Organisation de Coopération et de Développement Économiques
Organisation for Economic Co-operation and Development

26-Jul-2011

English - Or. English

NUCLEAR ENERGY AGENCY
RADIOACTIVE WASTE MANAGEMENT COMMITTEE

NEA/RWM/PEER(2011)3
Unclassified

SECOND QUESTIONNAIRE OF THE OECD-NEA INTERNATIONAL PEER REVIEW TEAM

At the request of the Swedish government, the OECD-NEA International Review Team (IRT) is examining the application by SKB for a construction license of a spent fuel repository in Sweden. Questionnaire 1, the NEA standard questionnaire with questions related to principles and good practice for safety cases, was submitted to SKB April 26, 2011 and answers were received June 14, 2011. The IRT members encompass a diverse knowledge- and experience-set. The 227 questions posed by the IRT members in this second questionnaire reflect the first reading of the SKB documentation from the individual and unique viewpoint of each IRT member. It is likely that a third questionnaire will be issued in due course.

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JT03305451

English - Or. English

1. INTRODUCTION

At the request of the Swedish government, the OECD-NEA International Review Team (IRT) is examining the application by SKB for a construction license of a spent fuel repository in Sweden. The IRT members encompass a diverse knowledge- and experience-set and, so far, have reviewed the information in SKB TR-11-01 from individual and unique view points.

In order to reflect this diversity, the 227 questions posed by the IRT members in this second questionnaire[1] are not pooled by subject but are presented as received from each individual IRT member. As a result, SKB may 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.

The questions in this second questionnaire are numbered and are organized per IRT member in sections 2.1 through 2.9.

SKB should anticipate receiving a third questionnaire, based on a further review of TR-11-01, more detailed and supplementary documents such as the process reports, and an analysis of the responses received.

2 QUESTIONS FROM IRT MEMBERS

2.1 Questions from IRT Member 1

2.2.1 Initial State

The following set of questions is related to the technical feasibility of the construction (including manufacturing) of the buffer, backfill and closure.

Q 2.1.1 What is the timing of the emplacement sequence of the buffer, canister and backfill for a specific deposition tunnel?

Q 2.1.2 Related to the open slot between the canister and the bentonite blocks, has the buffer time evolution been assessed under operational repository-like conditions (e.g., with respect to temperature and humidity)?

[1] Questionnaire 1, the NEA standard questionnaire with questions related to principles and good practice for safety cases, was submitted to SKB April 26, 2011 and answers were received June 14, 2011.

Q 2.1.3 Has the pellet emplacement in a deposition hole been assessed under wet conditions?

Q 2.1.4 Important bentonite properties such as swelling pressure and hydraulic conductivity are typically expressed as a function of the dry density. This is so in SR-Site for the backfill but not for the buffer. Is there any particular reason for that?

Q 2.1.5 Two different types of bentonite are considered in SR-Site. Has a comparative study of their different hydraulic and mechanical (including swelling pressure and strain for different dry densities) properties been performed?

2.1.2 Long Term Performance

The following set of questions is related to processes which might be relevant for the long term performance of the buffer, backfill and closure.

Piping erosion

Q 2.1.6 The model used in SR-Site for determining the buffer bentonite mass eroded by water is an empirical one. Does SKB consider this approach sufficient and why or, alternatively, is SKB planning to develop a hydro-mechanical model based on established physical laws in order to reduce existing uncertainties?

Saturation

Q 2.1.7 The water retention properties of bentonites, as expressed through a water retention curve (experimentally derived), usually indicate that even under full saturation conditions the bentonite is still in a suction state and hence it can keep absorbing water. Has SKB observed this bentonite performance as well? If so, has SKB assessed this performance for different dry densities and temperatures, under confined conditions?

Swelling

Q 2.1.8 Has the time evolution of the swelling strain under vertical stress been determined for different temperatures? Is there any significant difference in performance between the two proposed bentonites?

Colloid erosion

Q 2.1.9 SKB recognizes an incomplete conceptual understanding of buffer erosion (P.31, TR-11-01). Beyond the current approach and use of pessimistic hypothesis related to this process, is SKB also planning to fill this knowledge gap and reduce the associated uncertainty?

2.2 <u>Questions from IRT Member 2</u>

2.2.1 Initial State

The following set of questions is related to the technical feasibility of the construction (including manufacturing) of the canister.

Q 2.2.1 How did SKB come to the conclusion to use copper as a barrier material for the canister? Where is this documented? (There seems to be no documentation about any type of selection process in SR-Site.)

Q 2.2.2 In which way does SKB plan to develop quality-control data for the production in real world dimensions? How will quality control at the production site be handled?

Q 2.2.3 Related to the welding of the canister, so far only few demonstration welds have been made according to SR-Site. Will there be further investigation to give a detailed set of data? Presently SR-Site gives only very general explanations about the application of standard technology. During the demonstration experiments the need for improvement was shown. Would SKB agree?

Q 2.2.4 How will failures in the process of welding be treated? Is there a solution for incorrectly welded canister lids? Is there a process description to handle such cases? Will there be a procedure for repair? Will the canisters be rejected and have to be unloaded again? How will it be prevented that canisters with not-acceptable welds be deposited?

2.2.2 Long Term Performance

The following set of questions is related to corrosion processes which might be relevant for the long term performance of the canister.

Q 2.2.5 Experiments with test canisters (minican) showed high corrosion rates, as determined by electrochemical measurements. Were these results included in the safety assessment or will they and how?

Q 2.2.6 Are data available concerning the corrosion behavior of the welds? Which measurements were made to evaluate the corrosion behavior?

Q 2.2.7 There are only very few long-time corrosion experiments with coupons and/or test canisters. During evaluation of the results some of the samples were damaged. Are there additional experiments or will there be such? Which experimental data were used for long-term assessment?

Q 2.2.8 Copper corrosion strongly depends on the formation of protective layers. SR-Site in general is giving the impression that cuprite is the main corrosion product. This does not seem to be completely supported by the results from the minican experiments. Would SKB agree? How does SKB treat the possible layers from corrosion products and how does this affect the lifetime assessment?

Q 2.2.9 Usually, there is no strict linear progress of corrosion if one considers layer formation. Thus one would expect higher rates for the initial state followed by slower processes. SR Site refers to higher corrosion rates in the initial state only, due to changes in the environment. If these changes take place they affect the stability and formation of the layers during the initial and the following states of the repository. By which procedure is this effect take into account?

Q 2.2.10 Transport processes strongly influence the kinetics of chemical reactions. From the assessment given in SR-Site it is not clear how transport of corrosion products is acknowledged in the safety assessment. There is information about transport of corrosive substances, but not of corrosion products, it seems.

Q 2.2.11 How is the influence of changes in the environment of the canister, due to the corrosion products, on the corrosion processes considered?

Q 2.2.12 There is a discussion about copper corrosion in pure water without oxygen. If this process has to be taken into account, corrosion rates higher than assessed in SR-Site have to be considered. Are there experiments that deal with this type of corrosion? The theoretical assessment given in TR-10-30 is known but is it sufficient?

Q 2.2.13 If one assumes the possibility of copper corrosion in pure water in anoxic conditions, what would be the influence under repository conditions? Are there experimental data available for the assessment of copper corrosion under anoxic repository conditions? What is the behavior of copper that formed corrosion products under oxygen and later is exposed to anoxic conditions?

Q 2.2.14 Regarding SCC, there are no values for critical tensile stresses that would lead to SCC. If one considers mechanical stress onto the canister, what would be the influence of the mechanical properties of the copper canister and how would it be ensured that all production canisters will fulfill this demand? What magnitude of tensile stress is expected and what magnitude of tensile stress is considered detrimental? The canister process report TR-10-46 does not seem specific on this point.

2.3 Questions from IRT Member 3

These questions relate to the geology of the Forsmark site, the initial state of the underground openings and geosphere processes (TR-11-01 Chapters S, 4, 5.2, 7.4.5).

