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Memo

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SKB's response to NEA's third questionnaire on post-closure safety in SKB's licence application

This document presents SKB's responses to the NEA international review team's third questionnaire on post-closure safety.

The responses are provided as part of the International Peer Review undertaken by OECD/NEA as requested by the Swedish Government of SKB's reporting on post-closure safety in the licence application for a spent nuclear fuel repository.

The responses provided are to the questions specified in the file "Third Questionnaire OECD NEA IRT October 7 2011.docx" obtained by SKB from SSM on October 11, 2011. NEA's brief introduction and the original questions are included in the text below. SKB's responses are given in bold after each question.

In the responses, references on the formats TR-xx-xx, R-xx-xx and P-xx-xx refer to SKB reports of the TR, R and P series, respectively. Many of these are included in the licence application and all are available at www.skb.se.

Regarding additional documents requested by the IRT or referenced in our responses:

- The report P-10-18 requested in Q 2.7.1 is now available at www.skb.se.
- The two documents requested in QFU 2.9.1 are written in Swedish and therefore presumably of little value to the IRT. They will be provided on request:
  - SKBdoc reference "1175208 - Tillverkning av kapselkomponenter" (Translated title: "Manufacturing of canister components")
  - SKBdoc reference "1179633 - Oförstörande provning av kapselkomponenter och svetsar" (Translated title: "Non-destructive testing of canister components and welds"). Much of the material in this reference can, however, be found in reference "1175236 - Reliability in friction stir welding of canister", that is provided in response to Q 2.9.1 (next bullet point)
- Together with this document, SKBdoc reference "1175236 - Reliability in friction stir welding of canister" is delivered in response to Q 2.9.1
- The English translation of R-10-08, requested in Q 2.8.15 of IRT's second questionnaire is now available at www.skb.se as R-11-14.
- The background report /Follin et al. 2006; P-06-54/, will be available at www.skb.se before November 11, 2011.

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Third Questionnaire of the OECD-NEA International Peer Review Team

1 Introduction

At the request of SSM, the OECD-NEA International Review Team (IRT) is examining the long-term safety aspects of the application by SKB for a construction license of a spent fuel repository in Sweden. It was anticipated that the written questions arising from IRT's review of the application would result in a total of three questionnaires. This is the third questionnaire.

This third set of questions is based on further study of SKB TR-11-01 Long-term safety for the final repository for spent nuclear fuel at Forsmark, main report of the SR-Site Project, Volumes I, II and III, and of supporting documentation prepared and provided by SKB. There are also some further questions that arose from the SKB's answers to IRT Questionnaire 2 (provided by SKB on September 6, 2011). These questions are identified as follow-up questions (QFU) to Questionnaire 2 in the present Questionnaire.

The questions in this third questionnaire are numbered as in Questionnaire 2 (but with (3) in the question number) and organized per IRT member in sections 2.1 through 2.9. Therefore, SKB may again find partial overlap in some of the questions, in which case the provision of one answer would suffice, providing that SKB indicates which questions are being answered in one response.

Note that the IRT would like to receive a number of reports (as specified by several of the reviewers in the following questions).

2 Questions from IRT Members

The IRT members encompass a diverse knowledge and experience set, and have reviewed the information in SKB TR-11-01 and supporting documentation from individual and unique view points. In order to reflect this diversity, the questions posed by each IRT member were not pooled together by subject but are presented as received from each individual IRT member. The questions were provided with a number and minor editing was applied.

2.1 Questions from IRT Member 1

2.1.1 Follow-up Questions to Questionnaire 2

QFU 2.1.1: Questions related to answer to Q 2.1.2
Is a 1 cm open slot between the canister and the bentonite blocks realistic for a feasible canister emplacement operation (especially under wet conditions)? Has this specific aspect of the canister emplacement operation already been demonstrated?

Yes, all full scale installations in the Äspö Laboratory have used the same gap width (1 cm).

QFU 2.1.2: Question related to answer to Q 2.1.5
The referenced report (TR-06-30) seems to be focused on mineralogical properties of a set of different bentonites, with little emphasis on hydraulic and mechanical properties. Is there any other SKB report more focused on thermal, hydraulic and mechanical performance of the two bentonite materials considered in SR-Site?

The hydraulic and mechanical properties of main interest for the long term performance, hydraulic conductivity and swelling pressure, are well covered in chapter 4 in TR-06-30.

Thermal as well as hydraulic and mechanical properties for unsaturated bentonite have not been studied systematically for alterative materials. The uncertainty in the boundary conditions (availability of water) has been judged to be of much more importance for the water saturation and the thermal evolution than the difference between the materials.

The stress/strain properties of the materials are documented in SKB TR-10-41.

QFU 2.1.3: Question related to answer to Q 2.1.8
Several laboratory tests performed on Febex bentonite (Ca-based bentonite) have shown that the final swelling strain (and hence the sealing capacity of the bentonite) decreases very significantly with increasing temperature. Question 2.1.8 was related to this aspect of bentonite performance. Has SKB analyzed the swelling strain evolution with time of the two selected materials for different temperatures and dry densities?

The swelling pressure and hydraulic conductivity of MX-80 have been investigated at different temperature for different dry densities (see e.g. TR 95-20) but not for the other material. The results have been used and confirmed in modelling of the wetting and homogenisation evolution of the field tests in Äspö HRL. No significant influence of temperature on swelling pressure was found and the hydraulic conductivity follows the viscosity change of water. Any direct measurements of the swelling strain at different temperatures have not been done but it is a function of the swelling pressure and the hydraulic conductivity so it can be predicted. In addition a possible influence of temperature (which was not found) will disappear when the temperature returns to ambient.

2.1.2 Questionnaire 3 Questions

No new questions for Questionnaire 3 from Reviewer 1

2.2 Questions from IRT Member 2

2.2.1 Follow-up Questions to Questionnaire 2

QFU 2.2.1: Questions related to answers to Q 2.2.7 and Q 2.2.12
There is no specification of further experiments given in the answers and/or the documents. What is the schedule and timetable of experiments and investigations to clarify the open questions referring to copper corrosion under repository conditions? The outlook by F. King at Eurocorr implies further actions but does not give any details.

The planned SKB research is described in SKB's RD&D Programme 2010 /TR-10-63, available at www.skb.se/ with focus on the period 2010-2013. The planned studies of copper corrosion are described in chapter 23. The main areas for research experiments and their extension in time will be:

- **the behaviour of copper in sulphidic solutions, including the suggested SCC effects i high concentrations (2011-2013)**
- **further attempts to better quantify microbial activity in compacted bentonite (2012)**
- **verifying the corrosion propensity for base metal (2011-2012), and welded and cold-worked copper (2013)**
- **measurements of possible hydrogen gas development from copper in pure, oxygen gas free water (2011-2012)**
- **studies of copper-bentonite interaction (2011-2012).**

More theoretical work will be performed on:

- **solubility of pyrite (2011)**
- **thermodynamic and kinetic (electrochemical impedance spectroscopy) studies of chloride solutions (2011-2012)**
- **quantum mechanical studies of copper surfaces in pure water and of the properties of copper compounds with hydrogen and oxygen (2011-2013)**

On-going long-term experiments relating to copper are the LOT project, the Minican project and electrodes mounted in the Prototype repository. For both, parts of the experiments are currently being dismantled and will be analysed during 2011-2012. Further experiments are being considered with the aim of providing an experimental environment that is as close as possible to the repository environment. The expected outcome of such experiments is primarily to verify the corrosion behaviour from lab experiments and theoretical calculations. It is, however, a challenge to design an experiment where the expected, very limited long-term corrosion rate of copper is observable in the presence of inevitable initial, short-term transient effects like the reaction of copper with residual oxygen.

Generally, it is expected that the outcome of the studies mentioned in the bullet points above will allow a less pessimistic treatment than in SR-Site of the phenomena in question, or further corroborate the assumption that the phenomena are of negligible importance for long-term safety.

QFU 2.2.2: Question related to answers to Q 2. 2.10 and Q 2.2.13
Due to the academic discussions about the effect of pure water on copper corrosion, the approach via calculations does not appear to be completely satisfying: How does SKB treat the experimental confirmation of the discussed effects? If hydrogen is produced: What might be the effect of hydrogen atoms and/or molecules to the surrounding barrier formed by bentonite? How does this affect the transport properties?

SKB is trying both to repeat Hultquist's experiments and to understand the behavior of copper in pure water, and several studies are on-going. The most important regarding

confirmation of the experimental results by Hultquist is the repetition of the gas experiment at Uppsala University (planned to be finalized in 2012). Furthermore, a test tube sealed with a palladium membrane, that was prepared 20 years ago (as an attempt to repeat Hultquist's test tube experiments 1986), has been analysed (to be finalised 2011), new tests with copper in test tubes are on-going, as well as attempts to synthesise CuOH, a possible corrosion product according to Hultquist's interpretation of his experiments. All these are to give experimental data to compare with more theoretical studies conducted as SKB research to describe the reaction mechanism, reaction products, thermodynamics and kinetics.

Still no reaction product more stable than Cu_2O has been found. A surface reaction that produces hydrogen is one possible way of explaining the measured hydrogen. Such a reaction would only produce a limited amount of hydrogen, and thus have limited effects in the repository. Furthermore, such a hypothesis is experimentally testable against the hypothesis put forward by Hultquist et al., and the design of the aforementioned gas experiment at Uppsala University allows such a test.

