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Workshop on Rock Mechanics Issues and their Implications for Groundwater Flow

Main Review Phase

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SSM perspektiv

Bakgrund
Strålsäkerhetsmyndigheten (SSM) granskar Svensk Kärnbränslehantering AB:s (SKB) ansökningar enligt lagen (1984:3) om kärnteknisk verksamhet om uppförande, innehav och drift av ett slutförvar för använt kärnbränsle och av en inkapslingsanläggning. Som en del i granskningen ger SSM konsulter uppdrag för att inhämta information och göra expertbedömningar i avgränsade frågor. Workshopar organiseras sedan för att diskutera läget för SSM:s aktuella granskningsinsatser samt konsulternas uppdragsresultat om specifika processer, säkerhetsfunktioner och barriärer av stor vikt för SKB:s säkerhetsanalys SR-Site för kärnbränsleförvaret i Forsmark. Synpunkter samt slutsatser som resulterar från workshoparna är workshopdeltagarnas syn och inte nödvändigtvist SSM:s.

Workshopens syfte
Det övergripande syftet med denna workshop var att föra samman experter inom bergmekanik och hydrogeologi för att diskutera deras uppfattning om säkerhetsrelevansen samt lämpligheten av SKB:s konstruktionsförutsättningar för hydrogeologiska parametrar för berget runt kärnbränsleförvaret. Experterna stödjer sig på granskningsresultat av mekaniska processer som leder till skador i berget under tiden före och efter förslutning av förvaret. Skador i berget påverkar bergets hydrogeologiska egenskaper och därmed långtidsutvecklingen för de tekniska barriärerna samt utsläpp av radionuklider från förvaret.

Sammanfattning av workshopen
Rapporten beskriver resultatet från en workshop om bergmekanik och hydrogeologi som SSM organiserade den 30/9 och 1/10, 2013. Rapporten redovisar de frågeställningar som diskuterats samt summerar viktiga synpunkter som uppnåtts. Redovisningen bör inte ses som en fullständig dokumentation av alla diskussioner under workshopen och individuella påståenden från deltagarna bör hanteras som deras uppfattning och inte SSM:s ståndpunkter.

SKB:s förmåga att identifiera och kvantifiera signifikanta parametrar för skador i berg och parametrarnas utveckling efter förslutning av förvaret diskuterades. Rapporten bidrar till bedömning av konsekvensanalysen för utsläpp, med fokus på hydrogeologi och radionuklidtransport, samt bedömningen av möjliga brister eller underskattningar i SR-Site. Avslutningsvis redovisades preliminära slutsatser från workshopen till stöd för kommande bedömningar om tillståndsansökan uppfyller föreskriftkrav samt om behovet av eventuella tillståndsvillkor.

Projektinformation
Kontaktperson på SSM: Flavio Lanaro
Diarienummer ramavtal: SSM2011-3636
Diarienummer avrop: SSM2013-4577
Aktivitetsnummer: 3030012-4084

SSM perspective

Background

The Swedish Radiation Safety Authority (SSM) reviews the Swedish Nuclear Fuel Company's (SKB) license applications under the Act on Nuclear Activities (SFS 1984:3) for the construction and operation of a repository for spent nuclear fuel and for an encapsulation facility. As part of the review, SSM commissions consultants to carry out work in order to obtain information and provide expert opinion on specific issues. Workshops are organized for the discussion of the current status of SSM's review findings and consultants' opinions reached on particular processes, safety functions and barriers of central importance in SKB's safety assessment SR-Site for a final disposal of spent fuel at Forsmark. The viewpoints and conclusions expressed at the workshops are those of the workshop participants and do not necessarily coincide with those of SSM.

Objectives of the workshop

The objective of this workshop was to bring together experts in the field of Rock Mechanics and Hydrogeology to discuss their views about the safety relevance and suitability of SKB's design premises on the hydrogeological properties of the rock around the repository based on the review results on the mechanical processes that lead to rock damage before and after closure. Rock damage affects the hydrogeology of the rock and in turn the long-term evolution of the engineered barrier system and radionuclide releases from the repository.

Summary of the workshop

This report describes the outcome of the workshop organized by SSM on Rock Mechanics and Hydrogeology that was held in Stockholm on the 30/9 and 1/10, 2013. The report summarizes the issues discussed and extracts the essential viewpoints that have been expressed. It should not be considered as a comprehensive record of all the discussions at the workshop and individual statements made by workshop participants should be regarded as opinions rather than SSM's point of view.

Considerations on SKB's capability of capturing and quantifying significant parameters on the rock damage and their evolution after closure of the repository were discussed. This will support considerations on the consequence analyses of releases, with focus on hydrogeology and radionuclide transport, and on possible omissions or underestimations in SR-Site. At the end of the workshop, preliminary conclusions were to be reached on the fulfilment of the regulatory requirements for granting a License and on any need of License Conditions.

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Contents

1. Introduction

This note is a record of the Swedish Radiation Safety Authority’s (SSM) Workshop on Rock Mechanics Issues and their Implications for Groundwater Flow as a part of the review of the Swedish Nuclear Fuel and Waste Management Co’s (SKB) safety analysis SR-Site included in the license application under the Act on Nuclear Activities (SFS 1984:3) for the construction and operation of a repository for spent nuclear fuel. The workshop involved SSM staff and those consultants who had been reviewing SKB documentation on these issues, plus the authors of this note.

At this stage of the License review process, it was considered that the outcome of SSM’s ongoing review and the latest Consultants’ scientific assessments should be able to reach preliminary conclusions on the scientific soundness and completeness of SKB’s application for the fulfilment of License requirements and formulation of any needed License Conditions.

SSM invited eight consultants working with Rock Mechanics and Hydrogeology and seven SSM staff members to the Rock Damage and Hydrogeology Workshop in Stockholm, September 30 and October 1, 2013. The agenda of the Workshop is presented in Appendix 1 and the list of participants in Appendix 2.

Flavio Lanaro of SSM welcomed the participants to SSM and the Workshop and presented the agenda for the two days workshop.

1.1. Purpose of the Workshop

The purpose of the workshop was to combine the knowledge and evaluations of the Rock Mechanics and Rock Engineering consultants, doing reporting on their current assignments, with those of the hydrogeologists in order to ensure an integrated understanding on the evolution of fracture transmissivity and rock mass conductivity in the near- and far-field rock around a KBS-3 repository at Forsmark.

Considerations on SKB’s capability of capturing and quantifying significant parameters on the rock damage and their evolution after closure of the repository were to be discussed. This will support considerations on the consequence analyses, with focus on hydrogeology and radionuclide transport, and on possible omissions or underestimations in SR-Site (SKB TR-11-01).

1.2. Workshop Assignments and Discussion Topics

SSM’s Initial Review Phase pointed out a series of topics that are critical for demonstrating safety of the KBS-3 repository at Forsmark. During the workshop, preliminary statements on the results of the scientific assessment of the following topics were to be reached:

- Impacts of THM processes on fracture transmissivity (Near-field groundwater fluxes, C1-1-c) (see Figure 1).
- Flux on Q-pathways (Flux on Q pathways, C1-1-d, see Figure 1).

- Impact and uncertainties of the stress state evolution in near-field rock (Canister failure, C-2, see Figure 2).
- Applicability and reliability of Rock Engineering and geological methods for acceptance of deposition hole positions (Initial state, ISC-1-b, see Figure 3).
- Evidence of an EDZ (Initial state, ISC-4-a, see Figure 3).
- Safety significance of aspects not covered by SKB.

1.3. SKB's Pertinent Design Premises

SKB has concluded that the following hydro-mechanical requirements have to be fulfilled for guaranteeing the necessary level of safety of the KBS-3 repository (SKB TR-11-01, Sec. 5.2.1, p. 150 and Sec. 5.2.3, p. 158):

- The total volume of water flowing into an accepted deposition hole must be less than 150 m^3 until saturation of the buffer. For the current reference design, it is judged that the Design Premises are met if only potential deposition holes with inflows less than 0.1 ℓ/min are accepted;
- Fractures intercepting the deposition holes should have sufficiently low connected transmissivity;
- Before canister emplacement, the connected effective transmissivity integrated along the full length of the deposition hole wall and as averaged around the hole, must be less than 10^{-10} m^2/s;
- Excavation induced damage should be limited and not result in a connected effective transmissivity, along a significant part (i.e. at least 20 to 30 m) of the disposal tunnel and averaged across the tunnel floor, higher than 10^{-8} m^2/s.