Q 2.3.1 Where is it documented that no major design changes have occurred in recent years and that the identified set of processes of importance for long term safety is stable? (P.16)

Q 2.3.2 Where is the average distance between transmissive fractures at repository depth documented (primary data set)? (P. 17)

Q 2.3.3 Where are the *in situ* swelling pressures of the bentonite in deposition holes documented (1-15 MPa)? (P. 30)

Q 2.3.4 Where is the *in situ* hydraulic conductivity of the bentonite buffer in deposition holes documented (<1E-12 m/s)? (P. 30)

Q 2.3.5 Where is the contribution to safety of the deposition tunnel backfill, and plug and clay in ramp and shaft documented? (P. 37)

Q 2.3.6 The "target area" as defined in Figure 4-5 seems to also include unsuitable regions (SE of ENE062A), what is the purpose of this term? (P. 105)

Q 2.3.7 Figure caption: What is the "target volume in the north-western part of the target area"? (P. 111)

Q 2.3.8 Is "Investigation site" the same as "candidate area"? Why the use of two different terms? (P. 109)

Q 2.3.9 Why are the horizontal stresses at Forsmark higher than typical for the Swedish coastline? Is there a clear relationship to the sedimentary loading and erosion history? (P. 116)

Q 2.3.10 Fractures occur on all scales. What is the lower size limit of fractures considered in the discrete fracture network models? Where is this lower limit justified? (P.120)

Q 2.3.11 There seems to be no description of brittle fault rock (cataclasites, gauge, etc.) in the sections describing the mechanical properties of fractures and deformation zones. Do brittle fault rocks really not occur in the Forsmark region? Are all brittle fractures only extensile fractures? Why so? (P. 121)

Q 2.3.12 When comparing the *measured* maximum horizontal stress magnitudes in the target volume with those measured above the A2 deformation zone, can a clear statistically significant difference be shown? Where can an explanation/discussion be found of the large variations per depth interval within the same domain? (P. 124)

Q 2.3.13 Where can the detailed discussions be found about when and how fracture hydraulic properties can change in the future (short term, i.e., in response to the excavation, and on geological time scales)? (P.125)

Q 2.3.14 The first paragraph on P. 125 states that there is a poor correlation between *in situ* stress and fracture transmissivity. Is the heterogeneous stress field known well enough to draw such conclusions at the scale of individual fractures? (P. 125)

Q 2.3.15 What are the pieces of hard evidence for the postulated, pronounced regional hydraulic anisotropy? Where are they discussed in detail? (P. 125)

Q 2.3.16 What are the reasons to subdivide the target bedrock volume in three, not two, depth intervals for fracture domains? Where is a detailed discussion given? (P. 125)

Q 2.3.17 What is the test interval length of Figure 4-16 upper inset? (P. 126)

Q 2.3.18 The cross section of Figure 4-18 includes a thick till layer - which is normally a low permeability soil - overlaying high permeability fractured bedrock. A low permeability layer is also indicated on page 140 (at least vertically). Why does a flow net for such permeability layering not show primarily vertical flow in the aquitard and horizontal flow in the aquifer? Where are the two de-coupled water table levels discussed elsewhere in the text? Should flow lines crossing permeability boundaries not show refraction? (P. 128 & P. 140)

Q 2.3.19 Where can a detailed description and discussion be found of the (high) hydraulic gradients inferred from deep borehole measurements, that exceed topographic gradients? (P. 128)

Q 2.3.20 Where can the detailed data sources of Figure 4-22 be found (matrix pore water sampling locations, fracture groundwater sampling locations)? Are the data sources sufficient to characterize the hydrochemical conditions in the “target volume”? (P. 133)

Q 2.3.21 Where can the detailed descriptions be found of the “altered rock surrounding flow paths”? How old are these alterations? (P. 137)

Q 2.3.22 Where can detailed information be found about borehole hydraulic head measurements, about maps and sections with measured hydraulic heads (and interpolated contour lines), recharge and discharge zones? (P. 140)

Q 2.3.23 Where can a detailed description be found of the underground site characterization program? How is this program integrated with the construction activities? (P. 151 & P. 153)

Q 2.3.24 Where can detailed descriptions be found of grouting measures and grouting restrictions? (P. 155)

Q 2.3.25 Hydrogeological measurements often only refer to small test volumes in comparison to volumes that control long-term inflow to underground excavations. This is one reason why most design methods used to estimate groundwater inflow into underground excavations in fractured rock fail (sometimes catastrophically). Where can detailed descriptions be found of the predictions made for inflow to the KBS-3 repository at Forsmark? (P. 158)

Q 2.3.26 The statements made about correlations between fracture size and inflow (transmissivity) are surprising. Where can the detailed discussions related to the transmissivity criterion of 1E-6 m^2/s (radius >250 m) be found? Which local geophysical method is capable of detecting every fracture with a radius bigger than 250 m? (P. 158)

Q 2.3.27 Where can a discussion be found of the selected excavation method (drill and blast compared to tunnel boring machine)? (P. 159)

Q 2.3.28 In underground excavations of heterogeneous fractured rock, complex hydraulic head gradients might develop which do not need to be uniformly oriented towards the excavation (e.g. deposition borehole) during the initial saturation phase. Could such shortcuts not lead to unexpected erosion of buffer material and clay? (P. 227 ff)

2.4.1 <u>Questions from IRT Member 4</u>

These questions relate largely to the hydrology of the Forsmark area. The questions are based on TR-11-01.

Q 2.4.1 It is not clear how the flow-dimensions and their spatial distribution are treated in the analysis. For example, according to the analysis of Pipe Strings System (PSS) data, 20 to 30 % of analyzed data suggest their flow-dimension to be close to 1-D, i.e., channeling flow. However, the DFN model and the ECPM model seem not to directly include the channeling flow effect. It might result in a conservative model because fractures tend to be well-connected. On the other hand, correction of transmissivity is necessary in the case where the channeling flow is taken into consideration, and the well-connected fractures approach does not necessarily constitute a conservative model. It would be helpful to receive information on how SKB considers the heterogeneity issue, especially the effect of the flow-dimension, and how it propagates to the safety discussion.

Q 2.4.2 Similarly, how does the uncertainty on the fracture-size distribution of the bedrock affect the results such as the numbers of the loss of deposition holes, the values of Q1 through Q3, and the F-factor? Also, it would be helpful if SKB provided their strategy to reduce the uncertainty by future survey in the area.

Q 2.4.3 The reasons for choosing three correlation models between fracture size and transmissivity are not clear. Only qualitative reasoning is shown. It is understood that a quantitative discussion for this kind of model is difficult; however, it is desirable to know how and why SKB chose three models, i.e., full correlation, no correlation, and semi-correlation, for the analysis.

Q 2.4.4 It is not clear how the criterion for the discharge to the deposition holes, i.e., less than 0.1 L/min., was determined.

Q 2.4.5 The numbers of deterministically treated fracture zones are different between the local and regional models. Is there any reason for this? And, how was the effect of this change evaluated? Also, how did SKB define the size of deterministically treated fracture zones to be longer than 1,000 m?

Q 2.4.6 Are the total head distributions from measurements using deep boreholes and the model result consistent? It seems that some discrepancy exists between the measured data and the calculated results, especially in the deeper part.

Q 2.4.7 In relation to the question 2.4.6, it is not clear whether the treatment of the pore pressure for the mechanical analysis and the groundwater flow analysis is consistent. For the mechanical analysis, a simple hydrostatic pore pressure increase by ice loading is considered; however, mechanical loading and the change of recharge amount/discharge location should affect groundwater flow, and hence, pore pressure distribution. Especially if the hydraulic conductivity of the formation is quite low, the loading/unloading-induced pore pressure effects could be important. It would be necessary to argue the consistency between the mechanical and hydrogeological analysis for long-term processes. In other words, how are the mechanical/fluid flow coupling processes by ice-mass loading/unloading taken into account? And how is the effect evaluated?

Q 2.4.8 The interference test results are used to validate the model used in this study. However, the spatial scales for the test and the discretization of the model may be different. How is this scale issue treated for validation purposes?

Q 2.4.9 For long-term safety analysis, information on the east/northeast of the candidate site may be necessary. What is the status on the acquisition of sub-sea information? And how does SKB evaluate the uncertainty of these data on the results of their analysis?

Q 2.4.10 Is the model scale appropriate for analyzing recharge/discharge locations? The obtained discharge locations seem to be very close to the model boundary, and hence, they might be affected by the boundary conditions of the model.

Q 2.4.11 For the discussion of several glacial cycles, is it appropriate to simply repeat the processes? Can all the processes, e.g., distribution of groundwater chemistry, be considered to become the same after one cycle of glacial cycle? Is there any supporting evidence?

Q 2.4.12 For the calculation of F-factors by the particle tracking approach, it seems that the rejection of deposition holes by FPC and/or EFPC criteria is not taken into account. It would be helpful if SKB explains the reasons for this apparent inconsistency.

2.5 <u>Questions from IRT Member 5</u>

2.5.1 Reference scenario, initial state

Canister and insert

Q 2.5.1 SKB recognizes that the canister and the insert have to meet the rigorous design premises (e.g. Vol. 2 p. 435, Vol. 3 p 766, p. 817, p.822). How is the quality of production assured? Are non-destructive testing methods available? What are the consequences if the required quality cannot be assured?

Q 2.5.2 SKB states that: “given the technical challenges in meeting the rigorous requirements and NDT capability, it might be considered appropriate to relax the requirements for the canister…” (Vol. 3 p. 822). Does SKB plan to change the design premises? What consequences may be expected?

Q 2.5.3 Statements on the initial state of the canister and the insert and their development on the long term are based on analysis of BWR canister and inserts. PWR canister and inserts are considered to be more robust and SKB assumes that they will meet the requirements if the BWR meets them (Vol. 1 p.175). Has SKB actually analysed this? Where is it documented? Is it planned to later include analysis of PWR?

Buffer, backfill, plug

Q 2.5.4 According to SKB the deposited buffer density and the composition of the buffer and the backfill are among the most important safety related features (Vol. 1 p.22). SKB concludes that in order to assure the sealing abilities of the plug and the bentonite an aperture smaller than 5 µm in the contact zone between the concrete plug and the rock surface is required (Vol. 2 p.304). SKB further recognizes that it is not known how tight the plugs can be made (Vol. 2 p.306). How is it assured that the buffer, the backfill and the plug will meet the design premises? How is it tested?

