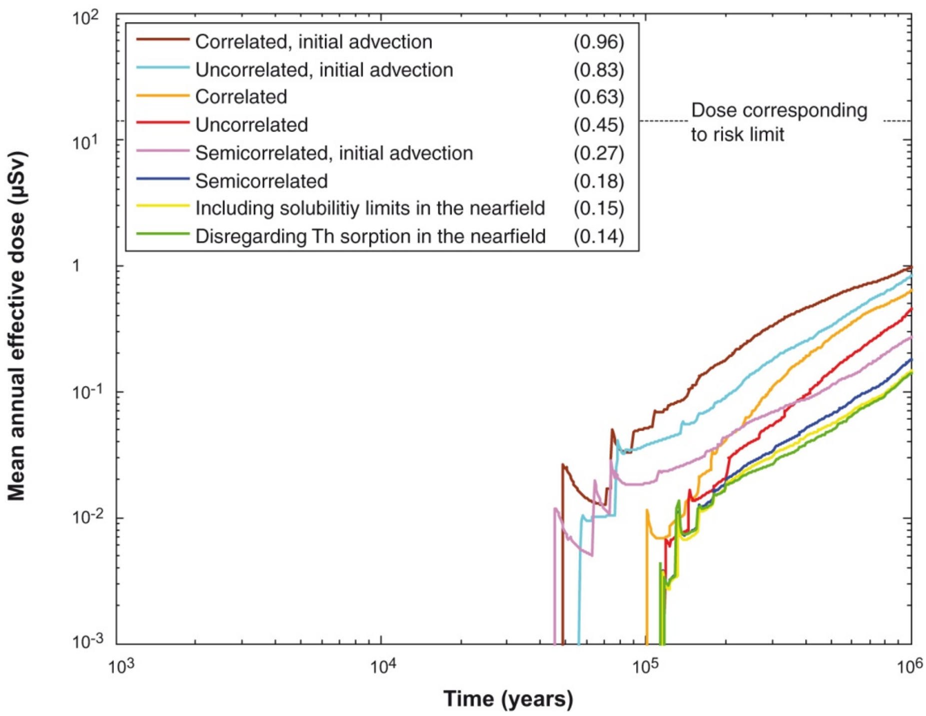

Figure 2. Summary of far-field mean annual effective dose for probabilistic calculations for the corrosion scenario. The peak doses are given in parentheses in µSv.

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As seen in the figure, the semi-correlated base case (the dark blue curve) yields a dose that is less than an order of magnitude below the pessimistic compliance case, i.e. the correlated case with initial advection (the brown curve). Assumptions underlying the transport cases are discussed in the following.

- Generally, the input data to the transport calculations are given as probability distributions established in the SR-Site Data report. These have been cautiously selected according to established procedures, but cannot be characterised as particularly pessimistic and should hence not bias the system understanding.

  - One possible exception to the above is the fuel dissolution rate in the very long term. The following is stated in section 13.5.5 of the SR-Site main report: "*Even though there is hardly any uncertainty in the fact that the radiolytic dissolution rate of spent fuel will decrease with time, the SR-Site model pessimistically neglects this decrease and assumes a constant dissolution rate, which varies within broad ranges to cover conceptual and other uncertainties.*" Since the fuel dissolution rate is the main determining factor for the radionuclide release rate from the near field, it could be argued that a "best estimate" fuel dissolution rate would be even lower than the lowest value (the fraction 10^{-8} / year) in the distribution used in SR-Site. No attempt was, however, made in SR-Site to substantiate such a value.

- For reasons given in section 13.5.2, subsection "Radionuclide release", solubility limits are cautiously not taken into account in the erosion/corrosion scenario. A variant case where solubility limits, including the effects of co-precipitation of radium with barium, are taken into account is also calculated. As seen in the resulting yellow curve in Figure 2, the reduction relative to the semi-correlated case is very minor. This is another effect of the common underlying cause of high erosion rate, high corrosion rate and low geosphere retention in a few deposition positions, namely the high groundwater flow rate at these positions. The high flow rates renders the solubilities ineffective as limiting factors for outward transport of radionuclides from the deposition positions since the solubilities are, in most cases, never reached due to the high water turn-over in the deposition holes. The assumption of neglected solubility limits, including co-precipitation of radium and barium, is thus not seen as biasing the understanding of the system. As seen in the more detailed figures 13-24 and 13-25 of the SR-Site main report, this also applies to all important nuclides and not only the dominant Ra-226.

- Containment by the insert and by the fuel cladding when the copper canister has failed is neglected. This is, however, not seen as biasing the results significantly since the copper corrosion failure times are of the order of 100,000 years and this is long compared to any containment time that could be substantiated for the cladding or the insert at the deposition positions under consideration.

