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Additional information requested by the IRT at December hearings

This note concerns two issues on which the NEA IRT required additional information at the hearings held with SKB in December 2011: *i*) an analysis of the confidence in the mean number of failed canisters (relating to the confidence in the high-end tails of hydrogeological flow distributions) for the three hydrogeological conceptual model variants and *ii*) a more detailed account of the additional "what if" case of canister corrosion and radionuclide transport calculated in response to IRT hearing question #11.

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1 Confidence in high-end tails of the hydrogeological flow distributions

Introduction

Only the high-end tails of the flow distributions of the three hydrogeological model variants contribute to canister failures due to corrosion in the analyses reported in SR-Site. Only a limited number of realisations have been made of each hydrogeological model variant. During the course of the hearings, the IRT requested an analysis of the confidence in the mean values obtained with the limited number of realisations. This analysis is provided in the following.

Analysis

Table 1 shows, for each realisation of each of the three hydrogeological model variants, the number of deposition positions that have sufficiently high flow rates to cause canister failure due to corrosion, assuming that advective conditions prevail in the buffer throughout the assessment period. These are thus the number of positions for which failure would occur if the highest sulphide concentration considered in SR-Site ($1.2\cdot10^{-4}$ M) would prevail throughout the assessment period.

The following is noted:

- The mean number of failed canisters is determined also by the distribution of sulphide concentrations. Since the issue under consideration is the confidence in the high-flow tail of the output from the hydrogeological model, the relevant part of the hydrogeological distribution is captured by using the highest sulphide concentration when determining a lower limit of the high-end tail of the flow distribution.
- The total number of deposition positions in the hydrogeological model was 6,916 before rejection according to the EFPC criterion. The number of remaining positions after rejection varied slightly around 6,000 between realisations. The results were scaled to exactly 6,000 in the compliance calculation, but this minor correction is not considered in the following, for simplicity.

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Table 1. The number of deposition positions with sufficiently high flow rates to cause failure within 10^6 years in the corrosion scenario. The results of each realisation of the three conceptual model variants are shown in the table.

Hydrogeological conceptual model variant		
Fully correlated	**Uncorrelated**	**Semi-correlated**
15	47	5
17	49	7
60	52	3
33	42	1
33	42	4
		11
		3
		6
		5
		6

As seen in the table, and as reported in SR-Site, ten realisations were made of the semi-correlated hydrogeological model variant and five realisations of each of the fully correlated and the uncorrelated variants. In the SR-Site compliance calculations, the pooled results from all realisations of a particular model variant were used. It is then the mean value, taken over the realisations in question, that is of interest to determine the calculated risk.

The confidence in the mean value can be determined if the distribution underlying the resulting number of high-flow positions is known. Assuming simply that this is a normal distribution yields the 95 percent confidence limits shown in *Table 2*.

Table 2 Statistical analysis of the data in Table 1, assuming a normal distribution.

	Hydrogeological conceptual model variant		
	Fully correlated	**Uncorrelated**	**Semi-correlated**
Number of realisations, *N*	5	5	10
Student's *t* distribution, $t_{0.025,\ (N-1)}$	2.78	2.78	2.26
Mean value, *m*	31.6	46.4	5.1
Standard deviation, *s*	18.0	4.4	2.7
Lower 95% confidence limit*	9.2	40.9	3.2
Upper 95% confidence limit*	54.0	51.9	7.0

*The lower and upper confidence limits are obtained as $m \pm t_{0.025,(N-1)} \cdot s/\sqrt{N}$

As an alternative, a log-normal underlying distribution was tried with the following motivation: In a related problem, namely the determination of the number of canister positions intersected by large fractures in a geological discrete fracture network described by a similar mathematical model as the hydrogeological models, it was demonstrated that the resulting distribution is to a good approximation log-normal /Hedin, 2008/. Also in that case, the fracture lengths are Pareto distributed and the task is to identify the typically less than one percent of the canister positions intersected by the largest fractures. A log-normal distribution also has the obvious advantage of only taking on non-negative values.