Deposition hole acceptance criterion EFPC

Q 2.5.5 According to SKB the acceptance of deposition hole according to the established EFPC criteria is one of the most important safety related issues (Vol. 1 p. 22). SKB recognizes as well that it is important to continue the development of acceptance criteria.
How is the successful application of EFPC assured? Has the successful application been tested? What are the consequences if not all existing water-bearing fractures are detected when applying EFPC? How many fractures could experience advective conditions without jeopardizing the safety? What are the consequences if more than the assumed water-bearing fractures will be detected?

2.5.2 Long term performance

Advective conditions/EFPC

Q 2.5.6 In its assessment, SKB makes several assumptions concerning the occurrence of water-bearing fractures and advective conditions in the buffer with regard to application of EFPC. In the reference scenario it is assumed that "roughly 70% of deposition holes do not have a flowing fracture intersecting the deposition hole" (Vol. 2 p.346). This is assured due to application of the deposition acceptance criterion EFPC. It is further assumed that: "No deposition holes are expected to reach advective conditions during initial temperate period (Vol. 2 p. 434); " Up to 2% of deposition holes may experience dilute conditions during a glacial cycle, only one deposition hole is calculated to lose buffer mass"(Vol. 2 p.537); and "Even for the most unfavourable cases less than 10% of the deposition holes reach advective conditions (Vol. 3 p.580). How many fractures may have advective conditions without jeopardizing the safety?

Transport resistance

Q 2.5.7 SKB assumes that 90% of all potential deposition holes have F-Values above 10^6 y/m (Vol. 2 p.430).The transport resistance has been characterised as one of the input variables having the most impact on the dose calculation (Vol. 3 p.690).Which F-Values are possible without jeopardizing the safety?

Colloid formation/ Buffer erosion

Q 2.5.8 SKB recognizes that the buffer colloid release/erosion process is poorly understood (Vol. 3 p.575) and that there is a conceptual uncertainty in the erosion model (Vol. 3 p.577). SKB also states that several safety functions cannot be guaranteed for deposition holes that have experienced loss of buffer due to erosion/colloid release to the extent that advective conditions prevail (Vol. 2 p.541 ff). How does SKB plan to fill the knowledge gap and reduce the associated uncertainties? Is the assessment made by SKB on the safe side?

Q 2.5.9 SKB states that "about 100 kg of dry bentonite may be lost due to erosion without jeopardizing the function of the buffer. This situation is handled by avoiding deposition holes with too high an inflow…and is not further assessed in SR-Site" (Vol. 2 p.318). SKB concludes that "no deposition hole will lose so much buffer that advective conditions must be assumed" (Vol. 2 p.435). How much bentonite could be lost in case the application of EFPC is not successful?

Backfill erosion

Q 2.5.10 SKB states that "a redistribution of 1,640 kg is assessed to have no impact at all on the backfill performance" (Vol. 2 p. 306). How much backfill could be redistributed at maximum without jeopardizing the safety?

Plug

Q 2.5.11 SKB states that a failed plug performance is not assessed (Vol. 2 p.306).
Does this have any negative impacts on the dose and risk calculation? SKB notes that the loss of eroded bentonite in the plug is based on an empirical model (p.309). Is this assumed to be sufficient?

Copper Corrosion

Q 2.5.12 There have been concerns recently (e.g. from KTH) about the possible corrosion rates of copper under repository conditions, esp. induced by different sulphur compounds that are not addressed in the SKB assessment. Is there evidence that these processes can be reasonably excluded from the safety assessment?

Sulphide concentration

Q 2.5.13 SKB states that there is a large uncertainty in distribution of sulphide which has impact on the copper corrosion, e.g. SKB observes high sulphide concentrations in some boreholes without knowing why this occurs only in some of the monitored sections (Vol. 2 p.360. p.367). How does SKB plan to fill the knowledge gap and associated uncertainties?

Fuel dissolution rate

Q 2.5.14 Although the fuel dissolution rate is considered to have a high impact on the dose calculations (Vol. 3 p.690), the documentation concerning the fuel dissolution in SKB main document is limited. What impacts cause changes in the dissolution rate? Has SKB done any calculation with varying dissolution rates? Where are they documented?

Solubility

Q 2.5.15 SKB states that "many of the most hazardous radionuclides have a very low solubility in groundwater and thereby have a limited potential for outward transport" (Vol. 1 p.61). How has the solubility of radionuclides been determined? Where is this discussed/documented? Which values have been used in the model?

Biosphere

Q 2.5.16 In the biosphere model the distribution of vegetation and land use is modelled. The biosphere model has a spatial detail of 20x20 m (Vol. 3 p. 631). SKB states that "…site representative values were used for model parameters, and their uncertainties were not handled pessimistically…" (Vol. 3 p.645). How is this considered in the dose and risk calculation? Which consequences on the long term are possible due to changes in the model? What are the parameters having the most impact? How sensitive is the Biosphere model to variable radionuclide source terms?

Reference glacial cycle

Q 2.5.17 SKB has chosen a Weichselian type glacial cycle as the reference to assess the effects of future climate evolution, thus repeating the last glaciation cycle (Vol 2, p.287). The maximum known glaciation during the Quaternary has occurred during Saale and/or Elster Glaciations. Ice sheet thickness during Weichselian at the site is supposed to have been 2900 m, while the Saale ice sheet thickness is estimated to have been 3400 m (Vol. 3 p. 612). What is the reason why SKB focused on the comparably lesser glaciation during the Weichselian? Is it unlikely that the next glaciation will be of Saale- or Elster-type? What are the expectable effects of a Saale- or Elster type glaciation?

Duration of climate periods

Q 2.5.18 Each interglacial is defined for 20,000 years (Vol. 2 p.319). Table 13-7 (Vol. 3 p. 676) shows the duration of each climate period in the simplified 120,000 year cycle.
What are the uncertainties of these assumptions, e.g., concerning the availability of agricultural areas? How are the uncertainties treated in the calculations? Which consequences would changes in the duration of the climate periods have on the calculated dose and risk?

Permafrost/repository depth

Q 2.5.19 Freezing of the buffer is ruled out for the reference scenario (Vol. 1 p.40). SKB concludes that permafrost will not reach the repository depth neither in the reference scenario nor in the most severe permafrost case (Vol. 3 p.592). The influence of climate and especially glacial conditions is discussed in terms of changes in hydrogeology and hydrochemistry, permafrost-influence, modifications of rock stresses and isostatic load on the container at repository depth. With respect to permafrost conditions, SKB states that "given that the uncertainty in the maximum depth of perennially frozen ground does not reach 450 m depth even in this most extreme unrealistic combination of all uncertainties, freezing of groundwater at repository depth is excluded in the reference glacial cycle." (Vol. 2, p. 447). Has SKB taken into account that the repository depth initially ranging from approx. 470 to 457 m (Vol. 1, p. 151) will not be preserved during its post closure evolution, as the Forsmark Site is expected to undergo further postglacial uplift in the range of approximately 70 m before the next glacial cycle (Vol. 2, p. 444)? How is a repetition of glaciation cycles (followed by depression and uplift and associated erosion phenomena) thought to affect the repository depth? Is there evidence that favourable conditions (e.g. Vol. 2, p. 540, 541) are preserved throughout the assessment period if a gradual reduction of repository depth with time is included?

Isostatic load

Q 2.5.20 Canister failure due to isostatic load is not included in the reference scenario since peak loads in the reference scenario (43.5 MPa) are below the design load of the canister (45 MPa) (Vol. 2, p. 530). The safety margin is not very high. Which consequences are expected if a more severe glaciation, e.g., comparable to Saalian is considered? This would add 4 MPa to the maximum isostatic load (Vol. 3, p. 614), resulting in a value of 47.5 MPa, which is above the canister design load.

Global warming variant

Q 2.5.21 Safety function indicators are considered to be similar to the ones of the initial temperate period. Therefore no detail account… is given" (Vol. 2 p.548). During a prolonged temperate period, higher erosion may occur. Has SKB considered this in the assessment?

Earthquakes

Q 2.5.22 The frequency of earthquakes is characterized as the largest uncertainty in the assessment of possible canister failure due to shear load. SKB states that seismic events that could impair the integrity would require an induced earthquake of approximately magnitude 5 (Vol. 2 p.297). SKB further admits that further investigation is required in order to determine the extent of damage zone which may host larger earthquakes (Vol. 3 p 834). To mitigate the earthquake hazard, current plans consider the application of the EFPC criterion (Vol. 1 p.157). Is the present knowledge considered sufficient to prove the safety? How likely is such an earthquake at the site?

Number of failed canisters/probability of canister failure

Q 2.5.23 "The containment function is provided by an intact copper shell of the canister" (Vol. 1 p. 42). The analysis indicates that containment is maintained even in the one million year perspective for a vast majority of canisters (Vol. 1 p. 42). SKB states that the number of failed canisters is substantially less than one. That is why the number of failed canisters is interpreted as the probabilities of canister failure (Vol. 2 p.536). What are the consequences if the probability of canister failure is not considered, but the number of canister failure is set to 1 for all cases when a number ≤1 has been calculated? How many canisters could fail at maximum, while still maintaining compliance with the risk criterion?

