# REGULATORY ASSESSMENT OF A SPENT FUEL REPOSITORY AT THE FORSMARK SITE SWEDEN; EVOLUTION OF GROUNDWATER SITE CONDITIONS

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*On the 16 march 2011 the Swedish Nuclear Fuel and Waste Management Company submitted a license application for the construction of a KBS-3 spent fuel repository at the Forsmark site in Sweden, which is currently being reviewed by the Swedish Radiation Safety Authority. The application concerns the KBS-3 disposal method, which is based on containment of spent fuel in cast iron insert /copper canisters placed in deposition holes at about 450 m depth in granitic rock. Each canister is surrounded by a 30 cm thick buffer of bentonite clay. This paper provides an overview of scientific and regulatory issues related to SKB's modelling of hydrogeology and groundwater chemistry with the purpose of scrutinizing the basis for SKB's corrosion failure analysis in the post-closure safety assessment. The corrosion failure analysis includes the advection corrosion case that involves chemical erosion of the buffer that may result from interaction with very dilute groundwater. The removal of buffer material through erosion may lead to enhanced corrosion of the copper canister shells by groundwater sulphide. The review findings presented in this paper mainly reflect the outcome of a number of external experts' reviews and from SSM's independent modelling of site hydrogeology. The assessment of the advection corrosion case in the licensing review has proven to be a challenging task due to its broad scope, complexity and multidisciplinary nature. Further, the compliance demonstration is based on spatial and temporal variability of both groundwater flow rates and groundwater composition in a deposition-hole scale, which both have a large impact on the modelling results. Regulatory scrutiny therefore needs to focus on the derivation of probability distribution functions for these variables.*

## I. INTRODUCTION

In this paper, we provide an overview of scientific and regulatory issues related to modelling work conducted by the Swedish Nuclear Fuel and Waste Management Company (SKB) in the area of hydrogeology and groundwater chemistry with the purpose of scrutinizing the basis for SKB's corrosion failure analysis in SR-Site. This analysis is a key component of SKB's main scenario in SR-Site and in the demonstration of compliance with SSM's risk target for the post-closure protection of human health. Intermediate review results related to particularly risk significant factors are reported.

The Swedish Radiation Safety Authority (SSM) has during the course of the review completed several review assignments involving external experts, with the objective of exploring conceptual uncertainties related to SKB's discrete fracture network approach for modelling groundwater flow. Corresponding expert reviews in the area of groundwater chemistry comprise long-term stability of redox conditions at repository depth, prediction of groundwater salinity evolution near deposition holes, and the spatial distribution of groundwater sulphide near deposition holes. Additional work by SSM in this area has covered independent alternative flow modelling, and reviews of quality assurance of SKB's flow modelling.

## II. THE FORSMARK SITE

The spent nuclear fuel from the Swedish reactors is planned to be disposed of in a deep geological repository located at Forsmark at the Baltic coast in Sweden (Fig. 1). SKB has selected this site based on a site selection procedure and a comprehensive surface-based site investigation program (1).

For the purposes of characterizing the groundwater site conditions SKB has carried out pumping tests in 21 core drilled boreholes down to a depth of about 1200 m in the granitic rock at the site. Flow logging with a spatial resolution down to 0.1 m has been performed in 15 boreholes using the POSIVA flow log tool (2). The objective of the flow logging, together with imaging of the boreholes, was to identify single flowing fractures in the boreholes. Large scale hydraulic tests have measured interference in boreholes at the kilometer scale. Results show that the uppermost 150 m of the rock are controlled by highly transmissive sheet joints, whereas the rock at repository depth shows very few connected flowing fractures occurring less than every 250 m in the boreholes in the repository area below 400 m depth (3). Hydrochemical investigations were to a large extent based on chemical analysis of groundwater samples from the same boreholes.