Hydrogen is indeed produced in the corrosion of copper by sulphide, and the effect of hydrogen gas on the buffer is discussed in the Buffer, backfill and closure process report, TR-10-47, section 3.3.3, and briefly in the SR-Site main report section 13.8 and section 14.4.4. As long as the hydrogen production rate is low, the gas will dissolve in the porewater and diffuse out of the buffer. This will always be the case before canister failure, even if copper corrosion and radiolysis are considered. At high production rates, e.g. when corrosion of the insert needs to be considered, a gas phase may form. Gas cannot be transported through bentonite at pressures below the swelling pressure. When the gas pressure exceeds the swelling pressure the bentonite will fracture and gas pathways will form. These pathways are however very unstable and will reseal when the gas pressure drops. Gas transport will therefore have no impact on the hydraulic properties of the bentonite barrier, see the Buffer, backfill and closure process report, TR-10-47, section 3.3.3.

Regarding chemical effects of hydrogen in the buffer, hydrogen could potentially reduce Fe(III) in the montmorillonite, but this effect is assumed to be small due to the low reactivity of hydrogen molecules.

QFU 2.2.3: Question related to answers to Q 2.2.14
The answer does not cover the question of giving a maximum value for the mechanical properties (hardness, residual stresses,…). There should be a procedure for the manufacturing of the canisters paying attention to cold working, influence of hest by welding and the possible deformation by surrounding rock movements. How would such a cold working influence the susceptibility to SCC?

Criteria for the maximum allowed cold work of copper during manufacturing as well as during transport and handling are currently being established, not only because of corrosion aspects but mainly to ensure the material properties required for the mechanical strength. The control parameters of the welding process will be required to be confined within pre-defined limits, in order for a weld to be accepted, see the SR-Site main report, section 5.4.2, p. 171 and references therein. Welded material will be further tested for corrosion properties (earlier tests are reported in SKB TR-06-01 and TR-07-

07). The same will be done for cold-worked material. Stresses in the copper canister induced by rock movements or otherwise is, furthermore, expected to be relaxed by creep in the copper. It is not argued that SCC in copper will be limited by the material itself, but rather by the very low possibility of simultaneous stresses, potential and detrimental ions.

2.2.2 Questionnaire 3 Questions

No new questions for Questionnaire 3 from Reviewer 2

2.3 Questions from IRT Member 3

2.3.1 Follow-up Questions to Questionnaire 2

No follow-up questions to answers in Questionnaire 2 from Reviewer 3

2.3.2 Questionnaire 3 Questions

New questions from Reviewer 3 are based on Reference Evolution (TR-11-01 Chapters 10.1 – 10.4): Thermal, mechanical and hydrogeological issues

Q 2.3.1 (3): p.296ff: The opening of the underground excavations will create a massive hydraulic sink with groundwater flow towards the excavations, a large scale change in hydraulic head fields, and a very significant reduction of pore pressures at the kilometer scale around the excavations. As shown in Zangerl et al. 2008a,b[1] such a pore pressure drawdown in fractured gneisses can cause significant surface deformations (in the order of 10 cm), shearing of pre-existing large scale fractures (indicated by surface displacements, but not definitely verified), and seismic activity (not yet published). Such scenarios could have an impact on the long term safety of the repository and possibly also on the nearby NNP (as long as the distance is a few kilometers only). Have such scenarios been considered?

An analysis has been made on the potential impacts on the nearby NPPs (SKB P-10-48, only in Swedish). The study concludes that displacements below the reactor foundation of the NPP Forsmark 1 would at maximum be less than 0.2 mm and that the maximum displacement between two turbine foundations would be in the order of 0.7 mm. Even if these displacements are small, the study recommends monitoring of groundwater pressure at few points between the shaft and the turbine hall. Such monitoring is now in effect.

[1] Zangerl, C., Eberhardt, E., Evans, K. and Loew, S. (2008). "Consolidation settlements above deep tunnels in fractured crystalline rock: Part 1—Investigations above the Gotthard highway tunnel." *International Journal of Rock Mechanics and Mining Science* ***45***: 1195-1211.
Zangerl, C., Evans, K., Eberhardt, E. and Loew, S. (2008). "Consolidation settlements above deep tunnels in fractured crystalline rock: Part 2 –Numerical analysis of the Gotthard highway tunnel case study." *International Journal of Rock Mechanics and Mining Science* ***45***: 1211-1236.

For long term safety, such scenarios have not been considered for two reasons. 1) The drawdown in the rock will be quite limited due to ample supply near the surface water and the very tight rock at depth. The following is stated on page 299 of TR-11-01: The modelled drawdown is relatively small with maximum values around one metre except for the central area (CA) of the repository, where a drawdown of around ten metres is obtained /Svensson and Follin 2010/. 2) Subsidence in crystalline rock with a very limited overburden cover is not a pronounced effect, and we have ample experience from such facilities in Sweden and Finland, including Äspö HRL and ONKALO at Olkiluoto in Finland.

Q 2.3.2 (3): p. 296: Figure 10-6a (left) shows anomalies cross-cutting the middle part of the tunnel. What is their origin?

This is a vertical fracture being part of the model used in the analysis, see Figure 10-19.

Q 2.3.3 (3): p. 299: What is the assumed lifetime of the grout? Is grouting only relevant for the excavation and operational phase?

Yes, the grout is only expected to maintain its sealing properties throughout the operational period.

Q 2.3.4 (3): p. 300 & p. 302: The model predicts inflow mainly at the boundaries of the repository. When comparing inflow predictions with encountered inflows in underground excavations, not only the rates but also the locations normally differ very substantially. Why can you rely (so much) on these simplified modeling results?

The reason the highest inflows are found mainly at the boundaries is related to the fact that the gradients are the highest at the boundaries of the repository footprint; i.e., inside the footprint, between tunnels, the gradients are lower, This is illustrated in Figure 5-10 in /Svensson and Follin, 2010, R-09-19/. Inflow locations are the result of stochastic realizations and the predictive capability has to be evaluated in this context. We do not claim that we can rely on these results to any greater extent than we rely on other model results. However, it is noted that the quantitative results from the modeling study presented in /Svensson and Follin 2010/ are not included in the compliance calculations of SR-Site. Thus, even if the results in /Svensson and Follin 2010/ would be associated with greater uncertainty than say hydrogeological model results from other phases/periods, this would not affect the final results of presented doses and risks.

Q 2.3.5 (3): p. 301: Systematic comparisons between modelled tunnel inflows and observed tunnel inflows[2] show that also the transient rates (not only the locations and steady state rates) deviate very significantly. Many real inflows show much more dramatic decreases in rate than the model predictions, mainly due to limited extent conductive fractures and possibly also some HM coupling. Has this been taken into account when the inflow rejection criterion was defined?

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[2] e.g. Masset, O. and Loew, S. (2010). "Hydraulic Conductivity Distributions Derived from Inflows
to 136 km of Tunnels and Galleries in Crystalline Rocks (Central Alps, Switzerland) " *Hydrogeology Journal* ***18***: 863-891.

HM couplings are not considered at all in the inflow calculations. The effect of a limited extent of fractures is indirectly included through the use of the derived hydrogeological discrete fracture network model where only connected and conductive fractures are included. We agree that real inflows tend to be lower than those predicted by a model of the present kind. The definition of the inflow rejection criterion is related to buffer mass loss and an associated maximum inflow rate (p. 300-301 of Main report). The fact that the inflow estimated by the model most likely is an over prediction is not taken into account. Hence the results are deemed conservative.

Q 2.3.6 (3): p. 319: In the Alps we observe a little ice age between 1250 and 1850 AD. Has such an event not also occurred in Fennoscandinavia?

Yes, the Little Ice Age (LIA) was present also in Fennoscandia. For example, it made glaciers grow larger in the Scandinavian mountain range, as observed by moraine ridges dated by 14-C and lichenometry. A climate warming of around 1 deg C occurred as the LIA ended and warmer Holocene conditions again took place. This climate change is encompassed by the description of the Holocene climate on p. 319 of TR-11-01 (e.g. "annual air temperature variability was up to around ±1 degree C").

(In addition, in south-central Sweden the cooling during the LIA was not sufficient for permafrost conditions. Hence, the conditions at Forsmark were, also for the LIA period, defined as *temperate climate domain* (this climate domain is in SR-Site defined as conditions without permafrost at Forsmark, see TR-10-49, Section 1.2.3).

Q 2.3.7 (3): p. 330ff, p. 460ff: It could be expected that normal-stress-transmissivity models are very uncertain, because the stress-aperture relationships vary a lot between different lab experiments[3] and the aperture-transmissivity relationship is also highly uncertain. The cubic laws normally employed in UDEC and 3DEC yield very uncertain results. Why do you trust these modeling results so much?

We don't use 3DEC or UDEC to assess transmissivity effects, only to establish normal stress variations. The normal stiffness of the fractures (and how that stiffness varies with normal stress) is described in the Data report TR-10-52 (based on results of normal load tests performed on Forsmark fracture samples). These normal stiffness data control changes in the mechanical aperture, which are then translated to changes in hydraulic apertures, or (equivalent "smooth wall apertures"), cf. Fig 3-4 in TR-10-23. The parameters of the stress- hydraulic aperture expression (cf. Fig 10-20 in TR-11-01) are calibrated for that expression to be consistent with

- **Stress-mechanical aperture relations (based on stress-stiffness data)**
- **Mechanical aperture-hydraulic aperture relation (based on expression shown in Fig. 3-4 in TR-10-23 and on values of JRC0 given in the data report)**
- **Residual hydraulic aperture estimates based on fracture transmissivities observed at repository depth in Forsmark.**

[3] Zangerl, C., Evans, K., Eberhardt, E. and Loew, S. (2008). "Normal stiffness of fractures in granitic rock: A compilation of laboratory and in-situ experiments." *International Journal of Rock Mechanics and Mining Science **45***: 1500-1508.