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In this alternative evaluation, the statistics measures were determined assuming that the logarithm of the data in *Table 2* are normal distributed and the resulting 95 percent confidence limits were then transformed to linear space. The results of this analysis are shown in *Table 3*.

Table 3 Statistical analysis of the data in Table 1, assuming a log-normal distribution.

	Hydrogeological conceptual model variant		
	Fully correlated	**Uncorrelated**	**Semi-correlated**
Number of realisations, *N*	5	5	10
Student's *t* distribution, $t_{0.025,\ (N-1)}$	2.78	2.78	2.26
Mean value (^{10}log data), m_{log}	1.44	1.66	0.640
Standard deviation (^{10}log data), s_{log}	0.245	0.0411	0.281
Lower 95% confidence limit (^{10}log)*	1.14	1.61	0.439
Upper 95% confidence limit (^{10}log)*	1.75	1.72	0.841
Mean value (lin), i.e. 10^{mlog}	27.8	46.2	4.36
Lower 95% confidence limit (lin)	13. 8	41.1	2.75
Upper 95% confidence limit (lin)	56.1	52.0	6.93

*The lower and upper confidence limits in ^{10}log space are obtained as $m_{\log} \pm t_{0.025,(N-1)} \cdot s_{\log} \big/ \sqrt{N}$

Finally, it is noted that the underlying distribution should in principle be discrete. The approximate nature of the two tried distribution becomes more obvious when the calculated number of high-flow positions in the realisations of the hydrogeological model are small integers. In particular, the logarithmic transformation of the data would break down for realisations with no high-flow positions.

Conclusion

As seen in the tables, the normal and the log-normal distributions yield similar upper limits of the 95 percent confidence intervals. *Figure 1* shows the result of each of the hydrogeological realisations, the resulting mean values used in SR-Site and the 95 percent confidence limits for the log-normal case. The upper 95 percent confidence limit is less than a factor of 2 above the mean value for the fully correlated case used in the compliance demonstration. This is seen as a strong indication that additional realisations of the hydrogeological model would not change any of the conclusions in SR-Site. This will be further verified by additional realisations of the hydrogeological models, a task that was not performed within the SR-Site project due to time constraints.

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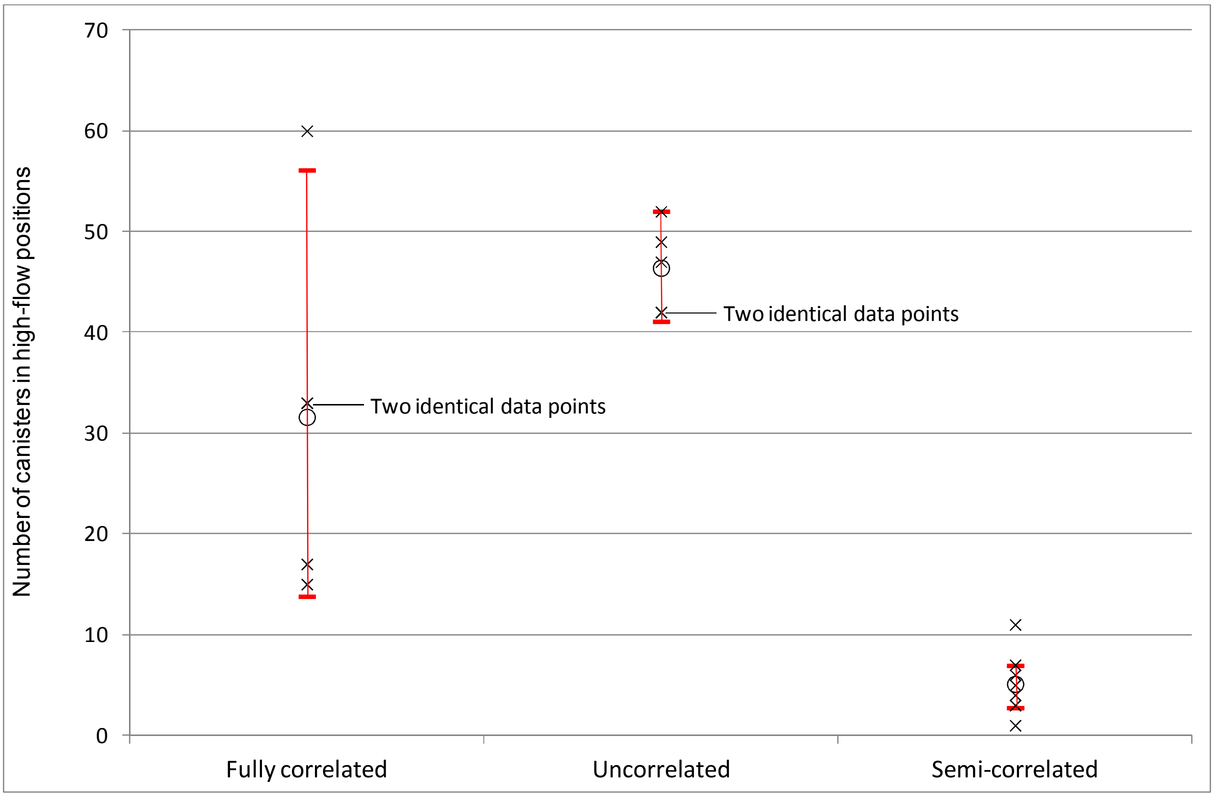