During SKB's site investigations SSM commissioned an independent site investigation tracking and evaluation group (INSITE) for geosphere issues to perform technical field reviews, review SKB documents and to interact with SKB through an issue resolution scheme. The work of the INSITE group was the basis for SSM's assessment of the site investigations. INSITE concluded in their summary report (4) that SKB has used best available methods for measurements and that the site investigation work had been conducted by first-rate expertise. At the same time INSITE identified a number of critical topics for resolution in the context of safety assessment.

SKB's hydrogeological site investigations at Forsmark resulted in a conceptual model implemented in different computer codes developed for different purposes. For the purpose of near-field flow analysis, a hydrogeological stochastic discrete fracture network model (hydro-DFN) was set up in the Connectflow code (5). The hydro-DFN model was up-scaled and implemented in an equivalent continuum porous medium model (ECPM) also coded in Connectflow. The ECPM model was used for analyzing the past hydrochemical evolution at the site and to check the validity of the model against different measurements. Parts outside the thoroughly investigated area were modelled with a continuum porous model (CPM).

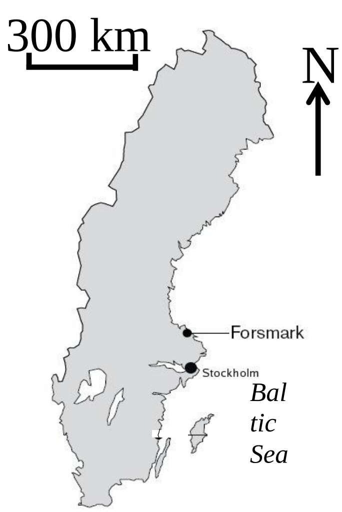


Fig. 1. Location of the Forsmark site in Sweden

## III. SKB'S SR-SITE SAFETY ASSESSMENT AND ITS MAIN SCENARIO

The SR-Site safety report analyses and demonstrates the long-term safety and radiation protection for the proposed repository for spent nuclear fuel at the Forsmark site in Sweden (6). In this paper we will address the advection corrosion case, which involves chemical erosion causing loss of buffer material and subsequent corrosion of the copper canister shell by groundwater sulphide (eq. 1).

$$2Cu + HS^{-} + H^{+} \rightarrow Cu_2S + H_2 \qquad (1)$$

The loss of buffer material eventually leads to advective conditions in the buffer and an elevated copper corrosion that may lead to canister failure and subsequent radionuclide releases. The extent and timing of this failure mechanism plays a key role in SKB's compliance demonstration.

Figure 2 is a modelling flowchart for SKB's analysis of the advection corrosion scenario. The chemical erosion mode for buffer has been thoroughly addressed from 2006 and onwards (7). The relevant scenario is that present groundwater at repository depth can at some point in the future be extensively diluted up to the point that bentonite colloids can form and remain stable. In deposition holes that encounter fractures with sufficiently high groundwater flow, erosion can then create a cavity in the buffer. Experiments have conclusively shown that colloidal stability cannot be assured below cation concentrations with the total charge equivalents of about 4 mM (8). The present content of alkali- and alkali-earth cations in the groundwater at Forsmark corresponds to about 100-120 mM, thus an extensive dilution is needed to initiate chemical buffer erosion. SKB has addressed two situations in which extensive dilution may occur; one is a rapid inflow of dilute glacial meltwater far into the future and the other situation is a very long period of temperate conditions during which slower meteoric water infiltration takes place. Because of the heterogeneous characteristic of the Forsmark bedrock dilute water infiltration is expected to only appreciably affect groundwater composition in a limited number of positions at 450 m depth. The quantification of the number of affected deposition holes is therefore an important issue.

Three "events" are associated with the breaching of the isolation safety function and radionuclide releases (see figure 2). First, if groundwater cation charge in close proximity to a deposition hole does not drop below the 4mM level, corrosion of copper will remain controlled by slow diffusion. If and when the cation content drops below this level, the buffer erosion rate is predicted based on the groundwater flow rate and fracture aperture (9). SKB considers the buffer failed when it has lost 1200 kg of its original mass of 22000 kg. A certain amount of buffer mass loss may occur without any appreciable influence on the canister corrosion as long as the buffer preserves its swelling pressure. However, the capacity to redistribute buffer mass has a limit and at some point cavity formation will occur near the flowing fractures.