Because of the many uncertainties, we don't trust the modeling results as such. Therefore there are two stress-transmissivity models: a best estimate model based on mean fracture normal stiffness parameter values ("B", cf fig 10-20 in TR-11-01), and a model based on stiffness parameter values that maximize the sensitivity to normal stress variations ("A"). For very low normal stresses, i.e. when adjacent rock blocks are close to losing the mechanical interaction, all these types of relations become very uncertain. For fractures in compression of a few MPa, even the worst case model ("A") gives modest transmissvity changes in response to typical normal stress variations. Stress-transmissvity relations, obtained from hydraulic test performed at different depths on Laxemar fractures, have been reported by Rutquist and Tsang /SKI Report 2008:8/. These results seem to be in support of the stress-transmissivity relations used in our reports.

Q 2.3.8 (3): p. 330ff, p. 460ff: Which quantitative relationships have been used to assess transmissivity changes in relation to fracture shear deformation?

The assessment of shear impact on stress is only made indirectly, i.e. by first calculating the shear and then assessing whether this shear implies a transmissivity change. See for example p. 145 of /Hökmark et al. 2010, TR-10-23/ where it is stated that "*even if the shear displacements are large for large (gently dipping) fractures, the effective normal stress is small only in a limited area around the tunnel opening. During periods of large shear displacements, the effective normal stress is higher than about 7.5 MPa at distances larger than about 5 m from the tunnel. This is well above the highest normal stresses applied in the lab-scale transmissivity tests performed by /Olsson 1998/. Therefore the additional increase in transmissivity caused by shearing is likely to be modest*". A discussion on the importance of normal stress (high normal stresses promote gauge production and suppress dilation) to the transmissivity effects of shear displacements is found on pp 27-29 in TR-10-23. The discussion is based on experimental, laboratory-scale, work on real rock fractures.

Q 2.3.9 (3): p. 341: The flow rates given here for operational stage A are low (one cannot call 1 L/s high). Do these values refer to a sealed repository and complete bentonite swelling? Does the given rate indeed correspond to the total flow rate at operational stage A?

The results refer to operational stage A, a sealed repository, no grouting and complete bentonite swelling. However, the full details of the calculation are not presented in the Main report but only in /Svensson and Follin 2010, R-09-19/. The setup and results are presented in section 5.4 and Appendix C of /Svensson and Follin 2010/. It is noted that some simplifications are made in the saturation calculations concerning repository layout (specifically, no central area, ramps, ventilation shafts or deposition holes are included). Also, it is noted that Figure 10-23 of the Main report is erroneous (the curve overlying the left vertical axes is not seen) relative to the original Figure C-6 of /Svensson and Follin 2010/. Here it is seen that the initial inflow is approximately 20-30 l/s. We apologize for the erroneous reproduction of the original figure.

Q 2.3.10 (3): p. 341: Why does the water that saturates the backfilled repository originates predominantly from the top of the model domain? In many deep tunnels in crystalline rocks, significant flow from below the tunnel can also be observed. This can be modeled with the assumption of a significant decrease of hydraulic conductivity with depth (which should also be the case for Fosmark?).

Visualizations of the flow field to the repository under operational condition are given in several figures in /Svensson and Follin 2010, SKB R-09-19/. The questioned statement is supported by the change in water salinity shown in Figure 5-12 and the particle flow paths shown in Figure 5-14.

Q 2.3.11 (3): p. 459: a rock mass deformation module of 40-45 GPa seems still quite high when considering fracturing at Forsmark. How has this value been estimated in detail?

The reason for the relatively high values is that many fractures are sealed and quite strong. For the Forsmark target area the modulus varies from 55 GPa (top 150 m) to 70 GPa (400 m and downwards). The assessment is found in SKB R-08-66 and SKB R-07-31. The 40-45 GPa modulus estimate on p.459 is intended to be valid on a much larger scale than that of the Forsmark target area, or the Forsmark tectonic lens. For the host rock surrounding the Singö deformation zone, at the location of SFR tunnel passage (which is outside the Forsmark Tectonic lens), it has been concluded that the modulus should be 45 GPa /SKB R-07-06/. The modulus of the rock mass within the Forsmark and Singö deformation zones are around 38 GPa if an "empirical" approach (based on determinations if RMR and Q) is taken /Table 4-4, R-08-66/. A more "theoretical" approach would give lower values /Table 4-5, R-08-66/. Of course the bounding analysis (horizontal stress reduction because of cooling of the upper crust) is uncertain, one of the uncertainties being the relevant effective, equivalent continuum, E-modulus. Since low values would reduce the stress impact and the following transmissivity effects, a lower value than 40 GPa would be difficult to defend.

Q 2.3.12 (3): p. 459: what is meant by "residual pore pressure"?

It is the excess pressure in the low permeability parts of the rock that remains as a transient after a major change in hydraulic boundary conditions or rock stresses (e.g. after a melting ice). This is more discussed in section 7.3 of SKB TR-10-23.

2.4 Questions from IRT Member 4

2.4.1 Follow-up Questions to Questionnaire 2

QFU 2.4.1: Questions related to answer to Q 2.4.1
It is understood that the effects of different methodologies on estimating flow-dimensions and PSS data tend to result in lower flow-dimensionality. It is also understood that SKB principally used PFL data for transmissivity estimation for hydrogeological modeling because SKB considered that PFL results are more representative for the modeling. However, as expressed in the previous question (Q 2.4.1), if the flow dimension is set to be larger than the actual one, the obtained transmissivities should become smaller, and hence, it will result in less conservative values. Because the estimation of actual flow-dimensions in fractures is very difficult, it is still desirable that SKB provides the IRT further explanation and/or opinion how the effects of possible smaller transmissivity estimation due to the assumption of radial flow are treated/evaluated.

As explained in Section 6.6.7 on p. 330 in the Data report for SR-Site (SKB TR-10-52), SKB regards the interpretation of single-hole hydraulic tests as highly uncertain and does not model fracture transmissivity (T) based on field data, since the T value is dependent on (among other things) the flow dimension. Instead, the flow modeling is based on three types of correlation models for T and fracture size, each of which is calibrated against the statistics of measured values of the specific capacity (Q/Δh). The concept of flow dimension is of conceptual value mainly.

Concerning the missing background report /Follin et al. 2006; P-06-54/, it is noted that the report is being completed now and will be available for the IRT in the beginning of November 2011.

QFU 2.4.2: Questions related to answer to Q 2.4.6
P. 289 on TR-08-05 was reviewed and the discussion in that section of the document was comprehended. However, subsequently another question arose. It is not clear how the hydrogeological situation in the deeper part, i.e., deeper than 200m, is evaluated. Groundwater chemistry data exist for the deeper part; however, pore pressures and/or hydraulic potentials seem not to be presented. Are there data on hydraulic potentials in the deeper part? Was the comparison between the measured hydraulic potential and numerically calculated results made? How does SKB consider the appropriateness of the hydrogeological model, especially in the deeper part?

The means and assumptions used by SKB to transfer measured point-water heads between packers in deep boreholes to environmental water heads are explained in Appendix K in /Follin et al. 2007, R-07-48/. It is noted that the spacing between the borehole packers used for head measurements are often quite long (tens to hundreds of metres). Furthermore, the fluid density generally increases with depth whereas the conductive fracture frequency decreases with the depth. Bringing these conditions together, it is obvious that the point-water pressures measured at depth are not very certain neither in magnitude nor elevation. To avoid a model that is calibrated against uncertain data it was decided to exclude the matching against in situ head measured in deep boreholes. However, in Figure J-4 and Figure J-5 of /Follin et al. 2007/ we provide an example of how the calculated environmental water heads at depth are used in the conceptual hydrogeological modelling.

2.4.2 Questionnaire 3 Questions

Q 2.4.1 (3): Flow paths can change due to climate changes and migration of ice sheets. It is stated that the steady state modeling results are used for particle tracking calculation and the estimation of F-values. Under the changing situation of climate condition, flow paths should change temporally according to the change of the external condition. How does SKB treat the possible effect of the changes of flow paths on the estimations of F-values and advective travel times? Also, are the calculated advective travel times presented in the report, and are the results evaluated to be reasonable? In relation to the previous question Q. 2.4.7, how does the possible remnant excess pore pressure during ice retreat affect the temporal changes of flow paths and the results of the particle tracking study?

The methodology used in SR-Site is briefly described in section 10.4.6 of the Main report (heading Comparison of the Darcy flux at different time slots during glaciation and deglaciation) and in section 13.5.6 of the Main report (heading Varying external conditions). In short, the effect of varying climate conditions is included through a scaling of the velocity along the flow paths from the repository to the biosphere. The scaling factor is obtained as the ratio of Darcy flux at deposition hole locations during different climate regimes relative to temperate conditions. The radionuclide transport code MARFA then re-scales the velocity along the flow paths for different climate regimes such that in effect modified advective travel times and F-factors are obtained (note that MARFA uses segment based values and not integrated values of travel time and F along a flow path). The flow paths originate from the temperate phase simulations. Thus, changes in recharge locations are not captured with the approach, only changes in velocity along the flow path and hence changed retention characteristics.

In on-going studies (post SR-Site), the effect of the simplified approach in SR-Site is analyzed using transient flow and transport simulations. Preliminary findings indicate that the spatial dilution in radionuclide discharge implied by the transient velocity fields associated with multiple climate regimes is not captured by the SR-Site approach. Hence the SR-Site results are conservative in this sense.

The advective travel times for temperate conditions are presented in /Joyce et al 2010, R-09-20/. An evaluation of the used aperture (or porosity) and resulting travel times is provided in section 5.4.8 of /Selroos and Follin 2010, R-09-22/.