Figure 1. The data points in Table 1 (black crosses), the mean values of the data (black circles) and the 95% confidence limits of the mean value assuming a log-normal distribution (red intervals).

Reference

Hedin, 2008. Semi-analytic stereological analysis of waste package/fracture intersections in a granitic rock nuclear waste repository. *Mathematical Geosciences*, **40**, pp 619–637.

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2 "What if" case of canister corrosion

Introduction

In response to the IRT hearing question #11, a "what if" case of canister corrosion and resulting radiological consequences, additional to the cases reported in SR-Site was calculated. The purpose was to construct a case where of the order of ten canisters fail. In the following, this "what if" case is briefly documented.

Canister corrosion

The corrosion case is identical to case H in figure 12-16, section 12.6.2 in TR-11-01, except that the sulphide concentration was, for all canister positions, assumed to be the highest of the values in the distribution of sulphide concentrations ($1.2 \cdot 10^{-4}$ M).

The case thus implies that

- The fully correlated hydrogeological model is used
- Advective conditions prevail in all deposition positions throughout the one million year assessment time
- The sulphide concentration is $1.2 \cdot 10^{-4}$ M at all deposition positions and throughout the assessment time

The corrosion case was calculated with the same model as used for other corrosion cases with advective conditions in the deposition holes. The resulting mean number of failed canisters was 31.6 (as also reported in the above section regarding the confidence in the mean value). It is noted that if only the realisation of the hydrogeological model yielding the highest consequences would be used, the number of failed canisters would be 60 (see Table 1 above).

Radiological consequences

The dose consequences for the "what if" corrosion case were calculated using the analytical radionuclide transport models described in section 13.4.4 of the SR-Site main report TR-11-01. In section 13.5.10 of TR-11-01 it is demonstrated that the analytical models yield results very similar to those obtained with the more detailed but also considerably more computationally demanding numerical models.

All input data to the transport models, except the canister failure times and positions, were identical to the case with the fully correlated hydrogeological DFN model and advective conditions in the deposition hole. (That case is documented in sections 13.5.3 and 13.5.5 (subsection "Cases with initial advection in all deposition holes") of the SR-Site main report TR-11-01 and in section 4.7.2 of the SR-Site Radionuclide transport report TR-10-50.)

Regarding the landscape specific dose conversion factors (LDFs), values calculated for a release spread over the landscape objects according to the distribution of release locations over time during the modelled interglacial period are applied, rather than the basic LDFs where the landscape object yielding the highest dose is pessimistically used to represent the biosphere, see section 13.2.3 of the SR-Site main report, TR-11-01.

Figure 2 shows the resulting dose curves. As seen in the figure, the peak dose (7.7 μSv/yr) is about a factor of 2 below the dose corresponding to SSM's risk limit of 14 μSv/yr. Had it

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instead been assumed that the releases from all failed canisters would reach the landscape object yielding the highest dose consequences, i.e. using the same pessimistic LDF values as in most other SR-Site calculation cases, then the dose limit would be exceeded by about a factor of 2.