Canister corrosion is then predicted by mass transfer of sulphide to the canister surface by advection rather than diffusion. Such an analysis cannot be based on the "highest" conceivable sulphide content but rather using a distribution of sulphide concentrations determined during the site investigations campaign. Groundwater flow rates are determined through an elaborate flow modelling work (10). The corrosion model based on advection suggests significantly higher corrosion rates compared to the case with an intact buffer with only diffusion controlled sulphide transport.

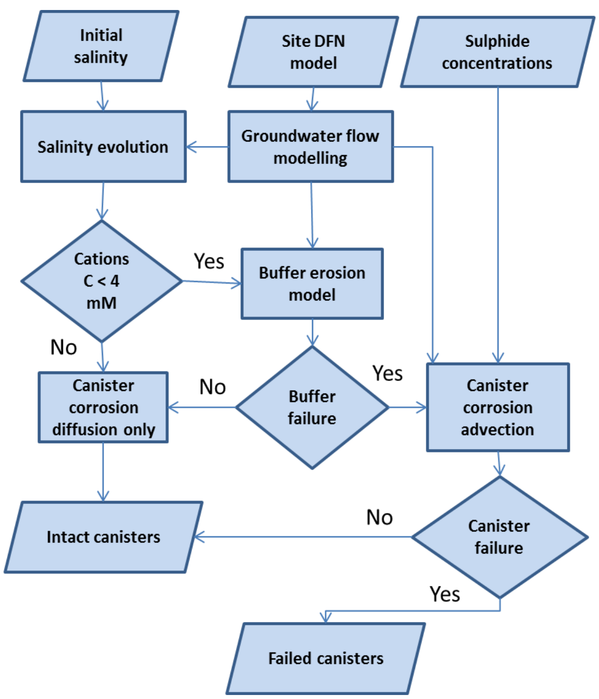


Fig. 2. Modelling flowchart illustrating the steps in SKB's canister failure assessment for the advection corrosion scenario in SR-Site.

## IV. GROUNDWATER FLOW MODELLING IN SR-SITE AND ITS REVIEW BY SSM

The conceptual model and the parameterization derived in the site descriptive modelling described above are used as input to the hydrogeological modelling in SR-Site (10). SKB studied the hydrogeological interactions of the backfilled and saturated repository during temperate conditions using a nested Connectflow model that includes a CPM representation of the tunnels and deposition holes and a hydro-DFN to represent the flow in the surrounding rock. The boundary conditions for this model are taken from the ECPM model. For far-field analysis the particle tracks of the nested model are continued in the ECPM and far-field CPM parts of the model. The hydrogeological impact of permafrost and glacial conditions are analyzed in SR-Site with an up-scaled hydro-DFN model implemented in DarcyTools (11). The Connectflow and DarcyTools ECPM models are used as a basis for calculation for groundwater chemical evolution (see VI.).

The hydro-DFN model calculates Darcy fluxes and particle tracks to and from every connected deposition hole to the model boundaries. Diffusive transport to and from the buffer from the surrounding rock is represented by equivalent flow rates calculated from flow results, fracture geometry, and diffusion parameters. Based on the particle tracks, travel times and the flow wetted surfaces along the tracks are calculated. The buffer erosion calculations depend on water flow velocities calculated from the Darcy fluxes. The corrosion calculations are based on the equivalent flow rates for intact buffer conditions and on the Darcy fluxes for eroded buffer conditions. Penetration times for dilute water depend on the flow along the particle tracks and associated flow wetted surfaces.

SSM has developed a strategy to effectively review the hydrogeological modelling in view of an extensive amount of data and documentation. SKB's modelling is complex, stochastic, and computer resources demanding. SSM has had four lines of review work covering (i) SKB's basic data and site descriptive modelling work, (ii) SKB's quality assurance work related to hydrogeological modelling, (iii) conceptual hydrogeological models, and (iv) SSM commissioned modelling studies.