As explained in our response to the previous IRT question 2.4.7, significant remnant excess pore pressures can only exist in parts of the rock with very low hydraulic diffusivity (i.e. volumes without well connected transmissive fractures), whereas these pressures will essentially immediately dissipate in more permeable volumes (i.e. where the significant migration flow paths occur). The impact from excess pore pressures on the flow can thus be, and is in SR-Site, neglected, whereas we do consider their potential impact on changing the rock permeability (as explained in other answers).

Q 2.4.2 (3): Quality control and appropriate management of field data is considered to be crucial for the reliability of the results on the hydrogeological modeling and further discussion based on the model results. For the quality control, in addition to following protocols for field measurements, evaluation and checking of measured data themselves are necessary. How does SKB control and manage the quality of these data?

All field data, regardless of scientific discipline, have undergone a review by at least three persons before storage in SKB's data base, Sicada. That is, the contractor, the client's (SKB's) representative, and the database manager. Finally, it is checked that the data provided by the P-report are consistent with the data in Sicada.

2.5 Questions from IRT Member 5

2.5.1 Follow-up Questions to Questionnaire 2

QFU 2.5.1: In General:

SKB states that some of the designs (e.g. for canister, plug) have not yet been finalized (see answers to Q.2.5.1. and Q 2.5.4). When does SKB plan to finalize these? Does SKB expect safety relevant changes?

The designs will at the latest be finalized before they need to be implemented. Given that the time for implementation differs between systems, the time left for finalizing the designs also differ. The design concerning repository access will be finalized before construction work can start, and will be described in a special document describing how safety and radiation protection matters will be taken into account during construction. This document needs to be reviewed and approved by SSM. Designs of systems in the deposition area (deposition tunnels, backfill, buffer, canister, etc) need to be finalized at least in time for the trial tests and will be reported in the Safety Assessment Report (SAR) to be reviewed and approved by SSM before operation can start. Any design change made after this would need to be reviewed and approved by SSM in a manner similar to how this is handled in any other nuclear facility. As stated in the license application, SKB will only consider design changes leading to maintained or improved levels of safety.

QFU 2.5.2: Questions related to answer to Q 2.5.1
SKB states the quality control of the manufacturing process is not part of the licensing process for the final repository but will be supervised by an authorized body. Which authorized body will supervise the manufacturing process including quality control? As the canister is the main barrier and essential for providing the safety, is there a cooperation/information exchange between this authorized body and the Swedish Radiation Safety Authority?

The license application describes the principles for quality control of the manufacturing process for the canister. TR-10-14 describes the items to be controlled and inspected during the canister design and in the manufacturing process. It also describes testing methods and experiences obtained from the use of these methods so far. The principles for the quality management system and its application in the production of the KBS-3 system components are described in Chapter 5 of TR-10-12.

The authorized body, or bodies, for supervision of the qualification of the different processes are not chosen yet. SSM regulations stipulate that for manufacturing and welding the third party organization is required to be accredited by Swedac, a government authority and also approved by SSM. For inspection the third party organization has to be approved by SSM.

It can also be mentioned that the organization that will carry out inspections (i.e. NDT) in the production must be accredited for the task.

The plans for quality control presented in the license application will be evaluated by SSM as part of their licensing review. SSM has already requested some clarifications on this topic. Further development of the programme for quality control is in progress and will be presented in the PSAR. The PSAR will be reviewed and approved by SSM before construction of the encapsulation plant and the final repository can start.

QFU 2.5.3: Questions related to answer to Q 2.5.2

SKB states that they are exploring the potential for revising the design premises from a deterministic rule of design premises to a probabilistic one, but the change will only be done if they can prove that safety is not affected. Is a possible revision of the design premises subject to a review/or a licensing process performed by the Swedish Radiation Safety Authority?

If we make such a change we will include this as part of the Preliminary Safety Assessment Report (PSAR) which will be submitted to SSM for review and approval before we can start construction of the repository. See also answer to QFU 2.5.1

QFU 2.5.4: Questions related to answer to Q 2.5.3
According to SKB`s answer damage analysis have been done mostly for BWR inserts and for one PWR case. Is it correct to say that, on this basis, there is currently no valid safety assessment for the disposal of PWR-Spent Fuel at the planned repository? As SKB is carrying out complementary analysis for the PWR insert, what is the time schedule to close this gap in the licensing information?

Based on the documentation provided in the application the following can be stated:

For the isostatic load case, strength analyses for both types of inserts have been carried out. This is also the case regarding damage tolerance analysis. In these analyses it is assumed that the materials properties are the same (equal to BWR) for both types of inserts. This is seen as a reasonable assumption but will have to be justified when additional materials data from PWR test manufacturing become available. These analyses will be reported in the next licensing stage, i.e. in the Preliminary Safety Assessment Report (PSAR), which will be submitted to SSM for review and approval before construction of the repository can start.

For the shear load case, strength and damage tolerance analyses have been carried out for the BWR insert. Regarding the resilience to shear loads, the PSAR will be built on a full analysis of the PWR insert, based on additional manufacturing tests, and of an updated analysis of the BWR insert.

The mechanical assessment of the PWR insert needs to be based on additional manufacturing data. Given the similarities in structure of and planned production processes for the two inserts, and the fact that several pessimistic simplifications were made in the mechanical analysis of the BWR insert, there is good confidence that the PWR insert can be demonstrated to comply with the design premises for the canister in the following licensing step.

QFU 2.5.5: Questions related to answer to Q 2.5.19 (and see also Q 2.7.3)
Taking into account the low denudation rates as discussed in the climate report, there is yet no or a very limited safety margin left in the 1 million-year perspective, regarding permafrost influence under extreme conditions. The answer to question 2.7.3 does not contribute much to the exclusion of a deeper repository. On p. 811, SKB states that “placing the repository some 100 m deeper would probably result in a risk contribution similar to the one obtained from the selected depth”. If future analysis would reveal concerns about the interaction between permafrost depth and repository depth, would that be an option to strengthen the system’s performance and robustness or is this ruled out?

This is essentially ruled out. Given the very pessimistic assumptions made in SR-Site, and given the relatively minor impact from freezing, would it to occur, we do not expect any future analysis that would suggest a need to increase the repository depth for reasons related to the development of the future climate.

The essential reasons for excluding a deeper repository are the increased engineering risks (higher and more uncertain rock stress) and the increased footprint (due to the thermal dimensioning) of going deeper.

QFU 2.5.6: Questions related to answer to Q 2.5.20
SKB states that the collapse load of the canister is substantially higher than the design load. Has it been taken into consideration to revise the canister design load (currently 45 MPa) in order to better reflect the real properties of the canister (collapse load 100 MPa)? This would ensure that the real safety margin (or a relevant proportion of it) is preserved and that the properties of the canister are not revised in future, maybe for economic reasons, to better reflect the current design load.

The design load for the canister is, by principle, derived from the anticipated loads in the repository. When the design is analyzed, margins are taken into account by using conventional safety factors in calculating the smallest acceptable collapse load for a specific design load.

The design premise for the isostatic load is planned to be revised, to better reflect the extreme ice load situations being the outcome of the SR-Site scenario analysis.

The reasons for changing the design premises and reference design adopted by SKB, is described in section 15.5.2 in the SR-Site main report (SKB TR-11-01).

QFU 2.5.7: Questions related to answer to Q 2.5.29
SKBs described the organization of funds which should allow SKB to maintain its organisation and personal resources as long as needed. What would happen in case of insolvency of SKB?

SKB is owned by the Swedish reactor owners and SKB’s nuclear waste management activities are funded through the Nuclear Waste Fund, as required by Swedish legislation. In addition to money deposited in the fund the reactor owners have to provide guarantees to the Government in case reactor operation is stopped prematurely or major unplanned events (see TR-09-23 for details). Hence, SKB’s nuclear waste management operations are guaranteed by the Fund and the reactor owners.

QFU 2.5.8: Questions related to answer to Q 2.5.32
SKB answered that sensitivity analyses are carried out at a late stage of the assessment, and the assessment led to no special “handling” afterwards. The identification of input variables should help to understand the impacts of variables in the calculations. After the identification of sensitive variables, the results of the sensitivity analysis should be used to check whether they correspond to the input-data of the calculation performed before. If not, the calculation has to be repeated by varying the variable’s values identified in the sensitivity analysis in

order to understand the effects on the calculated dose/risk. One could say that the sensitivity analysis is used to re-check the correctness of the input variables and the validity of the calculated dose/risk.

According to SKB`s answer to Q 2.5.32 it remains unclear whether SKB has taken into account such considerations/calculations. Please explain.

This follow-up question is possibly caused by the use of different definitions of the term "sensitivity analysis". The following approach is used in SR-Site (and is similar to approaches used in other safety assessments):

In the probabilistic calculation of dose, uncertain variables are sampled in accordance with distributions established in the data qualification. These distributions are based on the assessment of input data uncertainty reported in the Data report. This uncertainty assessment is thus the way in which the correctness of the input variables is established.

The probabilistic calculation is an uncertainty analysis where the output uncertainty is determined by the input data distributions and the nature of the mathematical model used in the calculation. The result is a distribution of the output entity, reflecting the output uncertainty, given the uncertainty in input data.

The subsequent sensitivity analysis is based on the result of the probabilistic calculation, to determine which of the uncertain input variables are the most important for the output uncertainty. Such an analysis can not be used to re-check the correctness of the input variables.

The results of sensitivity analyses in previous assessments were used, in early stages of the SR-Site assessment, to focus the data qualification on uncertain data important for the calculation end-point. The outcome of the sensitivity analysis of the final calculations in SR-Site is used to identify key uncertainties in data and processes yielding feedback to future assessments and R&D efforts. (These were essentially the same variables as identified in the previous assessment, SR-Can.)

QFU 2.5.9: Questions related to answer to Q 2.5.34
SKB describes in its answer the decisions for selection of certain techniques for BAT discussion. Can SKB provide a list of all techniques which were considered initially?