1.4. Goal of the Workshop

Prior to the Workshop, SSM presented a set of questions to the participants. SSM requested that the consultants' presentations and the topic discussions during the Workshop should answer the following questions:

- Are the ranges of safety relevant parameters proposed by SKB adequate and conservative?
- Do any feasible and credible alternative models lead to significantly different behaviour than the results from SKB's models?
- Are there omissions and, in that case, what is their relevance for the safety analysis SR-Site?
- Are the Design Premises scientifically sound? Can the related safety relevant parameters proposed by SKB be measured with sufficient precision and confidence?
- Is SKB's approach, with or without omissions, adequate for licensing construction, even though there may be alternative approaches?

As preparation for the Workshop, the consultants were requested to study specific sections of the high-level documents of the SR-Site report and relevant background reports.

2. Relevance of Rock Mechanics Issues for the Hydro-geological Analyses of SR-Site

The Workshop began with three presentations of SSM staff members on the important issues for Rock Mechanics relevant for the Hydrogeological and Radionuclide Transport issues.

2.1. Relevance of Rock Mechanics Issues for the Review of SR-Site

Flavio Lanaro presented SSM's Assessment Areas of relevance for the overall review of SR-Site:

- Confinement (Corrosion, Isostatic Load and Dynamic (Shear) Load)
- Initial State and Constructability
- Consequence Analyses
- Safety Analysis Methodology
- Fulfilments of Regulatory Requirements.

The Assessment Areas of special relevance for Rock Mechanics are mainly covered under Confinement and Initial State and Constructability. SSM has developed flow charts to illustrate the assessment procedure. Flavio Lanaro presented in brief three different flow charts to illustrate the procedure and the couplings between individual processes for critical issues within the Assessment Areas.

Figure 1 through Figure 3 illustrate the flow chart for process, also addressed as Working Package, C1 "Canister Failure due to Corrosion", C2 "Canister Failure due to Isostatic and Dynamic (Shear) Loads" and ISC "Initial State and Constructability". The flow charts illustrate the major tasks (dark blue rectangles) within a Working Package and the individual activities (pale blue rectangles) within a major review issue. The Working Packages support decision making and provide the answers to key questions in the green triangle. If the answer is "*yes"*, then the issue has an important effect of the buffer/canister integrity and thereby impacts the overall safety of the repository.

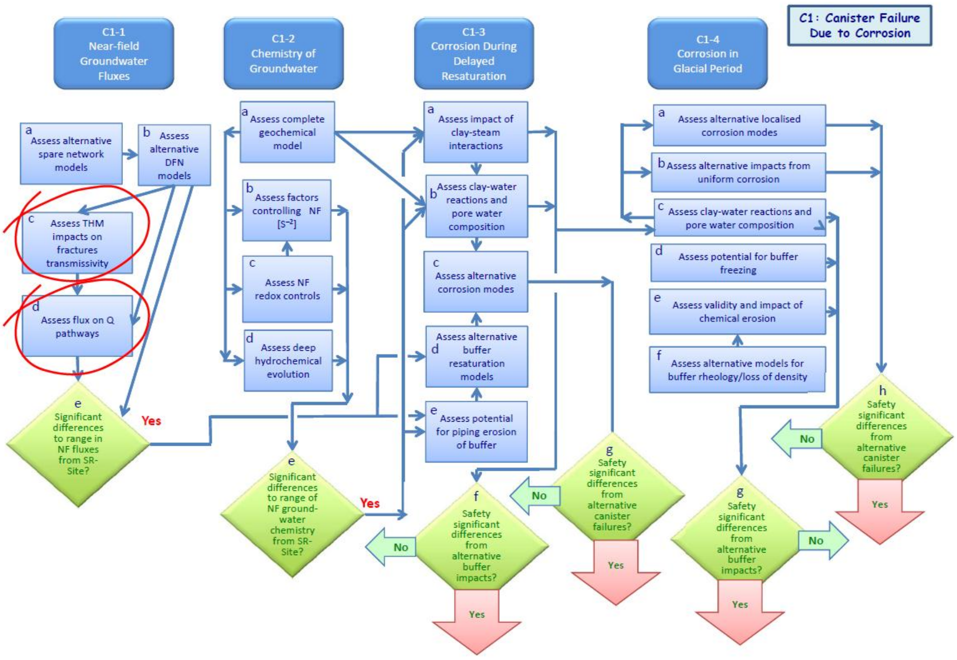

Figure 1: Decision making chart for Working Package C1 "Canister Failure due to Corrosion" in the Assessment Area "Confinement".

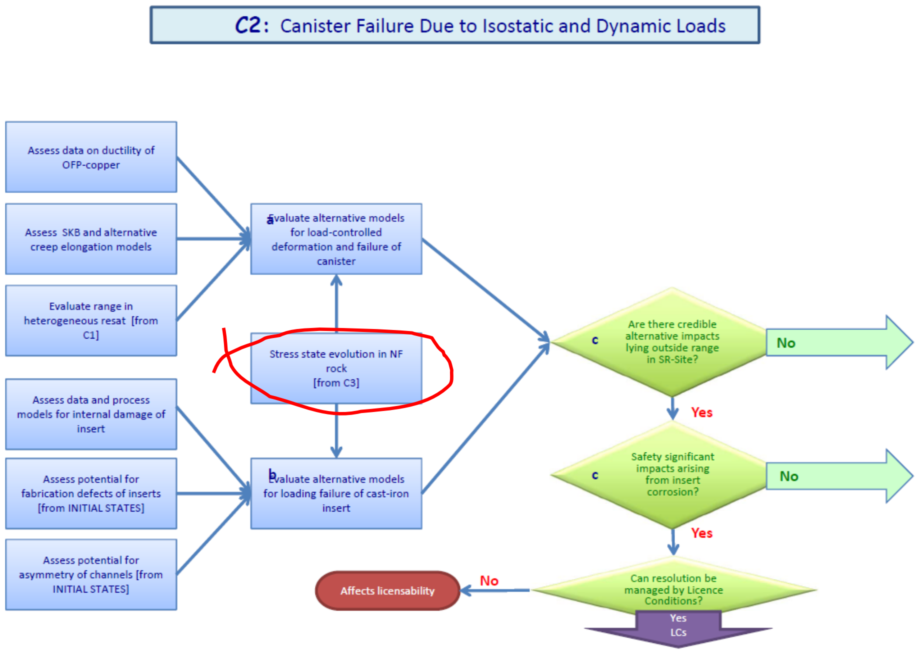

Figure 2: Decision making chart for Working Package C2 "Canister Failure due to Isostatic and Dynamic Loads" in the Assessment Area "Confinement".

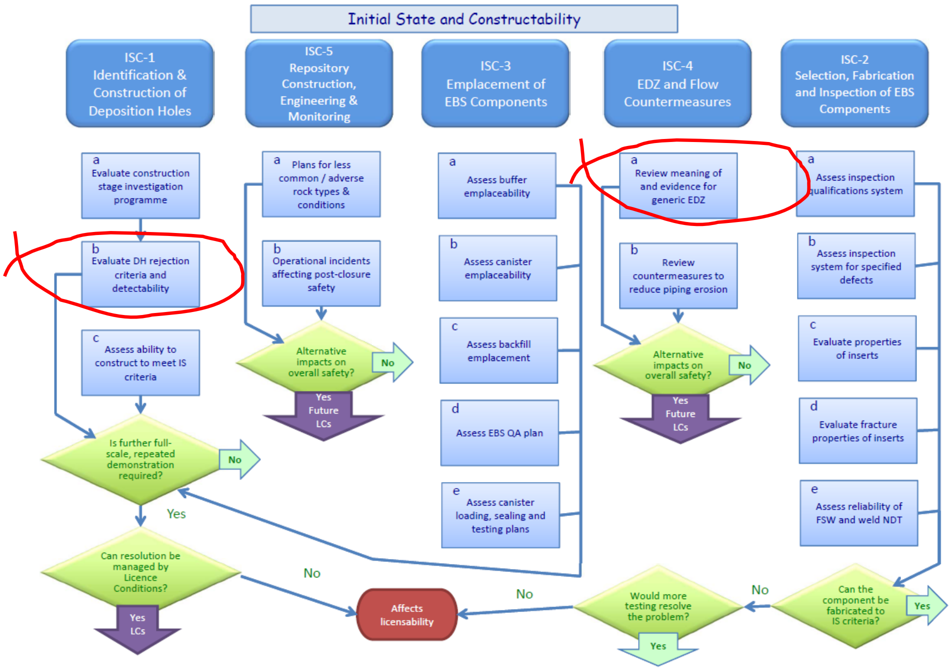

Figure 3. Decision making chart for Assessment Area ISC "Initial State and Constructability".