2.5.3 Analysis of scenarios

Likelihood of scenarios

Q 2.5.24 The scenarios which have been analysed are classified as less probable and residual scenarios. The residual scenarios are not propagated further in the assessment (Vol. 3 p.573 ff). Namely:

- Buffer advection is considered as a less probable scenario.
- Buffer freezing is considered as a residual scenario.
- Buffer transformation is considered as a residual scenario.
- Canister corrosion is considered as a less probable scenario.
- Canister failure due to isostatic load is considered as a residual scenario.
- Canister failure due to shear load considered as a less probable scenario.

Is this characterisation still valid in case the assumption of the glacial conditions are adapted to the more severe ones e.g. comparable to the Saalian cycle instead the Weichselian? Would the regulatory limits be met if the buffer freezing and/or canister failure due to isostatic load were considered as less probable scenarios?

Analysis of scenarios

Q 2.5.25 The two scenarios contributing to risk are the corrosion scenario with assumption of advective conditions in the buffer and the canister failure due to shear load while assuming an intact buffer (Vol. 3 p.618). In all scenarios of canister failure the correct application of EFPC is assumed (e.g. Vol. 3 p.599). SKB states that the number of canisters that may fail depends on the success of detection and avoiding large fractures in deposition holes (Vol. 3 p. 619). What are the consequences if not all existing water bearing fractures will be characterised with the EFPC?

Buffer advection scenario

Q 2.5.26 SKB calculates that consequences in terms of canister failure are similar (on average 0.17 compared to 0.12 in the reference scenario) if advection is assumed initially in all deposition holes (Vol. 3 p. 574). What assumptions underlie this calculation? What is the reason that the increase is so small?

Canister corrosion scenario

Q 2.5.27 The canister is assumed to fail at 114,000 years after deposition (Vol. 3 p.655). In the most pessimistic variants of the corrosion scenario SKB assumes the first canister failure and hence the first release to occur after around 50,000 years (Vol. 3 p.737).
How is this calculated? Which assumptions have been made? Are they pessimistic? Where is this documented? The failure time has been characterised as the one input variable having the most impact on the dose calculation (Vol. 3 p. 690.) When could the first canister fail at the earliest without jeopardizing the safety?

2.5.4 Additional analysis and supporting arguments

Records and memory keeping to protect from human intrusion

2.5.28 SKB states that countermeasures to prevent inadvertent intrusion are generally assumed to be preserved for between 100 and 500 years. In the assessment SKB assumes that an inadvertent intrusion such as drilling will take place at the earliest 300 years after repository closure (Vol. 3 p.745). Which measures will be implemented to keep and transfer the knowledge about the repository for this period? Where is this documented? How is it assured that the required resources are available?

Provisions not to allow an unsealed repository

Q 2.5.29 Based on the analysis of the case of an unsealed repository SKB concludes that the repository *should not* be abandoned prior to complete backfilling and sealing.
What is SKB planning in order to assure that the required financial and personal resources are available at the specific time?

Growing pinhole failure

Q 2.5.30 SKB postulates that one canister has an initial penetrating pinhole defect (Vol. 3 p.705). What are the reasons of postulating that there will be only one canister with such a defect? Can the quality of manufacturing and testing methods be assured?

Time beyond 1 million years

Q 2.5.31 Risk and dose calculations show that the peak is in some cases not reached within 1 million years. Has SKB calculated when the risk and dose peak is expected? What variables have impact on the time of the peak?

2.5.5 Sensitivity analysis

Q 2.5.32 The input variables having the most impact on the total dose at 1 million years are (Vol. 3 p.690):

- the fuel dissolution rate D_{Fuel},
- the transport resistance F and
- the failure time $t_{failure}$

How has SKB handled this in the assessment?

2.5.6 Robustness

Q 2.5.33 The statements on the robustness (Vol. 3 p.813) are very limited. Does SKB consider them as sufficient? Is it planned to add more considerations to this issue?

2.5.7 BAT

Q 2.5.34 In Section 14.3. SKB discusses several techniques to demonstrate optimisation and the use of BAT (Vol. 3. p. 761 ff). How has SKB decided which techniques are assessed to demonstrate optimisation and the use of BAT? Which criteria and which procedures have been applied in the selection? Where is this documented? Which alternative techniques have been assessed but not been chosen and why? Where is this documented?

Q 2.5.35 SKB recognizes that when applying an inflow criterion instead of the EFPC all unsuitable positions will be identified (Vol. 3 p.765). Why is the more strict inflow criterion not applied? Does SKB plan to apply the inflow criterion at a later stage?

2.5.8 Public Participation

Q 2.5.36 According to international recommendations, e.g., IAEA or NEA, stakeholders and the public ought to be included in the process of realizing a final disposal. What public participation measures have been used during site selecting and with regard to SKB`s application for construction? Which public participation measures will be implemented in future? Where are they documented?

2.6 <u>Questions from IRT Member 6</u>

These questions are based on a partial review of TR-11-01 and some background reports.

Q 2.6.1 Has SKB prepared a concise (20-30 page), plain language synopsis of the factors that contribute to the long-term safety of the repository? By this is meant a simple, easy to understand summary for the non-technical person of how the materials to be disposed, the site, and the repository design work together to provide for the overall safety of the repository. If such text only exists in Swedish, would it be possible to have it translated?

Q 2.6.2 Please describe the measures that SKB will take during construction and operation to monitor key geotechnical and design parameters in order to identify deviations observed from those conditions assumed in the license application that may affect compliance with applicable safety regulations. In particular, how will SKB use data collected during this period to verify its modeling assumptions?

2.7 Questions from IRT Member 7

These questions from IRT member are based on a once-through reading of SKB TR-11-01, the main report of the SR-Site Project, Volumes I, II and III.

Policy and other provisions to keep memory of the repository and also to avoid an unsealed repository

Q 2.7.1 The length of time it will take to build, fill and close a repository is of concern with respect to political, social and economical stability in a country. There is no example in the world of a similar large project that has needed this type of intense management and institutional control over such a long time, and certainly not for something as potentially harmful as spent fuel. SR-Site analyzes a completely filled repository with all deposition tunnels sealed but with the central area and the main shaft left open. What about a partially filled repository in which several deposition tunnels are left unsealed? The argument (made in SR-Site with respect to nuclear bombs) that, if this were to happen as a result of political, societal or economical problems, these problems would probably be more catastrophic than a left-open repository may be weak. Perhaps more attention needs to be paid to this possibility and how, in a changing situation, an unfinished repository can be made always passively safe; for instance, should there be criteria as to how fast finished tunnels should be backfilled and sealed?

Q 2.7.2 At some older nuclear sites in the world that are undergoing clean-up or decommissioning, there are considerable problems with existing records, and understanding of those records, kept over a time span of at most 50 years. The time span over which records must be kept for a repository while it is being excavated, filled and closed may potentially be much longer. How has SKB considered this?

Effects of water freezing

Q 2.7.3 Potential freezing of the repository is limited to freezing of free water. Permafrost penetration to repository level and buffer and backfill freezing occurs at lower temperatures, -2^{o}C and -4^{o}C. These isotherms do not reach the repository in the analysis. However, they come quite close in some cases in the analysis (i.e., with not a lot of margin, Figures 12-7, 12-8, 12-10, 12-11). While these cases may not be realistic, there could be many benefits to moving deeper with the repository such as even less fractured rock, less likely to have to reject deposition holes, longer timeframes for intrusion of dilute water, etc. There are also arguments against going deeper, mainly rock stress and perhaps costs? A better weighing of arguments pro and against going deeper could be made. As the case reads now, one gets the impression that much can be gained from locating the repository deeper but that the idea is rejected on weaker arguments.

Q 2.7.4 The argument on P. 592 why even the possibility of water freezing (0^{o}C isotherm) is very unlikely seems somewhat weak. It is always somewhat risky to analyse the most pessimistic conditions, finding some effects and then trying to argue that those effects are not serious or would not occur because the case or conditions are deemed unrealistic. With the occurrence of the Fukushima disaster, this type of arguing may be more vulnerable now. There should be more emphasis on the -2^{o}C and -4^{o}C isotherms not reaching the repository depth, it is these isotherms that affect safety functions. And it these safety functions that could perhaps benefit from more margin by going deeper with the repository.

General

Q 2.7.5 With respect to the feedback to assessed reference design and related design premises, SKB has presented its case and found no deficiencies. By mentioning reasons to revise the reference design one admits that no design will ever be perfect. At what point is it safe enough? It is safe now, according to SKB, in 2011 with the publishing of SR-Site. So there have to be compelling reasons to further refine the design in the future. Are there guidelines as to which improvements should be accepted, which rejected, what would guide this (the law of diminishing returns)?