Selection of techniques are made at several levels, ranging from the disposal method to specific production techniques, measurement techniques and support systems for different parts of the disposal system. There is no comprehensive list of techniques considered. R-10-40 describes the development of the KBS-3 method and provides some insight into the techniques considered over the years. The report is in Swedish with a comprehensive English summary. The illustrations provide some insight into different design variants of the barriers of the KBS-3 system that have been considered.

QFU 2.5.10: Questions related to answer to Q 2.5.36
SKB says it wants to continue the dialogue with municipalities concerned, other stakeholders and public in the future. What is planned in the near future?

SKB will continue to regularly organize information meetings open to the public on future plans and specific topics in the communities concerned. The dialogue with the Oskarshamn and Östhammar municipalities will continue. The license applications have been sent for review by SSM and the Environmental Court to Governmental agencies, the municipalities, NGOs and selected universities. SKB has held meetings with reviewers to inform on the contents of the license application and will respond to issues raised during the licensing process, sometimes directly to stakeholders in addition to the formal responses provided to SSM and the Environmental Court.

2.5.2 Questionnaire 3 Questions

No new questions for Questionnaire 3 from Reviewer 5

2.6 Questions from IRT Member 6

IRT member 6 has no further questions at this point.

2.7 Questions from IRT Member 7

2.7.1 Follow-up Questions to Questionnaire 2

QFU 2.7.1: Questions related to answer to Q 2.7.1
In the answer to Q 2.7.1 SKB states that "When a deposition tunnel has been sealed the main barriers are in place and the bentonite is passively safe". In the answer to Q 2.5.4 SKB states that "The sealing ability of a tunnel plug is only needed during the operational period of the repository". A situation could be imagined where the sealing ability of tunnel plugs would be tested for more than the design lifetime in the case that, for whatever political or economic reason, the repository remains only partially filled. If there were unsealed main tunnels, the sealing ability of deposition tunnel plugs may have to last longer than planned. Should these plugs be designed for longer lives than just the planned operational stage of a repository?

We do not plan to change the designed life time of the plugs, for two main reasons:

- **An incompletely sealed repository is assessed in section 14.2.8. The basic assumption in the case selected is that the repository is abandoned when all canisters are deposited and all deposition tunnels backfilled and sealed, but the main and transport tunnels as well as the central area, repository access (ramp and shafts) and the ventilation shafts in the deposition area are still open. At some point in time the plugs will lose their function and the backfill in the deposition tunnel will swell out into the main tunnels. From the simplified analyses carried out it can be concluded that abandoning the repository without backfilling and sealing all parts of the repository may imply that backfill in the deposition tunnels is lost and that the safety functions for containment are violated for deposition holes located close to the entrance of the deposition tunnels, but the analyses also shows that a not completely sealed repository is robust over a long period of time. Nevertheless, the conclusion is that the repository should not be abandoned prior to complete backfilling and sealing.**

- **Proving the sealing function of a concrete structure in the time range of 100,000 years or more does not seem possible and such a design criterion would not be practical to act upon.**

QFU 2.7.2: Questions related to answer to Q 2.7.19
In the answer to question 2.7.19 SKB states that the bentonite will be delivered from the supplier at 17% moisture. This means that the bentonite will not be dried for as long as usual by the supplier, which seems to make economic sense. However, generally most bentonite is dried to a moisture content of about 10% and the microbial experiments with bentonite at SKB appear to have been carried out with this drier material. This may have made a difference with respect to in situ viability of the microbes present. In uncompacted state at 17% water content, there likely will be more viable bacteria that at 10% water. Is SKB planning to repeat some of the microbial activity experiments with the 17% moisture material?

There are currently no requirements on the initial content of bacteria in the bentonite and no experiments are planned for materials with higher water content. As stated in the question, bentonite with a water content of 17% is not usually available "off-the-shelf" from the bentonite suppliers either. The content of microbes in commercial bentonites can be fairly high even if it has been dried to 10%. There is also a large variation in the microbe content and populations between different bentonites. An increase of original water content is therefore not expected to make a significant difference to this already very uncertain parameter.

QFU 2.7.3: Questions related to answer to Q 2.7.26
In SKB's answer it is stated that "….the system can be considered as closed with respect to vapour so severe precipitation of salts cannot occur". However, depending on the temperature distribution, some bentonite shrinkage around the canister and some cracking radially outward from the canisters likely will occur due to water migration as a result of the almost 100^{o}C at the canister surface. Depending on how long this lasts, some cementing of these fractures could be possible due to mineral precipitation (anhydrite for instance). These cracks are expected to heal upon saturation when temperatures moderate and the water returns to the dried-out bentonite, but this may perhaps not occur fast enough or complete enough to prevent fresh, viable microbes to move with the incoming waterfront to the canister surface. This may be a temporary effect but it could conceivably bring viable bacteria, including perhaps SRB close to or at the canister surface (which is now cooler; the initially present microbes would have been inactivated or killed by the high temperature). If SRB produce sulphide at this location, this could have a direct effect on the canister. In TR-10-47 SKB states that migration of microorganisms through compacted bentonite is not well studied. What work is planned by SKB to shed some more light on this question, including transport through incomplete fractures? Some work was done in other countries on this topic (Canada, Japan).

An experimental program which considers microbial effects in a copper/bentonite system with a variable degree of saturation has been initiated. The objective is to investigate if there is a "window" of saturation which is favorable for microbial activity.

2.7.2 Questionnaire 3 Questions

These new questions are based on review of:

- TR-10-67: An update of the state-of-the-art report on the corrosion of copper under expected conditions in a deep geologic repository. Section 2.3 Microorganisms
- TR-10-58: SR-Site – hydrogeochemical evolution of the Forsmark site. Chapter 8 Evaluation of other geochemical parameters
- TR-10-54: Comparative analysis of safety related site characteristics.
- TR-10-48: Geosphere process report for the safety assessment SR-Site. Chapter 5 Chemical Processes
- TR-10-47: Buffer, backfill and closure report for the safety assessment SR-Site Section 3.5.14 Microbial Processes and Section 3.45.15 Cementation
- TR-10-39: SR-Site -Sulphide content in the groundwater at Forsmark.
- TR-10-19 Principal organic materials in a repository for spent nuclear fuel. Various sections
- R-08-47 Bedrock hydrogeochemistry Forsmark. Chapter 4 Bedrock hydrogeochemistry Forsmark
- Yang, C. et al. Modelling geochemical and microbial consumption of dissolved oxygen after backfilling a high level radioactive waste repository. J. Contaminant Hydrology 93 (2007) 130-148.

Q 2.7.1 (3): In TR-10-39, page 30 (section 3.2.3) SKB states that: "In contrast to the presented views in this report regarding the Forsmark data, the conclusion from the MICROBE experiment, concerning sulphide concentrations, was that the low concentrations generally found during flushing or pumping as well as from the CCC method during the site investigations are artefacts and that the high values represent a more accurate concentration in the ground waters."

This is clearly not the opinion of the authors of TR-10-39, who argue the opposite, i.e., that the low concentrations are the true in situ ones and that the high concentrations are due to SRB activity in borehole sections, lines etc., sustained by the materials placed in the borehole.

The sulphide concentrations are extremely important for the corrosion rate of the canister. Has SKB resolved this contradiction in the data and interpretation between the geochemists and microbiologists? Which conclusion is correct? It is acknowledged that SKB has partially answered this question in the answers to question Q 2.7.37 and Q 2.5.13. Can SKB make report P-10-18 available please?

The quoted sentence in TR-10-39 is written in an unfortunate manner. According to the observations from the Microbe project, there are several possible explanations to the variability in sulphide concentrations during sampling (Hallbeck and Pedersen, Appl.Geochem. 23(2008)1796), and the conclusions from Microbe were that low sulphide concentrations *could be* artifacts (cf. last sentence in the conclusions of the paper quoted above). In later investigations published in P-10-18 it became clear that

pumping is needed in order to get rid of the influence from processes occurring in the borehole section, in the tubes and in the standpipe. The report is now available at www.skb.se.

SKB believes that all reasonable efforts have been made in trying to obtain sulphide concentrations representative of the groundwaters in the rock fractures. The processes involved in regulating sulphide concentrations are well described in the open literature. Nevertheless, investigations have been started at Äspö aiming at a better understanding of which processes are triggered, and why, when the waters in isolated borehole sections are standing. The advantage, as compared with the investigations reported in P-10-18 from surface-drilled boreholes, is that these tunnel boreholes have shorter tubes and no standpipe.

Q 2.7.2 (3): It is mentioned in several SKB TR reports that the organics in the bentonite are largely unavailable for biological reactions (e.g., TR-10-19). This is at first glance a reasonable assumption considering that this material has been in the clay naturally for a long time and if available, would have been consumed in microbial reactions a long time ago. However, the production of bentonite includes a heating (drying) step and this may make any complex organic matter naturally present more available for microbiological reactions. In addition, the effects of the initial heating phase on the bentonite surrounding the canisters may further break down this complex organic matter such that it becomes more bio-available.

It was shown in studies in Canada* that organic matter from bentonite-based buffer materials can be released increasingly upon heat treatment and that this organic matter appeared to stimulate microbial activity. In a repository setting organic matter from the bentonite could diffuse to interfaces. Microbial activity could, therefore, perhaps be stimulation at rock-bentonite interfaces where water comes in by diffusion and a gel layer is formed. Increased numbers of viable bacteria in bentonite (compared to clay matrix numbers) have been observed in other programs at such interfaces.

*References: Vilks et al. 1998. Radiochim. Acta 82, 385-391; Stroes-Gascoyne et al. 1997. Mat. Res. Soc. Symp. Proc. 465, 987-994.