2.2. Rock Damage and Hydrogeological Analyses in SR-Site

Georg Lindgren of SSM presented an overview of the hydrogeological calculation results presented in SR-Site. For long-term safety, SKB has been applying hydrogeological calculation results for analysing buffer erosion, copper corrosion and radionuclide transport. There are hydro-related design parameters (i.e. Design Premises) for the deposition holes and tunnels. To avoid piping and erosion of the buffer, the inflow to the deposition holes should be < 150 m^3, connected effective transmissivity < 10^{-10} m^2/s along and around deposition holes, effective non-continuous transmissivity < 10^{-8} m^2/s along deposition tunnel floor and < 10^{-8} m/s for the conductivity of the backfill.

The development of an Excavation Damage Zone (EDZ) around the deposition holes and tunnels increases the connectivity and transmissivity of the fracture network, which affects the fulfilment of SKB's Design Premises for acceptance of the deposition hole. SKB has not performed any hydro calculations for EDZ or spalling in the deposition holes arguing that spalling is localised and can be removed before deposition by scaling the walls of the deposition hole.

For the base case simulation, a 0.3 m thick EDZ around the tunnel is assumed. SKB models this by a transmissivity of 10^{-8} m^2/s to a horizontal fracture parallel to the floor of the tunnel. Two more cases are considered, with a fracture with transmissivity of one to two orders of magnitude higher and a void room in the backfill close to the roof of the tunnels. The Darcy fluxes through EDZ for the path Q2, starting at the top of the canister and ending in the EDZ of the tunnel floor, gives values 2.5 to 4 orders of magnitudes higher than the flux Q1 from a single horizontal rock fracture at the wall of the deposition hole (see Figure 4). These data are valid for the temperate phase of the repository. In the glacial phase of the repository, the Darcy flux is 1 to 2 orders of magnitude larger for Q1 and Q2 with respect to the temperate phase.

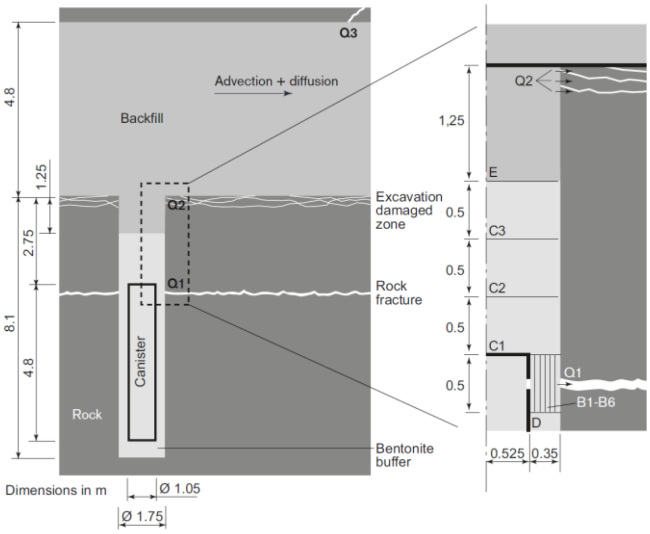

Figure 4. Near-field model representation in the SKB model COMP23. The transport paths Q1, Q2 and Q3 to a fracture intersecting the deposition hole, to the EDZ and to a fracture intersecting the deposition tunnel are illustrated. After SKB TR-11-01.

Georg Lindgren presented results of different particle tracking calculations and he also noted that Joel Geier's fracture network model of 2008 (Geier, 2008) shows that an EDZ would be the dominant transport path in the repository.

Ove Stephansson mentioned the recent results about geophysical measurements of EDZ in the Rock Mechanics niche of Posiva's ONKALO facility (Finland), where geo-electrical investigations in the floor of the niche showed a continuous EDZ. The depth of the observed EDZ was about the same over the test area and the profiles presented seem to indicate an isotropic pattern. Results of the resistivity measurements as conducted in the floor of the niche can be used to calibrate the depth of EDZ recorded with other geophysical instruments, e.g. ground penetration radar (GPR). SKB and Posiva have presented results of EDZ investigations mostly from the walls of tunnel sections where the blast damage and stress concentrations are the least. These results have not been conclusive about the non-continuity of EDZ. The presented new detailed information from the investigations under the floor of the Posiva tunnel shows that EDZ from the blast damage is continuous in the floor. The same result could be extrapolated to the hard rock at Forsmark. Therefore, a continuous EDZ in the floor of the deposition tunnels is a likely scenario for the flow and transport calculations in SR-Site.

Flavio Lanaro recalled a discussion during SSM's Initial Review Phase (see Eberhardt and Diederichs, 2012) about the fact that EDZ produced by damage from stress changes has to be distinguished from an EDZ produced by the excavation method.

SKB calculates the groundwater flow based on DFN models with intercepting planar fracture surfaces, so-called parallel plate flow model. Channel model conceptualisation may yield different distribution of inflow to deposition holes. This is under investigations independently by SKB and SSM.

2.3. SKB's Consequence Analysis Related to Rock Damage

SKB's approach to Consequence Analyses of Radionuclide Transport related to rock damage is performed through near- and far-field transport models. Shulan Xu of SSM presented the consequence analyses for the three near-field models Q1, Q2 and Q3. The equivalent flow rates for path Q2 are affected by spalling in the wall of the deposition hole since spalling short-circuits the flow from Q1 into Q2. The model considers the width, length and thickness of the spalling.

SKB postulates a growing pinhole failure mode from an initial defect in the form of a penetrating pinhole in the copper shell of the canister. Including spalling in the wall of the deposition hole produces doses in far-field calculation results about 4 times higher compared to the case that does not include spalling. According to SKB, the case that does not include spalling, in turns, give a dose that is about 12 times smaller than the dose corresponding to the regulatory risk limit (see Figure 6-14, SKB TR-10-50).

An EDZ implies a possible release path located in the floor of the deposition tunnel. In report SKB TR-10-50, calculation results of the annual effective dose are presented for three different assumptions of EDZ transmissivity: 10^{-8} (base case), 10^{-7} (EDZ 7) and 10^{-6} m^2/s (EDZ 6). The difference in dose between the base case and the most conservative model EDZ 6 is a factor 3. According to SKB, the most conservative model EDZ 6 gives a dose that is about 10 times smaller than the dose corresponding to the regulatory risk limit (see Figure 6-40, SKB TR-10-50).

Shulan Xu concluded that no effect of EDZ is considered in SKB's scenarios. SSM is presently in progress reproducing SKB's calculation case with the pinhole scenario for flow path Q2 and EDZ.

3. Occurrence of a Damaged Zone Around Deposition Holes and Tunnels

SSM's consultants had performed a range of technical reviews and modelling studies to assess the possibility and nature of rock damage around either the deposition holes or the deposition tunnels. The consultants' presentations are summarised below.

3.1. Modelling of EDZ Occurrence

Goodluck Ofoegbu and Kevin Smart of Southwest Research Institute, SWRI (USA), performed a study on SKB's models for predicting the occurrence of a damage zone around the excavations of the repository at Forsmark (Ofoegbu and Smart, 2013). An EDZ would enhance permeability relative to undamaged rock and could affect water flow and radionuclide transport. SKB assumes that the water transmissivity through a damage zone should be $<10^{-10}$ m^2/s for deposition holes and $<10^{-8}$ m^2/s for the deposition tunnels. For the deposition tunnels, SKB considers the occurrence of a damage zone at the tunnel floor only, according to flow path Q2 in Figure 4. The thickness of the damage zone is estimated to be 0.3 m and is generated due to construction by means of a drill-and-blast technique. For the deposition holes, only spalling from stress induced damage is considered. Generation of new fractures and/or displacement along existing fractures are dismissed in SKB's models.