The first point has previously to a large extent been covered by the work of the INSITE group (4) explained above. The second point has been covered by an external expert review of SKB's QA system (12). To address the third point SSM has put review efforts in the assessment of the derivation and appropriateness of the conceptual models that SKB employs by several external expert reviews (13, 14, 15, 16, 17, 18). Fourthly, SSM has engaged external experts for hydrogeological modelling of the Forsmark site (19, 20, 21) and buffer-rock hydrological interactions (17).

Hicks (12) concludes that the quality assurance of SKB's hydrogeological modelling processes is appropriate and that the modelling process is transparent and traceable. However, in the license application reports there is a considerable lack of precise referencing that hinders the reader to quickly trace the origin of statements and data.

When it comes to the conceptual models employed by SKB, the external experts acknowledge the work SKB has done, but have concerns that the hydro-DFN at repository depth is not well bounded by site data and that a different conceptual model could fit available data equally well as the ones put forward by SKB (13, 15). This problem partly owes to the very sparse network of flowing fractures detected at this depth, which makes model validation difficult. The experts, however, feel that SKB has presently not explored alternative conceptual models to a degree that would allow them to more confidently capture the conceptual uncertainties.

## V. SSM'S INDEPENDENT MODELLING OF GROUNDWATER FLOW

The objective of the modelling studies carried out by external experts for SSM has been to obtain independent order-of-magnitude estimates as well as additional understanding SKB's modelling work. SKB has with its recent work advanced the field based on very high capacity computer resources. Due to this complexity it has not been feasible for SSM to replicate SKB's work in detail. Instead, SSM has strived to obtain results from alternative modelling codes that can be implemented with smaller resources.

For instance, the hydraulic conductivity field was up-scaled from a hydro-DFN model for comparison with the input used in SKB's ECPM modelling (19). The results gave a reasonable agreement with SKB's corresponding calculations. Geier's study also showed that the upscaling of flow wetted surfaces and porosities is a particularly sensitive modelling step and that SKB's up-scaled results are not necessarily conservative.

However, when using parameters calculated directly from the hydro-DFN model this is not an issue. Geier (19) has with a DFN block-scale model obtained results for inflows to deposition holes using 100 x 100 x 100 $m^3$ domains. Results from using this approach provide an order of magnitude agreement with SKB's results, which gives some confidence that the Geier (19) and the SKB models are reasonably consistent at least in terms of flows to deposition holes.

With a simplified hydro-DFN model derived from SKB's geological DFN models, Geier (21) calculated conservative flow and flow related transport parameters. These results are intended as input to independent buffer erosion, copper corrosion and radionuclide transport scooping calculations. Due to the comparatively simple modelling approach it has been possible to explore some alternative geological structure models. Table 1 replicated from Geier (21) shows that the distributions of flow wetted surface values obtained with Geier's (21) simple series model are generally slightly more conservative than SKB's results. The minimum values differ about an order of magnitude while the upper part of the distribution is more or less equal.

TABLE I. Approximate percentiles of flow wetted surface values Fr (yr./m) from the temperate-climate model of SKB in comparison with the simple series model presented by Geier (21), for three alternative models for the relationship of fracture transmissivity to fracture size in combination with SKB's base-case model for the relation between fracture transmissivity and aperture.

| Transmissivity model | Min. | $10^{th}$ percentile | Median | $90^{th}$ percentile |
|---|---|---|---|---|
| **Semicorrelated (SKB)** | ≈ $4x10^3$ | $5x10^5$ | $2.5x10^6$ | $4x10^7$ |
| **Semicorrelated (Simple)** | $4x10^2$ – $8x10^8$ | $1x10^5$ | $2.5x10^6$ | $3x10^7$ |
| **Uncorrelated (SKB)** | ≈$4x10^3$ | $5x10^5$ | $4x10^6$ | $2x10^7$ |
| **Uncorrelated (Simple)** | **$1x10^2$ –** $8x10^3$ | **$3x10^4$** | $8x10^5$ | $1.6x10^7$ |
| **Correlated (SKB)** | ≈$3x10^3$ | $1.6x10^5$ | $2x10^6$ | $2x10^7$ |
| **Correlated (Simple)** | ≈$1x10^4$ | $8x10^4$ | **$5x10^5$** | **$1.6x10^6$** |