It is true that microbial activity in the interface bentonite/rock or bentonite/fracture cannot be excluded. However, it is unlikely that the organic content in the bentonite should be of importance. The temperature increase in bentonite in the drying process is rather modest and this will be even truer for an initial water content of 17%. The organic content of many commercial bentonites is also very low. Half of the bentonites in the ABM have an organic content below the detection limit (LECO).

Q 2.7.3 (3): TR-10-47 p. 165 (section 3.5.14): How serious is the possibility that microbial activity (i.e., Fe(III) reduction), will affect the swelling capacity of the bentonite? A Japanese paper* suggests it would be minimal. What is SKB's opinion on this?

*Reference: Nakano, M., and K. Kawamura. 2010. Applied Clay Science 47, 43-50.

Illitization induced by microbial reduction of structural Fe^{3+} should have been better described in the supporting documentation to SR-Site. It is clear that the process may occur even at laboratory timescales. However, in nature this process does not seem to be

very common. This is most likely due to the lack of nutrients, which also will be the case in the repository. The paper from Nakano and Kawamura draws the same conclusion based on modeling. The model presented in the paper does, however, not seem to be backed up by experimental observations and may seem a little speculative.

Q 2.7.4 (3): R-08-47 page 124 (section 4.10.4) indicates lower confidence with respect to data on U-bearing minerals in fractures. In Canada at the URL drawdown caused increased U in the groundwater, to the point that the pumped out-water in the holding pond had to be treated before it could be released to the environment. Is anything like this expected at Forsmark? Has anything like this been seen at Äspö? What measures would be taken at Forsmark to avoid high U concentrations due to drawdown?

No such U-mobilisation has been observed at Äspö. However, the biogenic Fe-oxyhydroxides accumulate radioactivity. These biofilm-precipitates are formed at the tunnel walls where reducing Fe(II)-rich groundwater emerges to the tunnel air. No special treatment of either the pumped waters or of the Fe-precipitates has been needed at Äspö. The situation is similar at SFR (the underground low- and intermediate level repository at Forsmark). This does not fully exclude the possibility that the situation that you describe at the URL might occur at Forsmark as well. The measure foreseen at the moment is monitoring of the composition of the pumped-out groundwater.

Q 2.7.5 (3): TR-10-39 P. 17 (section 3.1.1). Why would heavy pumping reduce microbial activity? If dilution with water from fractures that contain less active bacteria is the argument, the counter argument could be made, i.e., that heavy pumping could also increase sulphate reduction if water from very active fractures was pulled it. Could dislodging of biofilm material, as a result of heavy pumping, provide nutrients that would subsequently increase microbial activity in stagnant borehole water?

Pumping will in general result in a change of mixing proportions and gradients of the geochemical species in the fractures. Bacteria need time to adapt to the new conditions as the microbial activities are disturbed. Pumping may therefore in general change bacterial activity. The text in report TR-10-39 is somewhat contradictory as it states in paragraph 2 of section 3.1.1 that pumping may promote bacterial activity, while in paragraph 4 it states that it may reduce it. In any case, the possibility of pumping affecting microbial activity must be born in mind.

On the other hand it has been shown that the samples obtained when no previous pumping is performed correspond to the standpipe and to the tubes, or perhaps to the isolated borehole section, and they are sometimes chemically quite different from the waters inside the rock fractures, due to microbial processes favoured in the conditions prevailing in the standpipe, tubes, etc, see report P-10-18.

Dislodging of biofilm material could in principle affect the groundwater samples, but if this process happens there are no observations indicating that it may be important, and it has not been investigated by SKB.

Q 2.7.6 (3): RE: Biofilms in fractures: Has SKB carried out any work to look at naturally occurring biofilms on fracture surfaces in recovered core? What is the percentage sessile versus planktonic microbial biomass in the crystalline system? A common opinion is that most microbes in oligotrophic systems such as crystalline rock are expected to form biofilms but that is not always seen*. There are not many data sets available in which core and water are analyzed from the same source. What is SKB's opinion on this? Does SKB think it has a good idea of the in situ populations by just sampling the water?

*Reference: Lehman, R.M., "Understanding of aquifer microbiology is tightly linked to sampling approaches", *Geomicrobiology Journal*, Vol. 24, 2007, pp. 331-341.

SKB has performed a study on biofilms on fracture surfaces (Jägvall et al 2011). There are plans to initiate further studies on biofilms on fresh fracture surfaces. In addition, several studies have been performed on biofilms under in-situ conditions at the Microbe site at Äspö.

SKB has studied sessile/planktonic ratios on both fracture surfaces (FSM) and on artificial surfaces (LFR). The results are presented in Table 2 and 3 in Jägvall, et al. 2011.

However, because of the difficulties to sample biofilms on fracture surfaces a number of studies using biofilm reactors with glass slides have been conducted in order to study the ratio of attached and unattached microbes. This was done at the Stripa research mine (Pedersen and Ekendahl 1992a) and at Laxemar (Pedersen and Ekendahl, 1992b).

SKB is well aware that the suspended microbes are just a small proportion of the total microbial population in the rock. The attached portion is often found to be higher by several orders of magnitude in relation to the unattached bacteria. This can clearly be seen in Table 4 in Pedersen and Ekendahl, 1992a, but also in Pedersen and Ekendahl 1992b and Jägvall et al. 2011.

References:

- **Jägvall, Rabe and Pedersen, Abundance and diversity of biofilms in natural and artificial aquifers of the Äspö hard rock laboratory, Sweden. Microbial Ecology 61 (2011) 410**
- **Pedersen and Ekendahl, Incorporation of CO2 and introduced organic compounds by bacterial populations in groundwater from the deep crystalline bedrock of the Stripa mine. J. General Microbiol. 138 (1992a) 369.**
- **Pedersen and Ekendahl, Assimilation of CO2 and introduced organic compounds by bacterial communities in groundwater from south eastern Sweden deep crystalline bedrock. Microbial Ecology 23 (1992b) 1-14**

Q 2.7.7 (3): In TR-10-48 (P. 178 section 5.7.6) SKB states that after closure [of the repository] microbial activity will continue at a high rate, correlated with temperature. Where is the location of this activity? It is agreed that the activity will not occur much in the bentonite because of its high compaction (high SW. P., low a_w). Is the activity in the backfill and in the groundwater in the fractures? Why would SKB expect to always have higher microbial activity due to higher temperatures? Isn't it the case that most microbes in situ (in the groundwater) would probably be borderline psychrophilic and would first have to adapt to the higher temperatures? There are certainly optimum temperatures for most bacteria but with a canister output temperature of close to 100°C it is conceivable that in certain locations in a repository the temperature would be higher than the optimum temperature, certainly for the mostly psychrophilic population in the groundwater? Has SKB looked into the temperature sensitivity of the bacteria in groundwater samples and in sealing materials?

The temperature dependence with time at the rock wall closer to the deposition holes is illustrated in Figure 10-16 of the SR-Site report (TR-11-01). The Figure shows temperatures between 35 and at most about 65°C for the first 1000 years.

As a result of these higher temperatures the bacterial population diversity will change locally from psychrophilic to mesophilic and possibly thermophilic temporarily. Such bacteria have been observed in the bentonite (report for the ABM project in preparation). The probable increase in microbial activity in the backfill may speed up the consumption of oxygen and thus contribute to create anaerobic conditions.

SKB has not investigated the temperature sensitivity of the bacteria found in groundwater samples.

Q 2.7.8 (3): In TR-10-48 page 221 (section 5.13.9) SKB states that “Information on grouting materials is difficult to extract and there may be more information available.” Is SKB actively looking? Would information from nuclear reactors and containment be of use here?

SKB has not found additional information since the Process report was written. However, the radiation levels will be low in locations where grout may be required, see TR-11-01 p. 783 sub-heading Ge22.

2.8 Questions from IRT Member 8

IRT member 8 has no further questions at this point.

2.9 Questions from IRT Member 9

2.9.1 Follow-up Questions to Questionnaire 2

QFU 2.9.1: Questions related to answers to Q 2.2.2 and Q 2.5.1
TR-10-14 chapter 5 and TR-10-12 Section 5.3 for copper canister QC were reviewed.
The answer to Q 2.5.1 implies SKB has not yet worked out all the details on inspecting the canister and the canister inserts. If this is correct, what are the technical bases SKB used to determine the probability that a “defective” canister or insert would not be detected by the yet-to-be-selected NDE methods? Was human error (for example, human error in NDE inspection) also considered when developing the probabilities? (Apparently neither SKB document 1175208 nor 1179633 are published and it is, therefore, not possible to check these. Can these documents be made available?).

In Section 5.2.10 of TR-10-14, SKB states that 47 BWR inserts and 8 PWR inserts were manufactured for the testing program “prior to 2008”. Furthermore, this section states that only five BWR inserts and three PWR inserts were used to test for conformance to the required specifications. Are these, then, the total number of inserts upon which projections of insert failure probabilities are made?

The conformity to design premises is described in TR-10-14 p. 109-110 and on p. 101 it is stated that the conformity regarding mechanical loads is only valid for the BWR insert. For the isostatic load case the used preliminary NDT methods show good margins to the calculated allowable defect sizes, i.e. when the final NDT methods are developed in the future the margins are expected to be significant. For the shear load case we state that there are uncertainties in the calculations and the NDT methods and thereby also in the initial state.

We have not considered human factors in the estimated probabilities. However, an extensive project is in progress at BAM (Berlin) where we analyze the human factors for our automated inspections and especially the evaluation of collected data.

The references 1175208 and 1179633 are available but written in Swedish. They will be provided on request.