The objectives of the assignment commissioned to SWRI by SSM were to evaluate SKB's assessment of damage zone configurations and the confidence in their models. In addition SSM wants to know if the uncertainty in damage zone assessment is acceptable. The motivations of the consultants' assessment were the following:

- Evaluate basis for SKB's damage zone representation.
- Determine if SKB representation covers potential for excavation damage zone (EDZ) configurations.
- Evaluate basis for SKB's damage zone representation.
- Simulate stress-induced damage based on thermo-mechanical modelling with elastic-plastic modelling.

SWRI has conducted T-M analyses using the commercial program ABAQUS. Modelling has been done in 3-D using quarter symmetry models with dimensions in accordance with SKB's D2 Layout (SKB R-08-116). The thermal part of the modelling is performed at the start, followed by the stress modelling corresponding to uncoupled heat transfer modelling. The modelling covers a time period of 100,000 years, thus, a complete glacial cycle. Initial stresses are selected in accordance with the SKB stress model where SH = 40.1 MPa, Sh = 20.1 MPa and Sv = 12.2 MPa. The glacial load is assumed to be at most 24.5 MPa. Two elasto-plastic models were simulated with ABAQUS: i) one with intact rock properties and ii) one with rock mass properties that considers the effect of existing joints and fractures.

The results of the modelling show that, for a tunnel axis oriented parallel with maximum horizontal stress and using intact rock properties, with or without reduced tensile strength and elastic modulus, no spalling is developed. The same result for intact rock is also obtained when the tunnel orientation is 22° or 45° off with respect to the orientation of the maximum horizontal stress. When the rock mass properties are applied and the tunnel axis is oriented 45° or more away from the direction of the maximum horizontal stress, plastic strains develop in the roof and walls of the tunnels, as illustrated in Figure 5.

SWRI analysed a pessimistic model of the deposition hole and tunnel subjected to a maximum horizontal stress oriented 45° away from the direction of the tunnel axis and with strain hardening properties of the rock mass. The model results predicted inelastic peak strain in tunnel floor and at the walls of the deposition hole.
In the discussion following the presentation it was concluded that the generation of an EDZ precedes the generation of spalling, meaning that lower stresses are needed for generation of an EDZ than for spalling. It was also concluded that the magnitudes of confining stresses are important for the development of an EDZ and spalling.

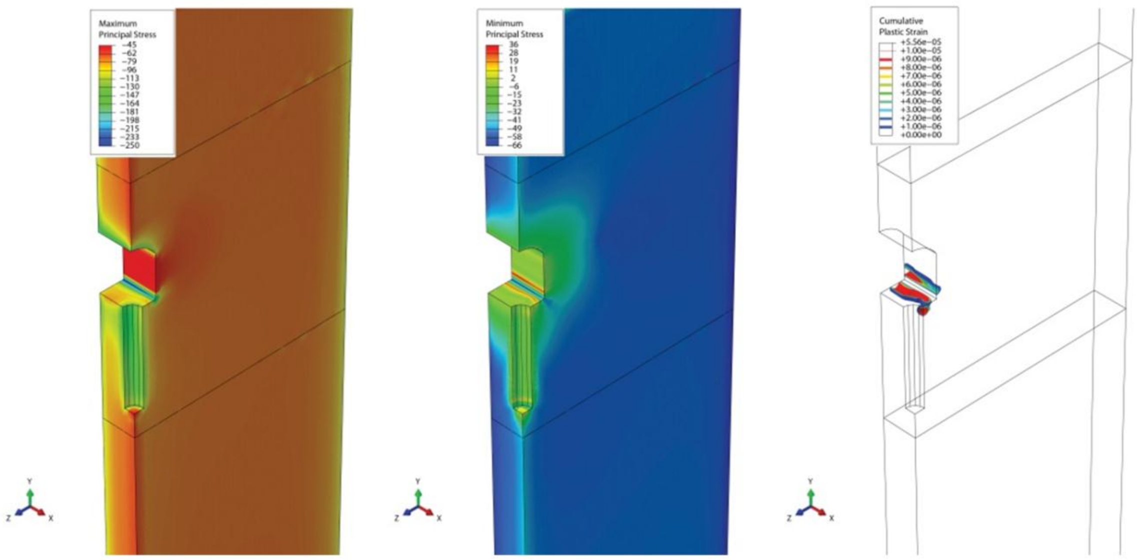

Figure 5. Results showing magnitudes of maximum principal stress (left column), minimum principal stress (centre column) and cumulative plastic strain (right column). Results are shown at about 8 years after deposition for a tunnel orientation 45° off with respect to the orientation of the maximum *in situ* horizontal stress. Stresses are in MPa. Cumulative plastic strain is due to tensile failure. After Ofoegbu and Smart (2013).

3.2. Rock Stress and Spalling Prediction

Tobias Backers of Geomecon (Germany) evaluated the Forsmark stress data and models and presented a methodology for theoretical analysis of spalling potential for the different phases of evolution of the repository (Gipper et al., 2013).

SKB has presented a stress model of Forsmark that has high stress magnitudes relative to normal conditions in Fennoscandia (Martin, 2007, SKB R-07-26). The stress model is, to a large extent, based on overcoring stress measurements. During the site investigations in Forsmark, SKB also made stress measurements with hydraulic methods, which resulted in about half the stress magnitudes in the horizontal directions (Ask et al., 2007, SKB P-07-206). The Geomecon company believes that too large weight has been assigned to the overcoring stress measurements by SKB. This is supported by the fact that these measurements are old (1980) and precede SKB's site investigations. Besides, the measurements were performed outside the rock mass volume (i.e. Rock Domains RFM029 and 45) of the target area at Forsmark and thus there are reservations about their representativety.

If omitting the overcoring stress measurements and re-evaluating the measured stresses from the target area, Gipper et al. (2013) presented a new stress model for Forsmark. The model is in agreement with the possible state of stress at any crustal depth determined after the concept of limiting stress ratios and frictional limits of the rock at Forsmark, see Figure 6 where: i) the overcoring stress data used by Martin (2007) fall outside the stress polygon for stress states at 500 m depth; ii) the stress data from hydraulic methods by Ask et al. (2007) agree with the strike-slip stress conditions at depth and; iii) Geomecon's stress model by Gipper et al. (2013) falls on the border between strike-slip and reverse faulting regimes with maximum horizontal stress SH = 35.5 MPa and minimum horizontal stress Sh = 13.3 MPa for a vertical stress Sv = 13.3 MPa. In conclusion, the stress polygon in Figure 6 shows that SKB's suggested stress model with SH = 41.0 MPa and Sh = 23.2 MPa might not be valid.

Spalling at the periphery of an opening in the bedrock at Forsmark is likely to occur once the tangential stress at the wall of the opening exceeds the crack initiation stress of the rock. The spalling strength of the main rock domain at Forsmark is 0.53 times the uniaxial compressive strength. For the main rock domain RFM029 with an average uniaxial compressive strength of 215 MPa, the crack initiation stress is on average 114 MPa.

Tobias Backers presented a methodology for the theoretical analysis of spalling potential for the different phases of the repository, which is illustrated in Figure 7. The minimum and maximum stress around a circular opening are defined on the axes of the diagram and the calculated tangential stress is governed as shaded bands in the figure, together with the selected failure criteria. Lowering the crack initiation stress means that the line for rock failure moves down in the diagram presented in Figure 7.