Boreholes management

Q 2.7.6 What is done with rejected deposition holes? It is not explicitly stated in SR-Site that they will be filled in. If deposition holes that were rejected because of too-high water inflow were left open they could fill with water, in which development of microbial activity could occur, producing organic matter that may not be desirable for a repository. Can it be stated that any rejected cavity will be grouted and filled in order not to have anything filled with water left in a repository? On P. 193, in Figure 5-17 it appears that rejected boreholes are filled in with backfill. This seems not mentioned anywhere else in SR-Site. Why is backfill used and not buffer? Backfill may allow microbial activity.

Q 2.7.7 There seems to be some doubt or ambiguity about the bottom plate in the SR-Site report. Is there not a simpler way of evening out the bottom of a deposition hole than the added complication of a bottom plate? Could SKB devise a method by which to compact a bottom layer of bentonite with a flat top *in situ* on which the first bentonite block can be placed? The inclusion of bottom plates seems to unnecessarily complicate the safety case of the design.

Q 2.7.8 Could modelling and direct observation be accurate enough to predict most the locations of holes that would be rejected because of the presence of water-bearing fractures, such that they are not even drilled? If too many boreholes are in need of rejection this could affect the foot print of the repository.

Q 2.7.9 Could one grout the fractures intersecting the deposition holes, such that water comes in by diffusion only? Why does some degree of piping have to be accepted? Is the addition of grout too much of a problem for the bentonite buffer?

Fuel

Q 2.7.10 Due to high BU fuel (P. 164), canisters will be deposited that will be only partially filled According to Figure 5.7 there will be about 600 of those, which is 10% of all canisters. Has it been considered to use canisters of different dimensions for these fuels rather than part-fill the reference canisters, for instance to save on materials? Is there more room for water than the stated 600 mL in these part-filled canisters or are they backfilled with something? If so, with what? If not, is there a problem with the empty space in these canisters?

Q 2.7.11 In Table 5-4, the calculated inventory, based on type containers, is always somewhat higher than the inventory assumed in safety calculations. This is then argued away taking fuel ages into account. This may create the notion of an argument after the fact. Could some calculations be provided that show that this is not detrimental, rather than just making the argument?

Q 2.7.12 The more recent ideas on what may affect fuel stability, i.e., alpha-self irradiation, radiation-enhanced diffusion, He-build-up and the influence from high BU are not discussed in SR-Site but the reader is referred to the fuel canister process report. A more thorough assessment of these effects in the main document would seem warranted. In some countries (especially France) some of these potential effects have been given much attention. What do the Swedish fuel specialists think of these potential effects? For example, what about fracturing of the fuel and increasing the fuel surface and dissolution rate as a result of He production?

Canister/Corrosion

Q 2.7.13 How was the corrosion depth value of trapped atmospheric O_2 (< 500 µm) derived (P. 316)? Calculated values given in the preceding text were 17, 34, 106, 260 and 768µ, depending on assumptions. How is < 500 µ derived from this? Would it not be better to say that the depth would be < 768 µm?

Q 2.7.14 What does it mean that 10^{-6}canisters may be sheared (P. 430)? What does it mean that less than 8.3×10^{-3} canisters may fail (P. 480)? If it means that < 1 in all of the 6,000 canisters may fail, why not just say that?

Q 2.7.15 Does the argument of evening out corrosion really work (P. 430)? What if the bottom of the defect was affected by the same rate of corrosion as the non-defected surface area of the canister? Would it never even out then? What would be the consequences in that case?

Q 2.7.16 There are some inaccuracies with the notation of safety functions (P. 746, P. 755). Can 1 says "provide corrosion barrier", not "ensure containment" in Fig. 10-2, and Bf1 is BF1 in Figure 10.2. They should be word-for-word the same to prevent confusion.

Q 2.7.17 Information about pitting corrosion and SCC appears scarce or absent in SR-Site. Were they shown to not be important? What are the arguments for leaving these processes out of SR-Site?

Buffer/Backfill

Q 2.7.18 In SR-Site both the terms dry density and saturated density are used which is sometimes confusing. It would be easy to provide a graph showing the relationship between dry density and saturated density, such that, if both terms are used, the reader can convert one value into the other easily.

Q 2.7.19 The original water content in the buffer material is adjusted to facilitate the manufacturing process (P. 185). What type of water is used for this? "Dry" bentonite may contain 7-9% water, so the water added could be 8 – 10% to arrive at a water content of 17%. There is a danger of adding unwanted elements (such as organics, sulphides and sulphate) if no controls are put on the quality of this added water.

Q 2.7.20 In Table 5-17 (and on P. 190 – 191) there are a number of dry densities specified for pellets, loose filling, etc. What is the rationale of all these different dry density values, aperture restrictions?

Q 2.7.21 The process of metallic iron affecting the montmorillonite in bentonite has been considered although the actual process is not really discussed in SR-Site. However, another potential process, i.e., buffer cementation due to iron corrosion products (from the inserts, once containers have failed) appears to be missing. Is the reason for omission of this potential process that containers fail only when the buffer is eroded, and not by any other means, such that it would not matter what Fe corrosion products would do to the buffer? It would still be advantageous to consider what could happen to some of the buffer functions if buffer were cemented by iron corrosion products. Has this been considered?

Q 2.7.22 Radionuclide transport is considered to be diffusion controlled in the buffer because of its tight contact with rock (P. 255 and P. 260). In laboratory experiments, it has been shown that microbes can move along the interface between a bentonite plug and the walls of a pressure cell, but not through the bentonite matrix, Therefore, rock-bentonite interfaces could possibly be preferred transport routes, because of the clay gel layer at the interface between bentonite and rock. Is this a credible process, has it been considered? Or is it disregarded because radionuclides can only escape from failed container and containers fail only when the buffer fails (i.e., erodes)? Should such a process not be analyzed anyway?

Q 2.7.23 Rather than sinking, could the weight of the canister just compress the bentonite? Could that lead to less dense buffer elsewhere in the deposition hole by initially creating a space near the top of the canister (P. 255)?

Q 2.7.24 Gas transport through compacted buffer appears to be not well-characterized or known (P. 265), even after reading section 13.8. Is more work planned on this?

Q 2.7.25 On P. 256 it is stated that repeated freezing and thawing has no effect on the sealing properties of buffer while on P. 265 it says that repeated freezing may affect the transport properties of backfill. This seems to be a contradiction; both materials are bentonite-based.

Q 2.7.26 In the reference evolution of the buffer an important process appears to be missing (e.g., P. 368-371, P. 389 and P. 395. 397). The initial drying out of the buffer because of high temperature from the fuel in the canisters is not discussed explicitly. Only a drying out of the buffer because of dry rock during installation appears to be considered. Buffer will initially dry out and may crack as a result of the high canister temperatures. These cracks could be quite long-lived depending how fast the water saturates the buffer which has quite a time span in the analysis. When these cracks "age" they may become encrusted and "cemented" by salt deposits and perhaps by other minerals. Is it certain that they heal again fully to their original density and to full swelling pressure, when the buffer saturates? If complete sealing of these cracks did not occur, what could be the consequences?

Q 2.7.27 In the analysis on P. 384 – 386 the possibility of very low swelling pressures is shown both in buffer and backfill. But no comment is made with respect to loss of safety functions of buffer and backfill in these pages, including the loss of enough density to keep microbial activity to a minimum. Has the possibility of increased local microbial activity and its consequences been analyzed?

Q 2.7.28 The idea of lowering the dry density of buffer to improve the shear failure analyses (P. 808) causes some concern. High density is needed for other safety functions such as suppression of microbial activity. This idea seems to leave the door open to reducing swelling pressure through decreasing dry density but it is not propagated to the other safety functions of the buffer. Even if the reduction is such that other safety functions are still okay, there would be a loss in the margin of safety for those functions. All other safety functions would need re-evaluation if a decision to reduce buffer dry density is made. For example, has SKB shown the margin in dry density for microbial activity? Buff 2 just stipulates high dry density, what is high, are there numerical values?

(Geo)Chemistry

Q 2.7.29 P. 240 mentions chemical reactions between bentonite and concrete. What are they? Are they treated? How, where?

Q 2.7.30 The calculations on P. 348 cause some confusion. Why was the calculation done for dilute salt concentrations of 1 g/L which is well above the dilute criterion of 0.3 g/L for erosion of buffer? If only 1-2% of boreholes drop to 1g/L, is there still a problem (1g/L is still much higher than 0.3 g/L)? A similar calculation is done for 3 g and 0.3 g on P.501. The different values are confusing, as well as the use of both mmol and g/L when considering dilute conditions. This could be standardized.

Q 2.7.31 How much will salts present in buffer and backfill materials affect groundwater salinity at repository depth? Has this been studied or modelled in other documents? If so, it could be mentioned in SR-Site and the reader referred to the pertinent document. Does dilute glacial water really stay dilute or will it pick up salts from fracture fillings in the rock and from buffer and backfill salts? Are there any data, or ongoing or planned studies?

Q 2.7.32 Global warming may cause an increased inflow of carbonic acid and sulphate (P. 547 and 548). If subsequently SRB turn this sulphate into sulphide, sulphide concentrations could increase. However, it is also stated that sulphide levels are expected to remain the same as current groundwater concentrations at Forsmark. If this is expected, then any increase in sulphide has to be counteracted, for instance by precipitation with Fe. Is there sufficient Fe to counteract any potential increases in sulphide levels in case of global warming?