Regarding BWR inserts, the projection of insert failure was based on the limited number of more recently produced inserts since those produced prior to 2008 were manufactured according to an outdated process to which essential improvements were done. A number of experiments were carried out prior to 2008 to establish the casting process and such castings are not relevant as their aim were to explore different casting parameters. When the process was finally established a prequalification of the process was done and a serial production was made of five BWR inserts. We consider these to be representative of the outcome of future production.

Regarding PWR inserts we are still working with the process and are awaiting representative materials data.

See also the response to QFU 2.5.4 in this questionnaire.

QFU 2.9.2: Question related to answer to Q 2.5.13
It is unclear from SKB's response whether the "anomalous sulphide production" remains a concern even with adjusted groundwater monitoring procedures. Please clarify.

The monitoring procedures at Forsmark were changed already in 2009 to encompass a series of five samples instead of taking a single sample. The purpose was to ascertain that a steady state value was reached for pH, bicarbonate, sulphide etc. However, a correlation between sulphide concentrations and borehole section properties was discovered. Since then samples are not anymore taken after a discharged volume corresponding to 3 to 5 times the borehole section volume, instead a model is used that takes into account the location and transmissivity of the flow anomalies in the isolated borehole section in order to calculate the groundwater volume that needs to be discharged to take a sample representative of the groundwater in the fractures. Also a regular washing (spooling) procedure for the stand pipe was introduced. These improvements are described in TR-10-39. Only monitoring samples using this modified methodology were used in TR-10-39 and in SR-Site. Subsequent regular sampling twice a year has proved that these sulphide values are reproducible.

Some of the monitoring samples showed higher sulphide values than the corresponding data collected during the site investigation; see TR-10-39. In the selection of sulphide

values used in SR-Site the available monitoring data were scrutinized, and representative values were included in the selected data set.

In summary: the anomalous sulphide production in isolated borehole sections and standpipes is not seen as a matter of "concern" as such, but given the importance of sulphide concentrations and production for long-term safety, studies are continued to gain more knowledge on this matter.

QFU 2.9.3: Question related to answer to Q 2.5.22
SKB's response provides a seismic probability value of less than one percent for the first 1000 years. What is the probability over the one million-year assessment period?

For the specific entity mentioned in the answer to Q 2.5.22, viz. the occurrence of M≥5 earthquakes within an area of 10 km radius, the probability over a one million year period would be high. The expected number of such earthquakes would be more than one if the data cited in the answer to Q 2.5.22 are directly extrapolated to one million years. However, the entity of relevance in the safety assessment is that of an earthquake occurring in any of the deformation zones susceptible to reactivation and located sufficiently close to the repository to cause canister damage through secondary movements in large fractures in the repository. Such probabilities are considerably lower as accounted for in section 10.4.5 of the SR-Site main report, TR-11-01.

QFU 2.9.4: Question related to answer to Q 2.5.23
What is the "higher number … for the shear load scenario"?

The same reasoning applied to the shear load scenario yields, with a mean number of failed canisters of 0.079 at one million years (Figure 10-124 p. 481 TR-11-01 Vol II) and a margin to the risk limit in this case of about a factor of 100 (Figure 13-69, p. 724 TR-11-01 Vol III), a similar number of canisters as in the corrosion scenario, i.e. around 10 (and not a higher number as stated in the response to Q 2.5.23).

QFU 2.9.5: Question related to answers to Q 2.9.1
It was not possible to check SKB's response because TR-09-22 could not be obtained from the SKB web site. The argument for the minimal effect of 600g of residual water on the cast iron insert was understood. Are there other impacts of the residual water on the UO_2 pellets themselves?

The report SKB TR-09-22 is available at the SKB web site. (If it could not be obtained, this could possibly have been due to a temporary technical problem.)
The assumption of one water filled fuel rod per fuel element is very pessimistic, the fraction of damaged fuel rods is typically less than 0.01%. No account is made in our analysis for these damaged rods e.g. they may have released most of the IRF already in the reactor or Clab and may undergo radiolytic dissolution both in the reactor water and Clab, releasing part of their inventory, which finally ends up in the filters. Once in a sealed canister with argon atmosphere and traces of air, the damaged fuel rods may oxidize in the presence of water vapour, however at a much slower rate than the reaction of iron with water vapour. The hydrogen produced through the reaction of iron with water vapour and the relatively short period needed to consume all water also contribute to a limited oxidation through grain boundaries of the fuel. Further, several

published studies on radiolysis of a few layers of water adsorbed on actinide oxides indicate that such surfaces catalyse recombination reactions (e.g. J. Hashke et al., J. Alloy Comp. 243 (1996) 23-35, A. Icenhour et al. Nuc. Techn. 146 (2004) 206-209), which would make the period with presence of oxidants in the sealed container even shorter.

QFU 2.9.6: Question related to answer to Q 2.9.4
Where can it be found how SKB "converts" the probability of detection of flaws into the probability that a canister will have particular degraded characteristics for the performance assessment?

Q 2.9.4 in the previous questionnaire concerns the detection of crack-like defects in the cast iron insert, of relevance for the insert's resilience to shear loads.

In the analysis of damage tolerance of the cast iron insert, the part of the insert that gets the highest load (in terms of max principal stress) for a shear movement according to the design premises is identified. This is also the part of the insert that is most sensitive to the occurrence of crack-like defects. It is then pessimistically postulated that a crack-like defect of a specified size is present at this location. In the damage tolerance analysis, the maximum defect size that does not lead to detrimental defect propagation for the design shear load is then determined (by varying the size of the postulated defect and analysing the mechanical consequences of the shear load). See further the reporting of the design analysis of the canister, SKB TR-10-28.

The so determined maximum allowable defect size is then used to put requirements on the NDT system for defect detection. This is thus a deterministic approach for establishing that a canister will sustain the design shear load, given that the NDT system fulfils the derived requirements.

This is expressed in the two first bullet point on p. 176 of TR-11-01:

- **"According to the damage tolerance analyses the maximum acceptable depths for crack-like surface defects in the circumferential direction is 4.5 mm for semi-elliptical shape and 8.2 for semi-circular shape. The insert is less sensitive to internal defects, allowing defects larger than 10 mm. The analyses also show that the results are clearly dependent on the buffer density. A lower buffer density means that larger defects can be accepted in the insert.**
- **The damage tolerance analysis gives acceptable defect sizes that put rigorous requirements on manufacturing and NDT capability for the insert. Based on the results and experience so far it is expected that these additional requirements can be implemented in production and the testing methods for verification."**

A number of pessimistic assumptions were made in the deterministic assessment. The buffer density was assumed to be the maximum allowed, the location and angle of the shearing rock fracture intersecting the deposition hole were assume to be those causing the highest impact on the canister, etc.

In the next step in developing the design analysis of the canister (now in progress), the deterministic approach is replaced by a probabilistic approach, where the above

mentioned pessimistic data may be replaced by probability distributions. Here, also e.g. the limited probability of a defect of a critical size being located in the most sensitive position is considered, as well as the probability-of-detection (POD) of the NDT system.

Regarding the canister's resilience to isostatic loads, a probabilistic assessment similar to that now in progress for shear load was made, where calculated failure probabilities were negligible for the specified design load. See the first bullet point on p. 175 section 5.4.3 of the SR-Site main report TR-11-01, with further details in section 4.3.1 of the Canister production report TR-10-14 and in the reporting of the design analysis of the canister, SKB TR-10-28.

(Regarding defects in the copper shell, see response to Q 2.9.1 in this questionnaire.)

QFU 2.9.7: Question related to answer to Q 2.9.7
The SKB response still does not directly address how SKB took a limited set of inspection data and extrapolated to their estimates of the anticipated number of defects for the entire fleet of disposal canisters.

The probability of critical defects for the copper shell is described in TR-10-14 p. 106-107. Based on the fact that the possible defects in the copper components mainly extend in a direction perpendicular to the corrosion barrier and on the experience that only one manufacturing defect has been found in the canister components, the welds are presently considered to be the potentially thinnest in the copper shell and no defects are anticipated in the machined components.

See also our response to Q 2.9.1.

QFU 2.9.8: Question related to answer to Q 2.9.37
Potentially, the primary difference in fuel characteristics with newer spent fuel will be the burn-up. Does TR-10-13 take this evolution of burn-up values into account?

The reference inventory used in the license application does indeed assume an increased burn-up over time, see section 5.3.2 of the SR-Site main report, TR-11-01, with further details in TR-10-13. See e.g. figures 2-3 and 2-4 in the latter report.

As a consequence, the impact of such a development is taken into account in the safety assessment.

The influence of higher burn-up in fuel dissolution is discussed in section 2.5.5 of the Fuel and Canister Process Report (SKB TR-10-46) and section 3.3 of the Data Report (SKB TR-10-52). The other consequence of higher fuel burn-up (and especially of a higher linear power rating) is the increase of the Instant Release Fraction, which is discussed in section 3.2 of the Data Report (SKB TR-10-52).

2.9.2 Questionnaire 3 Questions

Q 2.9.1 (3): RE Table 5-9 on P. 172: It is unclear how SKB arrives at the fraction of canisters with the specified canister thickness values shown in TR-11-01 Table 5-9 based on a relatively limited set of test values. For example, how does SKB arrive at the conclusion that “a few per thousand” have the stated thickness range based on the limited number of tests?

The thickness of the copper shell after machining is set to 47.5 mm for the weld, and this value is based on the lower tolerance in the weld region, 48.5±0.7 mm, minus the estimated uncertainty in the measurement of 0.3 mm. (The weld thickness is lower than the wall thickness for the rest of the tube since the copper tube surfaces that connect to the lid and base respectively are further machined.)
The value “a few per thousand” is an expert judgment based on the following. Firstly, it is unlikely that the machining in the weld region will be outside the tolerances as the tube thickness is easy to measure before welding, and that these values could be used as a reference for the final machining after welding. Secondly, the copper wall thickness can be measured with the above stated accuracy and it is only if the measurement fails simultaneously with the machining, that the copper wall thickness below 47.5 mm could occur. See section 5.4.2 in the SR-Site main report with further details in TR-10-14, section 7.1.5.