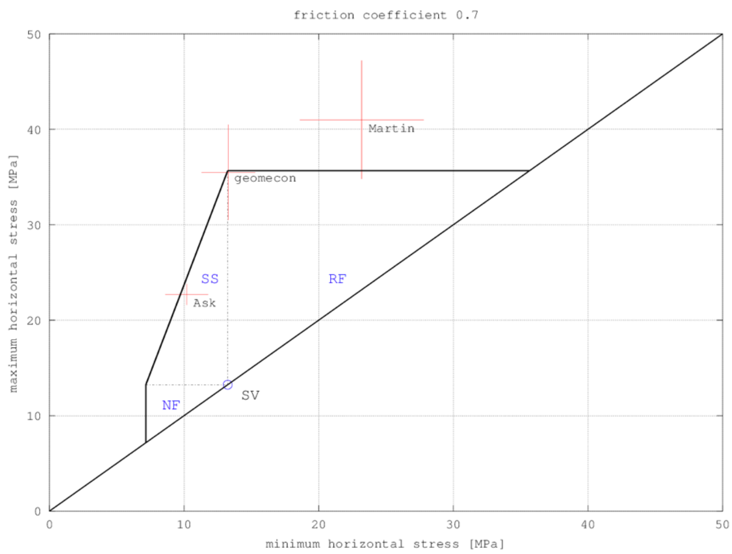

Figure 6. Stress polygon for allowable horizontal in-situ stresses at 500 m depth at Forsmark. The stress models by Martin (2007), Ask et al. (2007) and Geomecon's stress model are presented. After Gipper et al. (2013).

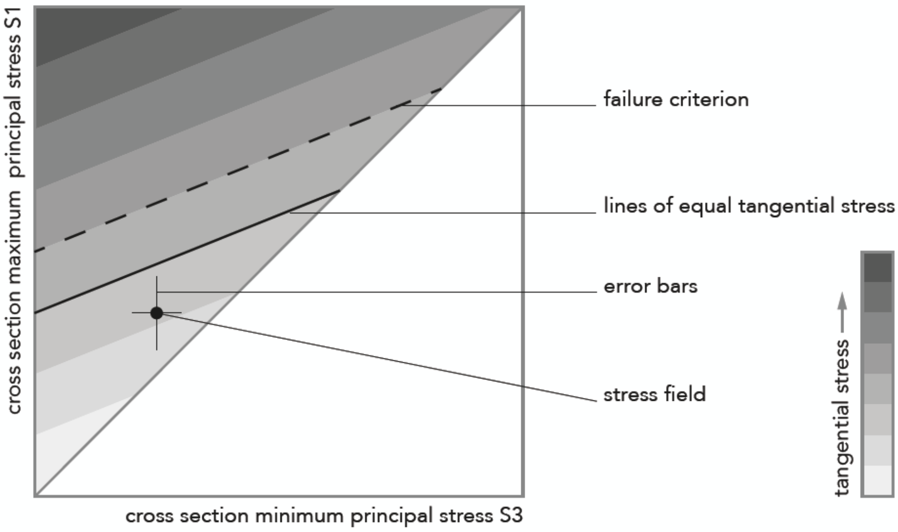

Figure 7. Stylized diagram of maximum horizontal stresses and the corresponding tangential stress at the periphery of a circular opening. Failure criteria correspond to contour lines of the tangential stress. The diagram can be modified to analyse each of the different phases of the repository development (excavation, thermal loading, glaciation) for tunnels and deposition hole. After Gipper et al. (2013).

Based on the result of the analyses for spalling of deposition holes and tunnels for different phases of evolution of the repository (excavation, thermal, glaciation), Tobias Backers presented a ranking of the spalling potential for each of the phases of the repository at Forsmark. Results of the scoping analyses and the ranking of failure potential have confirmed the general trend in the results presented by SKB.

In conclusion, applying the SKB stress model by Martin (2007) to the deposition holes, spalling will appear during excavation and severe spalling during thermal phase and glaciation. In addition, the relatively large stress difference between the maximum horizontal stress (SH) and the vertical stress (Sv), corresponding to the minimum stress, is likely to generate tensile failure in the wall of the tunnels once the tunnel axis deviates more than about 30° from the orientation of SH. The new stress model suggested by Geomecon would result in less pronounced spalling and tensile failure compared to SKB's stress model. Application of the stress model by Ask et al. (2007) based on hydraulic stress measurement results gives no spalling nor tensile failure for any of the phases of the repository.

3.3. Evolution of Fracture Transmissivity in Different Scenarios of the Repository

Ki-Bok Min of Seoul National University, SNU (South Korea), presented the motivation and objective of the study on fracture transmissivity, with the aim to determine whether the transmissivity range that SKB uses in the modelling is plausible (Min et al., 2013a).

Besides reviewing what it is found in the scientific literature, the group at SNU is performing numerical modelling to analyse the change in fracture transmissivity of the rock mass and the major deformation zones due to thermal loading from the spent fuel (Min et al. 2012 and 2013b) and the loading from future glaciations. In performing the modelling, the group uses DFN models developed by Joel Geier of Clearwater Hardrock Consulting

(USA) for SSM and based on fracture mapping data from Forsmark. Both the far-field and near-field of the repository are studied.

Many of the statements in SKB's reports on transmissivity changes due to thermo-mechanical processes are unclear and seem to contradict SKB's own results obtained from laboratory tests. There is also a lack of quantitative analyses in the reports presented by SKB. For example, SKB states that transmissivity change by shearing is prevented by the confining stress at the level of the repository and therefore can be omitted (Hökmark et al., 2010, SKB TR-10-23). At the same time and in the same report, SKB claims that about 4 mm shear displacement along a fracture can increase the local transmissivity by one to two orders of magnitude. SKB has performed shear tests on fracture samples from fracture domain FFM01 at Forsmark showing that dilations of the order of 5°-10° develop also at high normal stress of about 20 MPa (Glamheden et al. 2007, SKB R-07-31) affecting transmissivity when fractures are sheared some millimetres.

Ki-Bok Min presented a compilation of dilation angles from direct shear tests (Figure 8), where data from Forsmark are included by means of Barton's empirical relation with the normal load (Barton and Choubey, 1977). A fracture can be sheared and thereafter the shearing can be reversed so that the sample is moved back to its original position. In these conditions, there is always a residual dilation angle remaining in the sample, which means that the process is not completely reversible.

Another characteristic feature related to shearing and simultaneous flow is the anisotropy in flow parallel and perpendicular to the shear direction as was shown by Koyama et al. (2006). The shearing produces troughs on the fracture aperture perpendicularly to the shearing direction that results in a specific transmissivity change. However, the flow in the direction perpendicular to shearing can either increase due to fracture opening from overriding asperities, or decrease due to gauge material produced and deposited in the aperture troughs during shearing.

Thermal calculations of the near-field were presented, where temperature are calculated for a time period of 100,000 years where a maximum temperature of about 50° in the wall of the deposition hole is reached after about 30 years. The stress path for monitoring points away from the deposition hole was presented. The stress paths show large thermal stresses of the order of 25 MPa that are able to generate shearing along pre-existing fractures because of large deviatoric stress. A maximum displacement was obtained for fractures intersecting the deposition hole and dipping about 30°.

Thermal stresses have been modelled by SNU for single and multiple fractures intersecting the deposition hole. Two of the 2-D DFN models provided by Joel Geier have been analysed with the UDEC code. Shear displacement of about 5 mm and fracture openings of about 0.15 mm develop after 500 years. Comparisons of joint opening in fractures between models with average P_{32} (i.g. fracture frequency or intensity) as given by SKB and models with elevated P_{32} to take into account variability have been made. The analyses show that the models with elevated P_{32} give slightly larger shear displacements, but less joint opening. In conclusions, Ki-Bok Min explained the difficulties in using 2-D discrete element modelling for analysing the 3-D DFN models. In terms of geometry, 2-D modelling is not conservative enough because it significantly underestimates the connectivity of the true 3-D DFN geometry. However, 2-D modelling can be more or less conservative in terms of the possibility of shear sliding because this will depend on orientation of fractures with respect to the in-situ stresses.