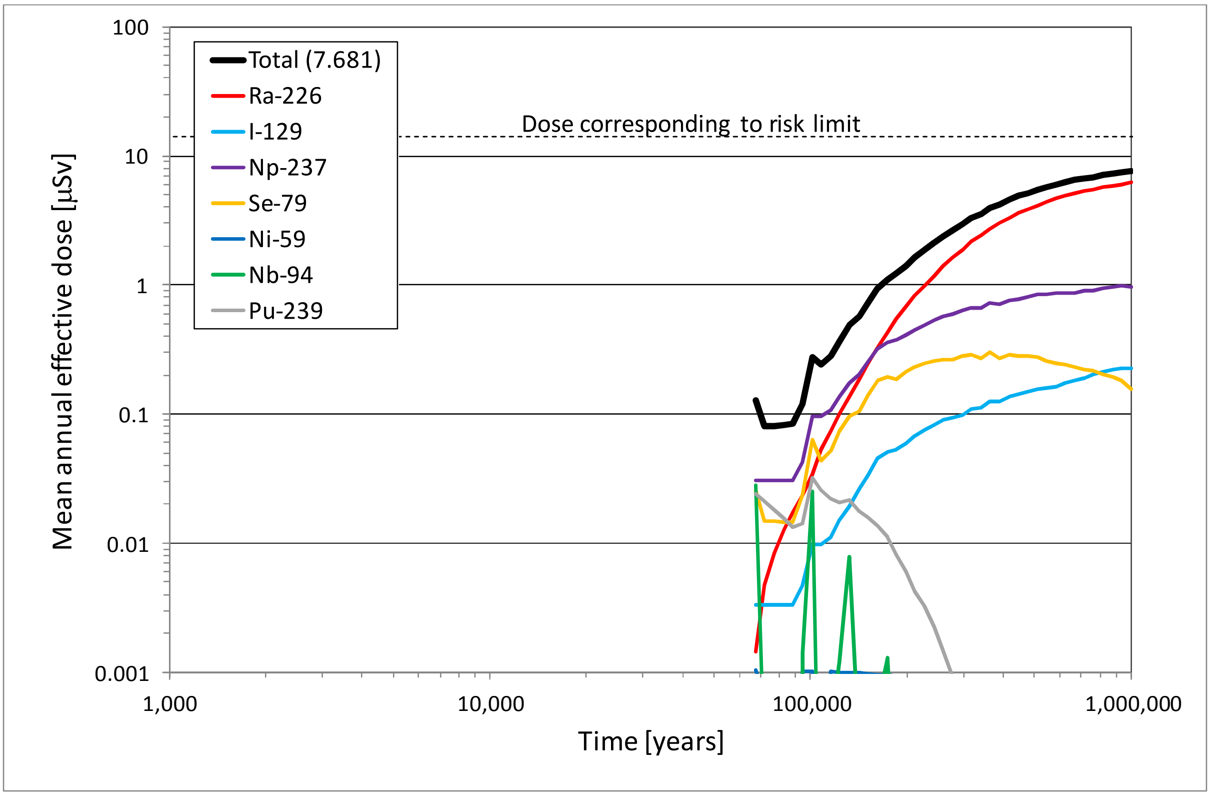

Figure 2 Dose consequences for the "what if" case of the corrosion scenario where both the maximum sulphide concentration and advective conditions is assumed in all deposition positions and where the fully correlated hydrogeological model is used.

Conclusion

It is concluded that, for the corrosion failure mode in SR-Site, a number of pessimistic and unrealistic assumptions are required to result in failure of a sufficient number of canisters to cause releases exceeding SSM's risk limit. The assumptions have no support in the scenario analysis where all routes to corrosion failure have been systematically investigated and uncertainties evaluated, and where a defensible approach with regard to compliance demonstration is then adopted when making assumptions and selecting data within the uncertainty range. Similar arguments can be put forward for the other scenarios analysed in SR-Site. The conclusion in SR-Site that a KBS-3 repository at the Forsmark site complies with the risk criterion is, therefore, seen as robust.

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