Q 2.7.33 Is there an inconsistency on P. 710 and 711? It is stated that sorption of Ra-226 in tunnels and soil reduces transport and dose considerably but on P. 711 it is stated that Ra has no affinity for bentonite. Buffer and backfill are both bentonite-based. So what is Ra sorbing on in the tunnels?

Q 2.7.34 The conclusion that no gas hydrates will occur at repository depth as based on permafrost studies seems to contradict the studies quoted. These studies indicated gas hydrate formation or past presence (P. 791). What would the effects be of the presence of gas hydrates on a repository? Why are they a concern?

Microbiology

Q 2.7.35 Has microbial activity as a result of superplasticizers (SP) in concrete materials been considered? On P 367 it is stated that the contribution of SP to the C concentration will be negligible. On what is this based, where can calculations be found? SP is largely C and for 1-2wt% in grout, this could contribute a considerable amount of C, depending on the amount of grout and concrete used.

Q 2.7.36 Nitrate-containing water is pumped out (P. 311). Many microbes are very capable of nitrate reduction (switch to nitrate as electron acceptor after O_2 concentration has been exhausted by aerobic respiration) and this may be the main reason why the fracture waters appear unaffected by any nitrate.

Q 2.7.37 High sulphide concentrations are identified as a concern in SR-Site, and sulphate reduction may have been enhanced in some boreholes by grunge in the boreholes (P. 360). Was there any material placed in the boreholes that could have leached organics? See for instant a recent paper from the Mont Terri project in which sulphate reduction completely dominated the geochemistry of the water in a borehole. The organics came from pH electrodes that leaked glycerol. This illustrates how something unexpected or overlooked can have considerably consequences for microbial and geochemical reactions.

Q 2.7.38 Microbes will use up O_2 largely in the backfill but not in highly compacted bentonite (P. 365); that distinction should be made, if one of the safety functions of the buffer (Buff 2) is to reduce microbial activity in thee buffer.

Q 2.7.39 On P. 596, a swelling pressure of 1 MPa is used as a criterion below which microbial activity may be enhanced. However, in Figure 10-2, the Buff 2 criterion for reducing microbial activity is high density. Density and swelling pressure are related and perhaps the safety function for reducing microbial activity should be both high density (with a numerical value) and a swelling pressure of > 2MPa? Which factor actually controls microbial activity is not entirely clear.. Density may affect the pore space available for microbes while swelling pressure may inflict a pressure higher than turgor pressure on microbes. Either effect would limit microbial activity. What is SKB's opinion on these two effects, are they not distinguishable or is one of these dominant in reducing microbial activity?

2.8 Questions from IRT Member 8

These questions are based on the lectures given by SKB and on the SKB TR-11-01 document.

2.8.1 Initial State

Canister Design

Q 2.8.1 Rigorous NDT methods are needed for the insert (P. 766). Are these methods available, described, qualified and already tested ? Where is this documented?

Q 2.8.2 The plug design is not completely determined, whereas the understanding of its evolution seems rather empirical. On what basis can SKB claim that plugs meeting the requirements will be industrially feasible?

Q 2.8.3 Demonstrators and prototypes: Is there a document presenting the components needing further development and testing, and presenting the detailed planning for these tests? In particular, are the knowledge gained and the planning of future experiments in the Aspö laboratory presented in a comprehensive way?

Q 2.8.4 Is it planned to have specific monitoring of some (or more) deposition tunnels to verify that the predicted evolution (saturation, absence of piping...) is effective? Is this described and planned in detail in a document?

Hydrogeological modelling

Q 2.8.5 What is the justification of the choice of the semi-correlated DFN model? Different arguments are given in different places (especially P. 350 where it is only said that the uncorrelated model does not fit empirical data, but nothing on the correlated one). Could a comprehensive argumentation be presented?

Q 2.8.6 How was the base case of the DFN model chosen, among the 11 realisations of the probabilistic model? The concern is that this base case leads to less canister failure (0.087) than the mean of the realisations (0.12) (see P. 533). But, is this significant?

2.8.2 Scenarios

Corrosion scenario

Q 2.8.7 In the scenarios, the correct application of EFPC is considered for granted (P. 599). In a pessimistic assessment, should not a failure in the implementation of this criterion, for a certain period during the exploitation, be considered?

Q 2.8.8 Why is the reference evolution described with the base case DFN model, whereas the corrosion scenario is evaluated with a set of realisations of the model? This leads to some confusion for the reader. Is the base case included in the realisations used to calculate the mean value?

Q 2.8.9 Could SKB present a table similar to Table 10-26 for each of the realisations of the DFN model (11 for the semi-correlated, 6 for the uncorrelated, 6 for the correlated), presenting depositions where advective conditions occurs, and failure time? Is it still true in all cases, as for the base case (see P. 533), that these failures require the highest sulphide concentration to occur before 1 Ma?

Q 2.8.10 Could SKB present (for example in an XL form) the breakdown of the probabilistic calculations for the three Figures 13-17, 13-26 and 13-27? More precisely, could SKB list the realisations of the probabilistic calculation contributing to the pulses observed, and present for each the details of the features causing the pulse:

- concerning the realisations and input data associated (e.g., realisation of the DFN model, concentrations...)
- concerning failure positions and time associated

Records and memory and future human actions

Q 2.8.11 With respect to memory: are the measures that are planned, to transfer memory of the repository, described in a document?

Q 2.8.12 With respect to the drilling case: The assessed impact of this case is very high, and seems unacceptable with regard to the health protection references. As it is mentioned, the assumptions are clearly unrealistic. As a result, no conclusion can be drawn from this scenario. Why is not a refinement of the assumptions presented, more realistic but still pessimistic, to assess this scenario?

2.8.3 BAT

Q 2.8.13 On P. 763 it is stated: "Since the calculated risk is below the regulatory limit, the selected copper thickness is deemed adequate from the point of view of BAT". Is the fact of being below the regulatory limit considered as a criterion for BAT?

2.8.4 Other

Q 2.8.14 Can SKB provide the document quoted on P. 54 in English (or at least a summary), presenting how the conclusions from former reviews have been considered?

Q 2.8.15 Can SKB provide the document SKB 2010b in English (or at least a summary), presenting the program for detailed investigation?

2.9 <u>Questions from IRT Member 9</u>

These questions are based on a review of TR-11-01

2.9.1 Reference scenario, initial state

Canister and insert

Q 2.9.1 What are the bases for the statement (P. 167) that no more than 600 grams of water will be left in the canister? What are the bases for the implication that if less than 600 grams of water is left in the canister, no degradation will occur?

Q 2.9.2 In Table 5-8 on page 168, is the value for niobium content of the PWR cladding correct?

Q 2.9.3 At the bottom of page 170, SKB states that for an isostatic load, the margins of NDT methods for detecting critical flaw sizes are adequate to make the probability of missing critical defects low. Are asymmetric loads also possible? If so, would the NDT methods for asymmetric loads be equally reliable?

Q 2.9.4 It is unclear why the units for the probability of detection using the current NDT methods (p. 171) are in millimetres. Please explain.

Q 2.9.5 On page 171, SKB states that deviations in the copper canister thickness that would reduce the canister thickness below 45 mm could be "detected with the naked eye" such that the probability of a canister having a thickness less than 45 mm is considered "negligible". Does SKB plan to use visual measurements to identify deviations from the design canister thickness below 45 mm?

Q 2.9.6 Table 5-9 on page 172 provides information on the design thicknesses of the copper canister wall along with the distribution of canisters with walls that are somewhat thinner than the design value. In the first part of the table, the fraction of canisters with a wall thickness between 45 and 47.5 mm (e.g., 1.5 to 4 mm narrower than the design tube thickness of 49 mm) is stated to be a "few per thousand". In the lower half of the table, the fraction of the canisters with thicknesses 10 to 20 mm lower than the design value is stated to be "one per thousand". Are these numbers consistent?

Q 2.9.7 On page 173 SKB notes that "eight tubes and twenty lids" were inspected, using NDT methods. Is the distribution of the canister thicknesses found in Table 5-9 on the previous page based on these 28 tests?

Q 2.9.8 On page 176 and again on page 177, it is stated that a key design premise is "a nominal copper thickness of 5 cm, also considering the welds." If so, then please explain the difference between the value stated on page 176 and the design value of 48.5 mm for the "welds" in Table 5-9 on page 172.

Q 2.9.9 Please confirm that for the purposes of canister failure estimates, the design values shown in Table 5-9 are used rather than the 5 mm value stated on pages 176 and 177.

Q 2.9.10 The statement at the bottom of page 177 implies that SKB plans to measure the temperature on the surface of the canister after emplacement. Please confirm if this is correct, and if so, provide the means of measurement and the period of time the measurements will be conducted.

Q 2.9.11 What are the bases for the design criteria of an exposure rate maximum of <1.0 Gy/h on the canister surface (pg. 178)?

Buffer, backfill, plug

Q 2.9.12 When will the design of the plugs, shown schematically in Figures 5-22 (page 197) and 5-24 (page 199), be completed?