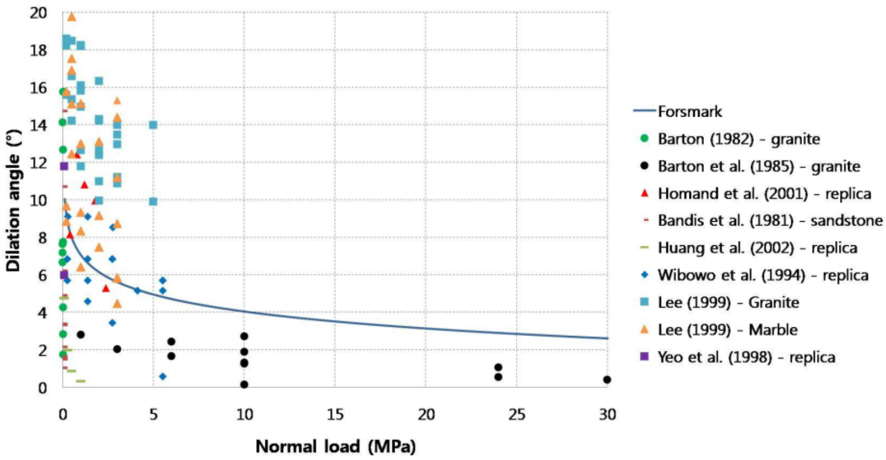

Figure 8. Dilation angle versus normal load for a set of natural rock fractures and replicas compiled from various sources. The curve shows data from shear box experiments on fractures from Forsmark. (Min et al., 2013b).

3.4. Techniques for Determination of Critical Properties in and around Deposition Holes

Erik Eberhardt and Mark Diederichs of Fisher & Strickler Rock Engineering (USA), have evaluated the geological and geophysical methods proposed by SKB with respect to their resolution, performance and reliability to measure the geomechanical parameters critical for determining deposition hole acceptability during repository construction and operation (Eberhardt and Diederichs, 2013). The presentation at the Workshop was given by Erik Eberhardt.

The Observational Method according to the Eurocode 7 (EUROCODE 7, 2004) will be applied by SKB for the construction of the repository at Forsmark (SKB R-08-116). The present version of the Eurocode is almost completely only applicable to soil mechanics and geotechnics. The International Society for Rock Mechanics has recently decided to establish a working group to speed up the work on the rock applications of the Eurocode. Hence, it will be several years before the Eurocode is ready for applications during the construction phase of the repository.

SKB's Design Premises for the construction of the deposition tunnels and deposition holes state that: "*Deposition holes should, as far as reasonably possible, be selected such that they do not have potential for shear larger than the canister can withstand. To achieve this, the EFPC criterion should be applied in selecting deposition hole positions"* (SKB TR-09-22).

SKB suggests that there is room to improve the Extended Full Perimeter intersection Criterion (EFPC) as it unnecessarily rejects holes intersected by relatively short fractures. In fact, the EFPC is very conservative: fractures as small as 3 m radius may lead to a rejected canister position compared to the critical fracture radius of more than 50 m. SKB is confident on the fact that visual inspection and fracture mapping are very robust methods, so it should be possible to detect all the fractures with full perimeter intersection. Reference in SKB report is made to on-going work in cooperation with Posiva to find other means to identify large fractures to increase the efficiency of the EFPC criterion.

Together with Posiva, SKB is studying the performance of geophysical measurement techniques. Detectability of Ground Penetration Radar (GPR) is limited to 10-20 m around the openings and in certain directions. The study by Posiva concluded that GPR alone can be used for detection of EDZ and long fractures. The detectability of Borehole Radar is limited to a penetration depth of about 10 m and about 20-30% of the FPI fractures in the borehole could be detected. Eberhardt and Diederichs reach the conclusion that detection of the full size of a fracture can rarely, if ever, be achieved due to the limited exposure afforded by underground openings and limitations in relying on geological signatures or geophysical techniques. These techniques would at best be able to identify fractures of radius larger than about 10 m. Eberhardt and Diederichs agreed on resistivity surveying and seismic refraction being able to detect EDZ depth from the openings with some confidence.

It is likely that critical fractures identified by the EFPC are also hydraulically active. SKB admits that a reference method for the selection of deposition hole positions with acceptable inflows still needs to be developed. At present, they have no alternative to the EFPC and the workshop postulated that characterisation of families of fractures with similar characteristics might be useful here. In addition, performance assurance measures should be developed to ensure that deposition holes initially assessed as being acceptable do not afterwards experience high inflows due to a change in the connectivity of the fractures intersecting the deposition hole, for example through the development of a high permeability EDZ/spalling zone in the floor of the deposition tunnel or due to drastic changes of the flow regime before and after closure of the repository.

SKB concludes that EDZ, if it develops, will not be continuous. However, the experiment on which this finding is based relies on block cuttings on the wall of the TASS tunnel at Äspö (Olsson et al., 2009, SKB R-09-39) and should only apply to blast damage (CDZ) and not to stress-induced damage (EDZ). In fact, with the maximum principal stress perpendicular to the walls of the tunnel, the stress concentrations should be higher under the floor than at the wall.

The distinction and separation of construction damage (CDZ) from stress-induced excavation damage (EDZ) is required (see Eberhardt and Diederichs, 2012), especially with respect to the mitigation and management measures proposed (smooth wall blasting).The findings and conclusions regarding EDZ and spalling are therefore the following:

- Assumptions regarding EDZ prediction may not be conservative.
- Uncertainties persist in the estimation of stress magnitudes and directions.
- Potentially non-conservative assumptions exist for long-term minimum strength contra short-term (upper-bound) crack initiation threshold from strain measurements in laboratory.
- High frequency GPR holds promise as a routine operational tool for tunnel scale EDZ depth determination.
- Resistivity surveying can detect EDZ depth with some confidence.
- Seismic refraction can detect EDZ but is not an operationally practical tool due to complexity of the equipment setup.

The bedrock at Forsmark contains subordinate rock types, such as amphibolites and vuggy granite. The thermal properties of these rock types have to be determined. In addition, there is a need for a likelihood assessment for the occurrence of 3-D geological anomalies that would not be detected visually within the combined geometrical coverage afforded by the deposition tunnels and deposition holes. Geophysical techniques exist for identifying certain types of subordinate rock groups (Figure 9).

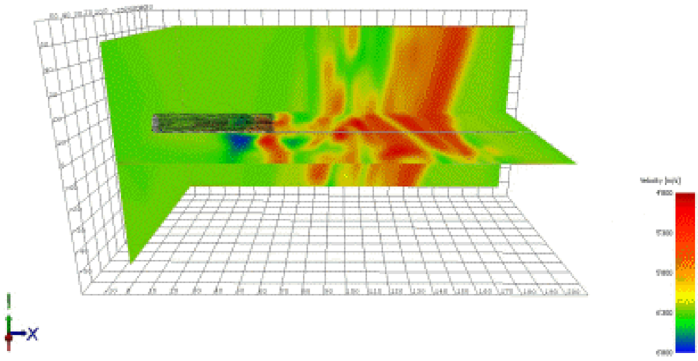

Figure 9. Geophysical methods can be applied for identification of subordinate rock types in the vicinity of the repository. The picture show seismic velocity distribution (blue low velocity and red high velocity) in the vicinity of an underground opening. After Amberg (Switzerland, www.amberg.ch).

4. Hydrogeological Considerations Based on the Rock Mechanics Results

Joel Geier of Clearwater Hard Rock Consulting (USA), started his presentation by pointing out the main identified uncertainty related to hydrogeology, namely, connectivity and channelling issues. The poor connectivity of hard rocks at depth, as in Forsmark, can be enhanced by coalescence of pre-existing fractures, micro-fractures and by shear dilation, extension and linkage of fractures. An EDZ in tunnels and spalling and/or EDZ in the deposition holes will enhance connectivity and channelling. The identified uncertainties in hydrogeological models are: a) sensitivity of connectivity, of fracture intensity, and size distribution and b) channelling effects on connectivity and concentration of flow. Also, the effectiveness of the application of EFPC for avoiding large conductors in the deposition tunnels is of importance for the hydrogeological models.

Alternative models for the relationship between deterministic structures and the DFN were presented by Joel Geier. He pointed out that there is a poor connectivity of SKB's Hydro DFN and the flow is mainly via very large fractures and a few associated smaller fractures. He presented results from a comparison of DFN models consistent with site data from Forsmark, but with clustering relative to minor and major deformation zones. In the same analysis, SKB's base case and a parametric variant were shown (Geier, 2011). The trend of the cumulative probability curves of the calculated flow to deposition hole, during the temperate phase of the repository and saturated buffer and backfill conditions, is similar for all analysed models. The mean inflow value to the deposition holes is about 100 ℓ/yr while the 90%-fractile would be about 1000 ℓ/yr.

The Geo-DFN model by SKB is also poorly connected but the heterogeneity in the Geo-DFN implies regions with better percolation. The alternative fracture model using elliptical channels according to Black (2013) was presented in brief.