- Regarding the modelling of the dose conversion factors summarised in section 13.2 of the SR-Site main report, the parameters describing transport and accumulation in the biosphere have generally been selected as "best estimate". However, for calculations of human exposure, conservative assumptions have been introduced to deal with uncertainties related to the use of contaminated land and water resources (in accordance with regulatory requirement).

  As the LDFs capture the consequences for the most exposed inhabitants (irrespective of exposure pathways, location in landscape and time), the analysis of LDF variation in sections 13.2.4-13.2.6 give good insight into what matters for "the worst case" dose, but may not give an unbiased picture with respect to underlying patterns in environmental concentrations of radionuclides. For example, the limited spatial and temporal variation for radionuclides where drinking water is the dominant pathway (Figure 13-9 in section 13.2.4), reflects the pessimistic assumption that a well is always assumed to be drilled into the release plume. Thus to deduce what factors are important for transport and accumulation of radionuclides in the biosphere (e.g. spatial and temporal variation, as well as the impact of individual parameters), LDF variation needs to be critically combined with the underlying information on sources and pathways of exposure.

- All dose curves shown in Figure 2 above are calculated under the assumption that present day, temperate conditions prevail throughout the one million year assessment period. The effect on system behaviour of a varying climate is illustrated in Figure 3 (identical to Figures 13-33 in section 13.5.6 of the SR-Site main report). The result demonstrates that the consequences for temperate conditions essentially form an upper bounding envelope of the more rapidly varying results of a time dependent climate.

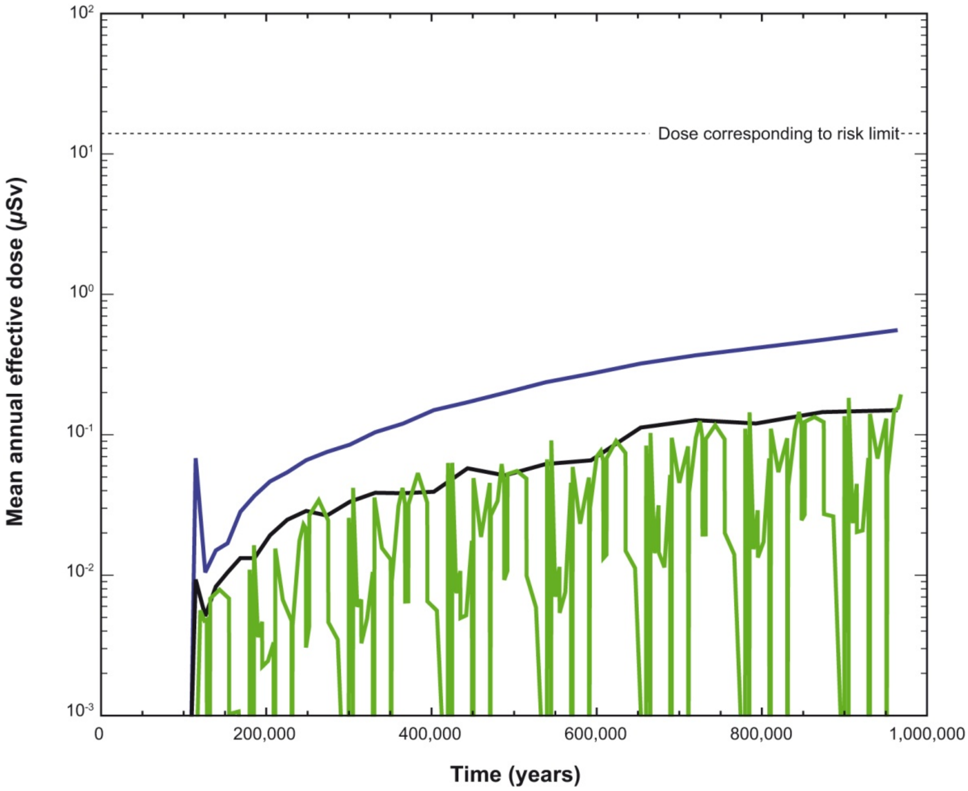

Figure 3. Expected doses with and without climate related flow changes for the semi-correlated case. The solid blue curve is the near-field release expressed as an annual effective dose. The black and green curves are far-field annual effective dose without and with flow changes, respectively. In addition to the flow, also the biosphere type is assumed to change in accordance with the varying climate when calculating the green curve.

In summary, it is our view that the data and assumptions used in the consequence calculations for canisters that have failed fail in the corrosion scenario essentially do not bias the understanding of the system for that scenario, and that this has been demonstrated by a reasonable set of calculation cases. To obtain the full view of the system understanding, not only the compliance case must be considered, but also the results of all variant cases and sensitivity analyses in the assessment.