For the local reduction in thickness due to defects in the welds, the stated defect sizes and the probabilities are built on studies of:
- **The reliability of the welding process: defects (detected) in two demonstration series of welding, the second one with an improved welding tool giving a largest defect of 1.5 mm.**
- **The surveillance of the welding process, specifying an allowed “process window”.**
- **The reliability of the NDT system, giving probability of detection, mostly expressed as the a90/95-values (90% of the defects with the size a will be detected with a confidence of 95%).**

The probability of 99.9% in Table 5-9 in TR-11-01 for local reduction of up to 10 mm due to defects is based on the following.
1. **A judgment that the probability that defects larger than 10 mm occurs is less than one per hundred. Such defects have never been observed when the welding parameters are within the process window and may therefore only possibly occur in the unlikely event of an undetected welding operation outside the process window.**
2. **The probability that a 10 mm defect would be missed is 10%, according to the analysis of the POD-curve of the NDT system. This a pessimistic value as the NDT methods show higher probability of detection for defects of this size.**

The evaluations of the welding process are described in reference SKBdoc “1175236 Reliability in friction stir welding of canister”, provided as a separate document together with these responses. In that reference, also an extreme value analysis is used to extrapolate the maximum defect sizes from the test series to a population of 6000 canisters, yielding the 10 mm used in Table 5-9 in the SR-Site main report.

3 Editorial comments

While the overall quality of editing of TR-11-01 is excellent, a number of small grammatical or typing errors were noted while reviewing TR-11-01 Volumes I, II and III. Suggested corrections are shown *in italics*. These are provided for SKB's information only and do not require a reply from SKB.

We thank the IRT for these comments. Most of them and a number of additional errors have been corrected in an updated version of the main report, available as a pdf file at www.skb.se. All corrections that are not purely editorial in nature have been marked on errata pages that have been e-mailed to the IRT. (Most of the corrections below are however editorial, and do not appear as corrections on the errata pages, but have been corrected in the updated version of the pdf file.)

P. 17 first line under S2.2: The Forsmark site is located in *the* northern part….

P. 22 fourth paragraph: …deposition holes are place*d*, not place

P. 205: Twice on this page the reader is referred to the previous section where monitoring is discussed. However, there is no discussion, just a referral to a report on monitoring.

P. 241 Table 7-8 not mentioned in text

P. 256 last line in paragraph named buffer freezing: thawing, not thawning

P. 276 second line under Data recommended for use in SR-Site modelling: ..often in *the* form of…

P. 303: 4th line from bottom: If the pellet*s* filling the seal…

P. 305: 2nd last line in paragraph above Erosion estimates in deposition holes:: However, measurements…. Add space before m

p. 356 Fig. 10-38 in legend black dots should be red dots

P. 361 3rd line below Fig. 10-42, should say "dissolved" sulphide content; one cannot access the precipitated sulphide. Last line on same page: sulphide should be sulphate

P. 362 second line in paragraph above Fig. 10-43: sulphide should be sulphate

P. 387: last line of second-last paragraph: section 10.3.10 is not about buffer erosion but about buffer and backfill chemical erosion; should be section 10.3.11.

P. 389: middle paragraph: Looks as if this paragraph has a different font, line spacing closer?

P. 396: Figure 10.68: add the word smectite to dissolution rate axis, such that figure can be understood without referring to text.

P. 413: decrease in instead of decreasein (space between words missing)

P. 417: Osmotic effects: first sentence have word(s) missing? According to what…?

P. 423: One but last paragraph: where is this subsection on SRB in B&B?

P. 424 Figure 10-88: Typo in legend of figure: the blue crosses represent (plural)

P. 432: Sub-heading near top of page: Should be: Geosphere (not rock) safety functions, as in Table 10-2.

P. 433: EDZ (if it exist*s*) last line first paragraph

P. 435: middle paragraph, 3rd last line: intersecting deposition tunnel*s*. Same on P. 436 last bullet: tunnel*s* or *a* tunnel.

P. 440: Figure 10-96: …result*s* in…..not result in: caption of Figure 10-96

P. 444: first paragraph: Use: "Very little is known…" and …"as is understood today"….. the "we" style does not occur in this report.

P. 446: 3rd last paragraph, first line: Talik*s*

P. 446: one but last line, add "the" last glacial cycle

P. 457: third line from above: *a*ffect instead of effect

P. 465 3rd line of 1st paragraph: ..should not exceed 5 cm (safety function R3b), and…. Add brackets (as in next line)

P. 468: 7th line from bottom one but last paragraph: ..endglacial earthquakes during *and* following

P. 492 first line of Performance measures: …are Darcy flux (*q*), advective travel time…. Add comma after (*q*)

P. 512: Middle of page: 2nd last line 4th paragraph *out in* instead of outin

P. 513: 3rd line 2nd paragraph: *calculate* instead of calculated

P. 525: Middle of Page: Birgesson et al *have*, not has

P. 531: 4th line 6th paragraph: *for about* instead of forabout

P. 538: last line 6th paragraph: *43.5* MPa, not 43 MPa.

P. 538 last line and 543 last line 3rd paragraph: *R3b*, not R3a.

P. 540: last line 5th paragraph: *for*, not for for

P. 541: 6th line 3rd paragraph: *does*, not do

P. 544: 7th line from bottom: ocean *water* (add water)

P. 570: Top of table: should FHA be in red? It is not different from the base case.

P. 571: 2nd line above 12.1.2: scenarios *are*, not is

P. 578: 3rd line 7th paragraph : ….of time during..., not of time *of* during... (remove *of*)

P. 596: third line from top: However, *no*..., rather than However, No... (remove capital). Two lines lower: *therefore* instead of thereby?

P. 598 1st line under Initial copper coverage: …was evaluated extensively (change order of words)

P. 599: 3rd line 4th paragraph: Brackets in wrong place? Hydrogen is not organic matter. Add bracket after biofilms and remove it at end of sentence.

P. 600: first line: data indicate, not indicates, data is plural

P. 621: 7th line from bottom: ..this does not reduce..., not reduce*d*

P. 629: 2nd last line 2nd paragraph: indicate*s*, not indicate

P. 630: 7th line 2nd paragraph: affect, not affect*s*; 3rd line from bottom of 3rd paragraph: contain*ed*, not contain (Holocene is past tense)

P. 631: 2nd line 2nd paragraph: reflect, not reflect*s*

P. 638: 8th line from bottom of page: However, for two radionuclides have… should be: However, two radionuclides have….; remove *for*

P. 645: 2nd line from bottom of 4th paragraph: *do* not; not does not; LDF's is plural

P. 655: 1st line, 2nd paragraph: occur; not occur*s*; failures is plural

P. 679: 6th line 2nd paragraph:: move slash (/) to after Geosphere Process report

P. 700: 1st line 3rd paragraph: None; the vast amount…. Change the comma to a semi-colon

P. 700: last line: *still not*… rather than not still

P. 705: 2nd line 2nd paragraph: offer*s*, not offer; pinhole is singular

P. 711: bullet A: *causing*…, instead of to cause.. the original sentence does not read well.

P. 713: 4th line from bottom: add *later in this section* after Fig 13-67.

P. 722: 7th line 5th paragraph:: Add gas *generated from corrosion* inside the container; sentence makes not enough sense otherwise.

P. 723: bullet 3: produce, not produce*s*

P. 725: 1st line 2nd paragraph: where no advective conditions occur in deposition holes; the sentence “as is” is colloquial.

P. 736: 2nd lat line above Candidate issues for the corrosion scenario: do not misunderstand issue on table for discussion, table here is Table 13-13; repeat Table 13-13 or say *this Table*

P. 740: top line of radiotoxic material…, not of *the* radiotoxic material

P. 740: 9th line from bottom: ongoing emissions… *have* no…, rather than has no…; emissions are plural

P. 743: 6th line 5th paragraph: site, not site*s*?

P. 756: 5th line 4th paragraph: to either the… rather than to either to the…; take “to” out:

P. 759: Figure 14-5, y-axis scale, is the unit correct? Should it be 10^{-6} etc., microSv?

P. 761: 1st line 2nd paragraph: fail*s*, not fail

P. 764: 5th line 1st paragraph: wa*t*er, not waer

P. 775: 3rd line 3rd paragraph: premise, not premise*s*?

P. 781: 4th line 2nd paragraph: details *are* neglected, not is neglected

P. 784: 3rd line 7th paragraph: studies reveal, not reveal*s*

P. 786:2nd line 4th paragraph: *the* same rather than same

P. 788: 5th line 2nd paragraph: occur*s* instead of occur

P. 788: 7th line from bottom: *uranium containing* or *uranium-containing* instead of uraniumcontaining

P. 798: 11th line from top: not, neither nor is a double negative… Better to say:… is not strongly affected by *either* societal changes *or*….

P. 809: 4th line 5th paragraph: *fewer* rather than less

P. 810: 3rd line from top in *the* above, or above; add *the* or remove *in*

P. 818: 4th line from top: design *basis value*, not design basisvalue

P. 824: 4th line from top: ...maintained reflect.., not …maintainedreflect…

P. 825: 9th line from top: remove *such*

P. 840: 12th line from bottom: values for input parameters, not values for input parameter values. Remove last *values*

Throughout the report (Vol I, II and III) there are several occurrences where the word "like" is used rather than "such as". Example: "This depends not only on the external conditions *like* the size of a future glacial load. It is better grammatically to use "such as" instead of "like".