The impacts of Rock Mechanics issues on Hydrogeology were summarised as follows:

- EDZ in deposition tunnels:
    - Continuous EDZ has been analysed by SKB but argued as unlikely;
    - Acts as a dominant conductor if Hydro-DFN model is correct.
- EDZ in deposition holes:
    - Connectivity and channelling issues.
- Shear dilation:
    - Increased flow rates following post-closure thermal period?
- Potential extension/linkage of fractures:
    - Changes in flow paths in post-closure period?

In the closing remarks about geomechanical-hydrogeological impacts on the safety case, Joel Geier emphasised that the critical issues are: a) the number of deposition holes that see high flow rates and b) the possibilities for focused upwelling of saline water or down-welling of dilute waters.

The correlation between flows observed during the construction phase and post-closure claimed by SKB is another important uncertainty. It was discussed the importance of estimating the fraction distribution of the post closure inflow into deposition holes for discerning between “dry” deposition holes, where saturation of the buffer occurs slowly through the EDZ, and “wet” deposition holes, where saturation is much faster. The impact of geosphere uncertainties can lead to the risk of a loss of canister containment and enhancement of advective conditions in deposition holes. This must be counterbalanced by the efficiency of the EBS and low spent fuel dissolution rates.

5. Discussion on SKB’s Design Premises

A session for general discussion was held at the end of the workshop and aimed at answering the specific questions posed by SSM on SKB’s Design Premises. SKB’s Design Premises focusing on the hydrogeological characterisation of the rock mass in the near-field currently cover:

- Water inflow into deposition holes
- Low connected fracture transmissivity in the near-field
- Connected effective transmissivity around deposition holes, which should be lower than 10^{-10} m^2/s
- Connected effective transmissivity along deposition tunnels, which should be non-continuous and lower than 10^{-8} m^2/s.

The workshop was asked to consider for each Design Premise:

- Are the ranges of safety relevant parameters proposed by SKB adequate and conservative?
- Do any feasible and credible alternative models lead to significantly different behaviour than the results from SKB’s models?
- Are there omissions and, in that case, what is their relevance for the safety analysis SR-Site?
- Are the Design Premises scientifically sound? Can the related safety relevant parameters proposed by SKB be measured with sufficient precision and confidence?
- Is SKB's approach adequate, with or without omissions, for licensing construction, even though there may be alternative approaches?

The discussion was managed by completing a set of tables summarizing the questions above. It was pointed out that SKB would clearly need to have Design Premises that can be verified during construction. In other words, there is no point in having non-measurable quantitative requirements, such as deposition hole wall transmissivity. SKB acknowledges that they still need to develop a practical and routine method for accepting deposition holes based on inflows.

The viewpoints and conclusions expressed at the workshop are those of the workshop participants and do not necessarily coincide with those of SSM.

5.1. Water Inflow into Deposition Holes

The workshop was asked to consider the Design Premise on limit to water inflow into deposition holes:

- Is the conceptual model robust (100 kg of eroded bentonite – corresponding to 150 m^3 of water flowing into the deposition hole before saturation of the buffer – buffer erosion at inflow of 0.1ℓ/min)?
- Is the value 0.1ℓ/min reasonable?

- What is the measurement threshold?
- Time for saturation: 3, 10, 100, 1000 or 10,000 years?
- Water inflow during saturation versus operational phase of the repository?
- Effect of grouting?
- Would there be enough deposition positions fulfilling the requirement?

In the discussion it was noted that 0.1 ℓ/min is not in fact a threshold for erosion (the actual threshold, if any exists, is not known), but is the value estimated to erode 100 kg of bentonite from a deposition hole buffer and transport it into void space in the adjacent disposal tunnel. SKB model assumes that the water inflow into the deposition hole where the bentonite is eroded has to predominate over the inflow into the deposition tunnel. In the backfill in each deposition tunnel, it is estimated to be a volume of about 1500 m^3 filled of air/water where the eroded buffer can be transported to.

SSM needs to check the erosion and mass transport rate calculations made by SKB and compare them with the measurement threshold for flow into deposition holes. These results can be compared with SKB's proposed 0.1 ℓ/min value where a piping erosion capacity of the water is assumed to be about 1 g/litre.

It was also suggested that operational requirements to work in a dry environment during EBS emplacement, plus time scheduling of the excavation and utilisation of the deposition holes, would push this value to much lower levels. In fact, at 0.1 ℓ/min, an empty hole would be filled with water in about 4 months. At much lower flows that might be reasonable for operations, piping might not occur because there should be a lower flow limit for the water to be able to carry away bentonite from the buffer. However, such limit is not put forwards by SKB. Furthermore, it is not clear whether the local heads that drive piping erosion would dissipate quickly or evenly after tunnels are sealed, so erosion might continue in some locations for longer than the 2 to 3 years implied by SKB's figures.

This discussion led to two questions:

- If flow continues for tens of years at lower gradients (e.g. while a whole deposition panel is open), what would be an acceptable maximum inflow rate into deposition holes (and from where) in order to keep maximum erosion to less than 5% of the buffer mass?
- How does this relate to operational practicality of wet hole inflows during buffer emplacement and the actual, practical lower measurement limit for inflows?

Recent results from Posiva indicate that flows as low as 10 mℓ/min could be measured in the demonstration deposition holes at ONKALO (Aro, 2013).

In summary, the Table 1 provides the views of the workshop on the questions raised by SSM on these issues.

Table 1. Summary of the workshop discussions on the issue of Water Inflow into Deposition Holes.

Issue	Suitable	Uncertain	Unsuitable	Comments
Is SKB's conceptual model/approach suitable?		X		Minimum flux for piping process in deposition holes; unknown detectable limits; operational gradients might vary.
Are there omissions relevant for SR-Site?	X			Clarifications needed: request for complementary information.
Are SKB's parameters/ranges relevant for SR-Site?	X			100 kg bentonite, saturation within 20-200 yrs
Is SKB's Design Premise suitable for SR-Site?			X	0.1 ℓ/min too large for operation.

5.2. Low Connected Fracture Transmissivity

SSM asked the following questions concerning this Design Premise on low connected fracture transmissivity:

- Is this Design Premise needed?
- Is this parameter suitable within SR-Site? Definitions?
- Connected transmissivity does not mean flow…
- Evolution of transmissivity after closure?
- How does this transmissivity relate to the Hydro-DFN?
- How does the Hydro-DFN relate to the Geo-DFN?
  (on-site mapping)
- Can this parameter be measured on-site?
- Is this related to the EFPC-criterion?

SKB states in SR-Site (SKB, 2011) that: "*fractures, or rather minor deformation zones, with a radius larger than 250 m and with efficient transmissivity larger than*10^{-6} m^2/s*, will be detected by the detailed investigations so that potential deposition positions intersecting such fractures would be avoided. Such fractures would have the potential of an inflow in the order of 25 ℓ/min.*"

Furthermore: "*The transmissivity limit of* 10^{-6} m^2/s *is seen as cautious considering the characteristics of such a fracture discussed above. In all hydrogeological calculations, this transmissivity/fracture length (T/L) criterion is implicitly included in the EFPC criterion, unless otherwise stated.*"

In general, the workshop considered that this Design Premise is not needed, as it cannot be measured and overlaps with the deposition hole inflow criterion. It is only likely to be possible to measure the transmissivity of a fracture that intersects a deposition hole, not the transmissivity of the connected network, as the free boundaries are too close and could include features such as the connected EDZ of an adjacent tunnel. In addition, transmissivity varies with thermal impacts and other load changes.

In summary, the Table 2 provides the views of the workshop on the questions raised by SSM on these issues.

Table 2. Summary of the workshop discussions on the issue of low connected fracture transmissivity.

Issue	Suitable	Uncertain	Unsuitable	Comments
Is SKB's conceptual model/approach suitable?		X		Need of justifications of this Design Premise. Motivation of the value $10^{-6} m^2/s$ (very transmissive fracture) should be given.
Are there omissions relevant for SR-Site?	-	-	-	N.A.
Are SKB's parameters/ranges relevant for SR-Site?	X			The connected transmissivity around a deposition hole is an input for radionuclide transport calculation.
Is SKB's Design Premise suitable for SR-Site?			X	Redundant parameter (see point above). SKB believes they can avoid high connected transmissive fractures.