For the vast majority of canisters that do not fail in the corrosion scenario, the system behaves differently. These canisters maintain their containment potential, and, as summarised in section 15.3.2 of the SR-Site main report, for these canisters "*...retardation is a latent safety function throughout the assessment period. A more general view of the retarding potential of the buffer and the host rock is obtained from the analyses of hypothetical, complete losses of barrier functions in Section 13.7.3.*" The results of those analyses also form an essential part of the system understanding since they demonstrate the retention function over the entire ensemble of canister positions. From the results of the postulated, hypothetical failures, it is e.g. obvious that other nuclides than Ra-226 may dominate the dose, and that both the buffer and the host rock provide considerable retention for many of the hypothetical failure cases.

Finally, it is important to bear in mind that a case where no erosion-induced advective conditions arise is included among the cases considered in SR-Site. Further research could well lead to a considerably strengthened support for this case where no canisters fail and where there are thus no consequences in the corrosion scenario.

System behaviour for the shear load scenario

In the shear load scenario, the likelihood of canister failures due to earthquake-induced secondary shear movements in fractures intersecting deposition positions is evaluated as are the consequences should such a failure occur. A number of pessimistic assumptions are made in the assessment of the *likelihood* of this failure mode, see e.g. sections 12.8.2 and 12.8.3 of the SR-Site main report for an elaborate discussion. In short, the pessimistic assumptions are:

- Shear-movement-induced *local* deformations in the canister insert that exceed criteria for local fracture propagation in the insert are assumed to always lead to *global* failure of the insert.
- No credit is taken for the containment capacity of the ductile copper shell once the insert is assumed to have failed.
- All shearing fractures are assumed to intersect the canister at the most unfavourable point and angle.
- The DFN model version that results in the largest number of potentially damaged canisters is used.
- The primary earthquake is assumed to occur on the deformation zone in the repository that affects the largest number of canisters and the largest earthquake compatible with the size of this zone is assumed.
- If a second, large earthquake occurs, it does so on the same zone as the first, and its induced secondary movements are pessimistically assumed to be parallel with those of the first.

Less pessimistic assumptions regarding the above factors would result in reductions of the calculated mean number of failed canisters in the shear load scenario, which was pessimistically determined to be 0.079 at one million years in SR-Site.

Regarding the *consequence calculations*, the modelling is similar to that of the corrosion scenario, with one significant exception: Advective transport times and retention in the geosphere are completely neglected since no attempt was made to characterise the transport characteristics of a deposition-hole-intersecting fracture after a major shearing event. A less pessimistic handling could potentially demonstrate that geosphere transport and retention are significant at least for early releases that are dominated by short-lived nuclides. (In contrast to the corrosion scenario, early releases cannot be entirely excluded for the shear load scenario, see Figure 13-49 in section 13.6.2 of the SR-Site main report.)

In summary, further work is likely to demonstrate that the system performs better than documented in SR-Site with respect to the likelihood of shear load failures and with respect to the retention properties of the geosphere for an early shear load failure. A probabilistic assessment of the response of the buffer/canister system to shear loads is underway and expected to contribute to an improved system understanding.

It is noted that the maximum risk pessimistically calculated for the shear load scenario is about two orders of magnitude below the regulatory risk limit.

For the vast majority of canisters that do not fail in the shear load scenario, the same arguments regarding system understanding as given above for the corrosion scenario apply.

Conclusions

The compliance cases in SR-Site show the system behaviour for deposition positions with properties at the extreme high-end tails of the distributions representing the entire ensemble of deposition positions at the Forsmark site. Also, a number of pessimistic assumptions are made in the compliance cases in order to demonstrate safety with a high degree of confidence.

As implied in the IRT's question, these deposition positions and the pessimistic assumptions are not seen as representative for the system in general. While the compliance cases are bounding, the discussion in this document demonstrates that the material in SR-Site allows *i*) definition of "best estimate" cases giving a more reasonable view of system functioning for the extreme deposition positions, in particular for the corrosion scenario and *ii*) a discussion of system behaviour for the entire ensemble of deposition positions.

The consequences for the best estimate case of the corrosion scenario is about an order of magnitude below that of the compliance case, with the same dominating nuclide (Ra-226) and the same type of safety function losses, but occurring to a lesser extent.

The system functioning for the vast majority of canisters that do not fail demonstrates the multi-barrier concept of the KBS-3 repository at the Forsmark site. For most of these deposition positions, all safety functions related to containment are fulfilled, throughout the assessment period, for the canister, the buffer and the host rock as demonstrated most extensively in the reference evolution (chapter 10 of the SR-Site main report) and retardation is a significant latent safety function as demonstrated in the analyses of hypothetical, complete losses of barrier functions in section 13.7.3 of the main report.