Q 2.9.13 On page 576, SKB states that the allowed variability of the composition of the selected buffer materials "will be defined at time of purchase of the buffer". Please explain why the allowed variability cannot be decided now?

Q 2.9.14 Should there be a Ca/Na ratio criterion for the bentonite buffer? Should the criterion be a range of values between which a buffer material would have the right combination of swelling properties without being too stiff so as to transfer rock shear forces to the canister? It is also noted that the Ca/Na ratio affects sorption properties (page 578).

Q 2.9.15 On page 426 it is stated "models indicate that the plug is saturated rapidly." SKB claims that the assumption of slow plug saturation is "pessimistic". Assuming the plug is designed similar to that shown in Figure 5-22, could there ever be a case where the hydraulic pressure to the left of the plug in this figure could exceed the pressure on the right? If so, the plug may become dislodged. Has this been considered?

Q 2.9.16 The Ca/Na ratios of the two bentonite materials provided in Table 5-10 (page 180) are potentially significantly different. On page 398, SKB states "the maximum free swelling of the bentonite is strongly dependant on the *valence* and concentration of the ions in the interlayer space." [emphasis added]. Since the Ca/Na ratios of the two bentonites are different, are the same design criteria used for both types of bentonite? If so, why? If not, what are the separate criteria?

Q 2.9.17 Table 5-11, page 181, provides the design criteria for the solid and ring-shaped blocks and the bentonite pellets – along with the accepted variation in the criteria. SKB notes at the bottom of the same page that the statistical variation of the solid and ring-shaped blocks shown in Table 5-11 (page 182) are based on measurements of 10 ring-shaped and 15 solid blocks. Table 5-12 provides one standard deviation and 99.9% confidence interval values. It is noted that the 99.9% C.I. value for the ring-shaped block density slightly exceeds the design value. Are the values in Table 5-12 based on sample sizes of ten and 15? Also, are the values in Table 5-12 for MX-80 or Ibeco bentonite? Are the same design criteria (Table 5-11) and variabilities (Table 5-12) used for both MX-80 and Ibeco bentonites?

Q 2.9.18 Please explain the differences in the 99.9% C.I. numbers in Table 5-13 (page 183) from the 99.9% C.I. values in Table 5-15 (page 186). It is also noted that the first three entries in the 99.9% C.I. column in Table 5-15 are slightly below the design criterion of >1950kg/m^3. Is this acceptable?

Q 2.9.19 A "Milos Backfill" will be used for the backfill (page 188). How do the properties of the Milos Backfill compare to the MX-80 and Ibeco bentonites that are planned for the buffer, and how do the property differences relate to the design criteria for the Milos Backfill compared to the MX-80 and Ibeco buffer bentonites?

Q 2.9.20 Row "Bu23" in Table 7-4 (page 230) refers to a montmorillonite density at saturation of 1650 kg/m^3. Earlier in this volume a number of 1950 kg/m^3 was referred to. Please clarify why the 1650 number applies for transport.

Q 2.9.21 On page 304, it is unclear what "a value of 10% is used *as an example* in SR-Site" means related to water saturation of the plug and its sealing ability.

Q 2.9.22 On page 309, it is stated that "[T]he plug design will under all circumstances be adjusted to meet the requirements and failed plug performance is not assessed in SR-Site." What technical bases does SKB have to have confidence that, indeed, the plug can be designed for all reasonably likely eventualities?

Q 2.9.23 SilicaSol is to be used to grout boreholes if cement-based grout "is unsuitable" (page 367). This must mean SKB has not yet determined whether cement-based grout will work. When and how will this be decided? It is also not clear what a "grouting hole" is. Does SKB mean small fractures, or the grout-filled portion of fractures, or boreholes, or something else?

Q 2.9.24 On page 373, please confirm that a "fast" and "slow" tunnel means a tunnel in which the groundwater flow rate is "fast" and "slow", respectively.

Q 2.9.25 Figure 10-52 on page 375 presents the results of calculations on the swelling pressure for various pellet slot sizes. While it is clear what the pressure in the pellet slot and the block is, please clarify how the "total" swelling pressure is derived for this figure.

Q 2.9.26 In Figures 10-57 and 10-58, the legends refer to “(Avg. 75%)”. Please explain what this means.

Q 2.9.27 Figures 10-65 (page 393) and 10-66 (page 394) provide results of calculations on the evolution of calcium and sodium as a function of position and time in two different buffer materials. It would be beneficial to see a side-by-side comparison of Na and Ca concentration evolutions for the MX-80 and the Ibeco bentonites using the *same* water saturation time (one short and one long), so the effect of the Na/Ca ratio between the two bentonites can be determined if the behaviour of the two types of bentonite was similar enough to *not* cause significantly different colloid stability behaviours between the two types of bentonite. Is such a comparison available?

Q 2.9.28 Figure 10-69 (page 398) shows the calculated influence of temperature on the stress-strain behaviour of the two different types of bentonite. Strain behaviour of the Ibeco bentonite may be significantly different for the two temperatures considered (20^{o}C and 150^{o}C). None of the curves shown, however, are for the peak buffer temperature criterion of 100^{o}C. Are plots of the behaviour at 100^{o}C for each bentonite type available? Also, SKB states that the difference in the shear properties between 20^{o}C and 150^{o}C are „not very prounounced“. Visually, the shear properties in the right figure in Figure 10-69 look different. What assessment was done to allow SKB to conclude the difference between 20^{o}C and 150^{o}C shear properties was „not very pronounced“?

Q 2.9.29 Table 10-8 provides a summary of the results from calculations of sensitivity analyses of the chemical composition of two different bentonites[2] - one of which is a heretofore unmentioned „Deponit CA-N“ bentonite. Is this a third bentonite type that may be used in the buffer or backfill? If so, where are the results for the Ibeco bentonite?

Q 2.9.30 In the discussion of the interaction of a degraded bottom plate and the buffer on page 411, was there consideration of the effects of the plate corrosion products that have a higher specific volume than the plate itself?

Q 2.9.31 On page 431, line 4, SKB uses the word „backfill“. Does SKB mean „buffer“?

Deposition hole (borehole) acceptance criterion EFPC

Q 2.9.32 Please explain what the three colours mean in Figure 10-5 on page 295.

Q 2.9.33 Please provide the transmissivity units in the legend for Figure 10-6 on page 296.

Q 2.9.34 On page 306 an empirical equation is used to determine the accumulated mass of eroding bentonite in deposition holes. Since the equation is empirical, did the erosion test upon which this equation must be based cover a sufficient range of conditions that may be expected during the evolution of the repository under the credible scenarios considered?

Q 2.9.35 In the middle of page 309, it is noted that the swelling pressure beneath the bottom plate “should not be allowed to reach [0.2 MPa]”. What methods will SKB use to ensure this will not happen?

Q 2.9.36 The text near the bottom of page 326 states “no information can be given regarding how the loss of canister positions is distributed…”. Yet Figure 10-8 (page 302) implies that for at least one criterion,

[2] The table states the results are for the evolution of the composition of the groundwater, but the text on page 405 implies the results in Table 10-8 are for the two buffer materials in the presence of a “typical” Forsmark groundwater.

the particular loss of locations could be determined. Under what circumstances can or cannot the distribution of the loss of canister positions be determined?

Fuel properties

Q 2.9.37 Will future fuel properties be the same as summarized on page 20?

2.9.2 Long term performance

Performance assessment models

Q 2.9.38 Figures 7-3 and 7-4 (pp. 242, 243) are the assessment model flowcharts for earlier and longer-term periods of time. There is an arrow connecting “radionuclide transport, far-field (TR-10-50)” in yellow to “doses (TR-11-01)”. Should the two be connected via the LDF values?

Transport resistance

Q 2.9.39 For the case of unsealed boreholes discussed on page 352, it is stated that 23% of the particles in the particle tracking model come out the unsealed borehole, which seems quite a lot of the entire flow. Yet SKB also notes this does not have much effect on the performance measures. Are these „performance measures“ ones that only relate to the flow field, or is there also no impact on overall assessed dose rates in the performance model?

Q 2.9.40 Figure 12-3 on page 579 points out that the “semi-correlated” case results in less advective positions than either the uncorrelated or fully correlated cases. It seems somewhat arbitrary, then, the particular amount of correlation that is used as the base case. Please explain why this particular “amount” of semi-correlation was used as perhaps any other value of correlation would result in more advective positions.

Colloid formation/ Buffer erosion

Q 2.9.41 The last sentence on page 357 states that the real groundwater composition variability will likely be larger than captured in SKB’s uncertainty assessment. Please assess whether this might have an impact on overall repository performance. For example, if there is a possibility that the ionic strength could be lower than the assessed uncertainty range, could this have a significant impact on buffer stability?

Q 2.9.42 The last line on page 358 says “*above* this limit“. Should it read instead “*below* this limit“?

Q 2.9.43 Regarding the safety function of the minimum charge equivalent of 4 mM, it is stated on page that calcium is the “most important” cation. Does this have an implication about the similarity or dissimilarity of the MX-80 and Ibeco bentonites as the two have potentially significantly different calcium contents?