5.3. Connected Effective Transmissivity lower than 10^{-10} m^2/s around Deposition Holes

SSM asked the following questions on the Design Premise on connected effective transmissivity around deposition holes:

- Is the value of connected effective transmissivity of 10^{-10} m^2/s relevant for SR-Site?
- How would this be measured?
- Does this value include the evolution of spalling with time after closure?
- How is this value related to the threshold of spalling depth of 5 cm considered in SR-Site?
- How many deposition holes exceeding this limit would occur in the repository?

It was assumed by the workshop that spalling could be isolated/sealed and would not contribute to the connected effective transmissivity before closure. The workshop considered it necessary to ask SKB how it is planned to use a possible range of geophysical techniques to measure this parameter. In principle, the general opinion was that it is possible to measure by direct or indirect means and measuring the parameter would be a valuable objective for verifying that the spalled volumes along the deposition hole do not become a pathway for radionuclide transport between Q1 and Q2.

Nevertheless, as with the previous Design Premise, the connected effective transmissivity would be affected by heat and SKB's proposed limit might have limited long-term meaning.

In summary, the Table 3 provides the views of the workshop on the questions raised by SSM on these issues.

Table 3. Summary of the workshop discussions on the issue of connected effective transmissivity $<10^{-10}$ m^2/s around deposition holes.

Issue	Suitable	Uncertain	Unsuitable	Comments
Is SKB's conceptual model/approach suitable?		X		SKB considers spalling and assumes that the highly deformed zone can be removed by scaling. It does not consider other rock damage than spalling (EDZ due to deformations and fracture opening). Long term evolution and thermal spalling are not included. This safety function is to rule out flow outside buffer.
Are there omissions relevant for SR-Site?		X		SKB does not specify how this parameter can be calculated.
Are SKB's parameters/ranges relevant for SR-Site?	X			Addition to flux Q2.
Is SKB's Design Premise suitable for SR-Site?		X		Need of explanation about how to obtain the effective transmissivity from direct or indirect measurements (geophysics) in situ.

5.4. Non-continuous Connected Effective Transmissivity lower than 10^{-8} m^2/s along Deposition Tunnels

The workshop was asked to consider the Design Premise on non-continuous connected effective transmissivity along deposition tunnels:

- Is the conceptual model relying on this parameter suitable for SR-Site?
- Can a continuous EDZ occur continuously along the deposition tunnel?
- How persistent is an EDZ "*along a significant part (i.e. at least 20-30 m)*" of the deposition tunnel compared to the total length along a deposition tunnel?
- How does EDZ evolve after construction of the deposition tunnel?
- Is the value 10^{-8} m^2/s relevant for SR-Site?
- Can this parameter be measured?

The discussion dealt with the continuity of EDZ in the deposition tunnels and concluded that the statement "*along a significant part (i.e. at least 20-30 m)*" (SKB TR-09-22) does not say how often this condition can occur in a tunnel.

In summary, the Table 4 provides the views of the members of the workshop on the questions raised by SSM on these issues.

5.5. Channelled Flow

The participants were asked to consider the following questions:

- Implications for the conceptualisation of Forsmark?
- Implications for the site characterisation? (shape of the fractures)
- Implication for SR-Site
- Implications for the modelling? (scales)
- Implications for the Design Premises?
- Implications for the acceptance criteria for the deposition holes?

There is an assignment from SSM to Clearwater Hard Rock Consulting on the topic which will be further discussed at the delivery of the results. However, the workshop ran out of time before this issue could be discussed.

Table 4. Summary of the workshop discussions on the issue of non-continuous connected effective transmissivity and <10^{-8} m^2/s along deposition tunnels.

Issue	Suitable	Uncertain	Unsuitable	Comments
Is SKB's conceptual model/approach suitable?			X	SKB needs to demonstrate on what basis EDZ does not occur. SKB only focuses on construction damage. Short term vs. long term damage is not considered. SKB's models taking into account EDZ are maybe more realistic than the conceptual model without EDZ.
Are there omissions relevant for SR-Site?		X		EDZ is not considered in the walls of the deposition tunnel. Difference in transport behaviour? (SKB uses much larger values for the floor).
Are SKB's parameters/ranges relevant for SR-Site?	X			SKB chooses values from 10^{-6} m^2/s down to 10^{-8} m^2/s and no EDZ.
Is SKB's Design Premise suitable for SR-Site?		X		Need of explanation about how to obtain Design Premises from direct or indirect measurements (geophysics) in-situ. Value and continuity of EDZ. Continuous measurements along deposition tunnels are not considered.

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APPENDIX 1

Agenda of the Workshop

Rock Damage-Hydrogeology Workshop
SSM, 30 September and 1 October, 2013

Venue: SSM office, room "Tosterön", gound floor,
Solna standväg 96, Solna, Sweden

September 30th, 2013

13.00 – 13.15	Welcome and introduction *Flavio Lanaro, SSM*
13.15 – 13.45	Relevance of the Rock Mechanics issues for the Hydro-geological Analyses in SR-Site *Georg Lindgren, SSM*
13.45 – 14.00	Relevance of the Hydro-geological analyses in and Radionuclide Transport in SR-Site, *Shulan Xu, SSM*
14.00 – 15.00	Rock Mechanics – Confidence of SKB's models for predicting the occurrence of a damage zone around the excavations *Goodluck Ofoegbu, SWRI*
15.00 – 15.30	Coffee
15.30 – 16.30	Rock Mechanics – Confidence of SKB's models for predicting the occurrence of spalling *Tobias Backers, Geomecon*
16.30 – 17.30	Rock Mechanics – Evolution of fracture transmissivity within different scenarios in SR-Site Ki-Bok Min, SNU
17.30 – 18.00	Introduction of workshop topics and assignments, *Lanaro and Lindgren, SSM Workshop assignment discussion.*

October 1st, 2013

8:30 – 9.30	Hydro-geological considerations based on the Rock Mechanics results *Joel Geier, Clearwater Hardrock Consulting*
09.30 – 10.30	Rock Engineering - Performance and resolution of geological and geophysical mapping and measurement techniques for determination of critical properties in and around deposition holes *Erik Eberhardt, Mark Diederichs, Fisher & Strickler*
10.30 – 11.00	Coffee
11.00 – 12.45	Workshop assignment discussion
12.45 – 13.45	Lunch
13.45 – 15.00	Workshop assignment discussion
15:00 – 15.30	Coffee
15.30 – 16.30	Workshop assignment discussion
16.30 – 17.00	Summary of the technical findings and workshop evaluation *Ove Stephansson, Steph Rock Consulting,* *and Flavio Lanaro, SSM.*

APPENDIX 2

List of Participants

Rock Damage Workshop
SSM, 30 September and 1 October, 2013

Ove	Stephansson	Steph Rock Consulting
Neil	Chapman	MCM Consulting
Tobias	Backers	Geomecon
Ki-Bok	Min	Seoul National University
Goodluck	Ofoegbu	Southwest Research Institute
Erik	Eberhardt	Fisher & Strickler
Mark	Diederichs	Fisher & Strickler
Joel	Geier	Clearwater Hardrock Consulting

			30/9	1/10	
Flavio	Lanaro	SSM	x	x	(Moderator)
Georg	Lindgren	SSM	x	-	
Jinsong	Liu	SSM	x	x	
Lena	Sonnerfelt	SSM	x	x	
Bo	Strömberg	SSM	x	x	
Shulan	Xu	SSM	x	x	
Carl-Henrik	Pettersson	SSM	x	x	

2014:23

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The Swedish Radiation Safety Authority works proactively and preventively to protect people and the environment from the harmful effects of radiation, now and in the future. The Authority issues regulations and supervises compliance, while also supporting research, providing training and information, and issuing advice. Often, activities involving radiation require licences issued by the Authority. The Swedish Radiation Safety Authority maintains emergency preparedness around the clock with the aim of limiting the aftermath of radiation accidents and the unintentional spreading of radioactive substances. The Authority participates in international co-operation in order to promote radiation safety and finances projects aiming to raise the level of radiation safety in certain Eastern European countries.

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Strålsäkerhetsmyndigheten
Swedish Radiation Safety Authority

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