Backfill erosion

Q 2.9.44 In the first bullet on page 529 SKB states that the amount of erosion will be the same for each of the eight glacial cycles over the one million-year assessment period. Has SKB considered the possibility that the erosion rate might differ for successive glacial cycles?

Q 2.9.45 SKB states "the conceptual model for quantifying the extent of erosion is associated with uncertainties that are difficult to quantify." (page 580). What approach did SKB use, then, to deal with erosion uncertainty?

Q 2.9.46 On page 702, SKB notes "there is no reliable method" to quantify the effect metallic iron will have on montmorillonite stability. How, then, will SKB address this issue?

Plug

Q 2.9.47 The top paragraph on page 306 states that it is not known how tight the plug can be made, but that it is assumed that "20% of the total volume of the tunnel will leak out through the plug". Also on page 309, SKB states "The plug design will under all circumstances be adjusted to meet the requirements and failed plug performance is not assessed in SR-Site." What are the bases for SKB's confidence that the plug design can be so adjusted?

Copper Corrosion

Q 2.9.48 In several places in TR-11-01, such as on page 528 and 575, SKB estimates that 23 deposition holes will have "advective conditions" by the end of one million years. Other discussion in the report evaluates the possibility of oxidizing and/or "dilute" conditions occurring in some deposition holes. Might the deposition holes experiencing "advective conditions" be the same holes experiencing oxidizing or dilute conditions? Based on the first bullet on page 605, SKB states there is no correlation because the boundary conditions are different. This requires additional explanation.

Criticality inside a failed canister

Q 2.9.49 On page 646 SKB states that the k-eff $\leq$0.95 criterion can be met for irradiated (rather than fresh) fuel. SKB also states on this page that acceptance criteria have been defined "to ensure that the fuel assemblies shall not, under any circumstances, be encapsulated if the criticality criteria cannot be met…" Please provide the bases for both of these statements.

Fuel dissolution rate

Q 2.9.50 Table 7-2 (page 223) states that "residual gas radiolysis/acid formation" inside a failed canister is "not relevant". Please explain.

Q 2 9.51 The fuel dissolution rate uncertainty/variability is quantified as a log-triangular distribution (page 661). Is there a plot of this distribution? For the probabilistic analyses, is the entire range of the distribution sampled?

Biosphere

Q 2.9.52 On page 644, SKB states that it is using the central parts of Öregrundsgrepen rather than newly drained organic soils. SKB has also stated that newly drained soils would have the highest contamination levels and could still be productively farmed for 50-100 years, which is one to two lifetimes. Why has SKB elected to use the central parts of Öregrundsgrepen rather than newly drained organic soils?

Q 2.9.53 What is a "provisional" biosphere FEP (Page 96, Section 3.3)?

Permafrost/repository depth

Q 2.9.54 In Table 10-27 on page 551, "Buffer backfill borehole seals", "Freezing of closure material" "12.4" row, should the last column of this row be "Can 3" rather than empty?

Isostatic load

Q 2.9.55 Row "C10" in Table 7-3 (page 226) states that stress corrosion cracking of the cast iron insert in a failed canister has been neglected. Please provide the basis for this.

Earthquakes

Q 2.9.56 On page 467, SKB states "estimates of anticipated earthquakes at Forsmark … are associated with some yet unresolved uncertainties and fundamental assumptions." One of aspect of the EFPC criterion is that "fractures with radii exceeding 225 m are avoided in deposition holes." (page 472) However, the text does not provide a description how fractures of this size are to be detected.

Q 2.9.57 It seems possible that earthquake motion could cause significant changes in the groundwater flow rates and directions, thereby mobilizing colloids. In row "Bu18" in Table 7-4 (page 229) it is stated that montmorillonite colloid release during earthquakes was "not specifically treated". Please explain what this means and justify why it was not specifically treated.

Q 2.9.58 It seems possible that local shear forces during an earthquake could damage the grouts that may be used in places throughout the repository. Row "Ge17" in Table 7-6 (page 237) states that degradation of the grout during earthquakes is "not relevant". Please explain why.

2.9.3 Analysis of scenarios

Screening of scenarios

Q 2.9.59 It is unclear what is meant by screening out a scenario if it is of "little intrinsic significance" (page 221). Please explain.

Q 2.9.60 On page 568 paragraph above section 11.2.3, and then again in the last paragraph, SKB mentions indicators that are not associated with a criterion. They say "the criterion was assessed to be *violated* [emphasis added]", but "violated" against what criterion? Perhaps what is meant is that SKB simply carries along the numerical value of those safety indicators into the quantitative scenario analyses? Please clarify.

Q 2.9.61 Table 11-1 (page 570) provides the results of the scenario selection process. SKB notes the red cells are deviations from the main scenario conditions. The last row of the table is for the "unsealed repository" scenario. As the unsealed repository case is a deviation from the main scenario, it is unclear why all of the boxes in this row are not red. Please explain.

Analysis of scenarios

Q 2.9.62 The two paragraphs above Section 11.3 on page 569 are an example of lumping deposition holes into just two groups: (1) "a single deposition hole"; and (2) "all (or many) holes". From a risk perspective, it may be important to assign probabilities to failure of specific numbers of deposition holes, e.g., P(1 failure); P(2 failures); P(3 failures), and so on to create a probability distribution function for the number of deposition holes that have failed. This is because the consequence of "X" holes failing may be "X" times the consequence of one hole failing. If so, then in the probabilistic risk assessment, it may be important to be able to multiply the probability that "X" holes are failed times the consequence of that many holes failing. By lumping the scenarios into just two categories (1 failure; >1 failures) it is unclear whether this approach can be carried into the probabilistic risk assessment properly. Please confirm that only two groups of deposition hole failure probabilities were used and, if so, justify lumping the number of failures into just two categories.

Rock shear scenario

Q 2.9.63 Calculations of the potential for rock shear on page 481 consider the buffer material properties for just a Ca-bentonite. Is a Ca-bentonite the limiting form of bentonite with respect to transmitting rock shear to the canister?

Q 2.9.64 The external conditions involved in the rock shear scenario are provided in two bullets on page 618. Should there be a third bullet that says something like "Glacial load changes" along with appropriate discussion in the text?

2.9.4 Sensitivity analysis

Q 2.9.65 Since many of the variables in the sensitivity analyses have been fixed rather than considered as uncertain, the sensitivity analyses presented in TR-11-01 would not, by definition, detect the potential importance of uncertainty in the fixed variable on the overall results. What analyses have been done to assess the potential impact on the risk analyses for these fixed variables for which SKB acknowledges that the values of the variables are uncertain?

Q 2.9.66 It is unclear whether the assessment that 23 deposition holes experiencing advective conditions is a fixed number or the mean of a distribution. Please clarify. If the latter, is the distribution carried into the probabilistic assessments?

Q 2.9.67 Similarly, SKB states it used the mean value of [HS^-] "for all deposition positions" (page 603) rather than a range of values from an uncertainty distribution. Given that higher [HS^-] concentrations could lead to canister failure by corrosion, please justify the exclusive use of the mean rather than a distribution of [HS^-] concentrations.

Q 2.9.68 The dominant radionuclide contributing to dose is Ra-226. What are the factors that contribute to Ra-226 being the dominant contributor to dose? Are there uncertainties that might cause another radionuclide to dominate the contribution to total dose rate?

Q 2.9.69 Please explain why the "peak of the means" is "more difficult to interpret".

Q 2.9.70 Has SKB used "horsetail plots" (plots of individual realizations all in a single figure) to provide a graphical representation of the distribution of dose versus time outcomes?

2.9.5 BAT

Q 2.9.71 When assessing BAT, it seems SKB has only considered whether the BAT option can reduce releases or doses from the repository. There appears to be no assessment of the potential for increasing near-term risks by use of a BAT meant to reduce long-term risk. For example, the repository is designed to avoid peak bentonite temperatures above 100°C using a specific set of "techniques" (design features), such as canister size, disposal hole spacing, etc. Construction, loading, and transportation of canisters, construction and loading of tunnels and disposal holes also have near-term risks primarily to workers, but also to the public to a lesser extent. Presumably, the more canisters that need to be constructed, loaded, and transported to the site, and the more tunnels and deposition holes that need to be constructed, the higher the near-term risk to workers and the public will be. Hence, in this example, while altering the design "technique" to allow for higher bentonite temperatures runs the risk of increased long-term doses, the near-term risk, by having to use fewer canisters, tunnels, and deposition holes, may be reduced. When evaluating BAT options, has SKB considered the impact on near-term risks as well as long-term risks of each BAT option? Also, is cost a factor in evaluating BAT?

Q 2.9.72 SKB notes on page 82 that in cases where there is considerable uncertainty in calculated risks, priority should be given to the use of BAT. Throughout TR-11-01 SKB notes many pessimistic assumptions and values of variables were selected due to the large amount of uncertainty regarding processes or variable values. Did SKB consider the substitution of BAT instead of using pessimistic assumptions or values for each of these cases?

Q 2.9.73 Given that the use of "design premises" is to limit the number of design choices, is the use of design premises and BAT compatible?