## VI. EVOLUTION OF GROUNDWATER COMPOSITION AND ITS IMPACT ON ENGINEERED BARRIER PERFORMANCE

SKB has presented simulations for groundwater chemical evolution during both an extended continued period of temperate conditions and for periods with glacial and peri-glacial conditions, which are based on coupled hydrological modelling of mixing proportions of end-member waters and PHREEQC geochemical modelling (22). A key emphasis of this work is to establish the spatial variability of groundwater composition in a deposition-hole scale. In this paper, we will only discuss limited aspects of this problem area which are closely related to buffer erosion and copper corrosion. For the evolution of groundwater cation content, SKB has chosen to rely mainly on a conservative simplified flow model, which does not include representation of chemical reactions and assumes that the only process that will counteract a dilution is diffusive exchange of cations with stagnant pore-water in the rock matrix (23). For the groundwater sulphide content which is a key variable in the corrosion assessment, SKB utilizes a distribution of sulphide concentrations measured at the Forsmark site.

SSM's initial separate review assignments by McMurry (24) and Bath (25) covering groundwater chemistry issues were to a large extent in agreement and suggesting that SKB's data interpretation and modelling methods are broadly acceptable. However, important uncertainties arise because of simplifications and assumptions used in the modelling for instance related to omitted processes such as ion-exchange and weathering of silicate minerals, omitted measurement values for sulphide, and the use of a generic data for the composition of the very deep shield brines.

An in-depth external review of the long-term salinity evolution has been provided by Bath (26). This topic was identified as particularly significant for SSM's main review phase. According to this external reviewer, the combination of complex ECPM and DFN modelling involving many assumptions and a certain lack of clarity in the reports makes it a challenge to achieve full understanding of all modelling steps. Impact of uncertainties in the flow modelling are difficult to evaluate based on SKB's reporting given that the results are based on few model variants with only a limited sensitivity analysis to explore uncertain parameters and model assumptions. Lack of discussion about the role and responses of essentially intact rock was also noted. The composition of infiltrating water is a key boundary condition in determining modelling results and here SKB's analysis only reveals the impact of either an extreme zero salinity water or water with a cation content which is already above the level that would result in buffer erosion. It is also pointed out that uncertainty exists regarding the exchange of cations with matrix water due to limited data availability and a possible limited penetration depth. In spite of this, this reviewer concludes that dilution of groundwater down to 4 mM is improbable since the uncertainty is balanced by the contribution of a "base level of mineralization" provided by chemical reaction which is omitted in SKB's modelling. Overall, it is recognized that a small number of the most exposed deposition holes could still be affected by buffer erosion.

Another groundwater chemistry area with a key role in the canister corrosion analysis is SKB's assessment of the utilized distribution of groundwater sulphide content. This distribution is based on a selection of measurement values from the Forsmark site which are regarded to be representative of conditions at repository depth through an expert judgment procedure (27). In an external expert review, it was concluded that SKB's approach can be regarded as broadly defensible (28). Two aspects of the selection procedure worth mentioning are the omission of some high sulphide measurements and second the assumption that measured values will apply indefinitely. Regarding the former, such high measurement values were assumed to be comparatively short-lived duration and most likely related to disruption of the natural system during sampling. Regarding the latter, SKB admits that variations in time are likely to occur but gradual decreases are expected during future glacial states (27). As pointed out by Bath (28) measured sulphide content in groundwater is most likely affected by variation in microbial sulphate reduction (MSR) rates caused by availability of sulphate, substrates and nutrients as well as environmental conditions (exemplified by equation 2).

$$SO_4^{2-} + CH_4 + H^+ \rightarrow HS^- + CO_2 + 2H_2O \qquad (2)$$

Bath (28) calculated simple mass-balances and limiting cases to obtain a view of the maximum extent of the involved chemical reactions. The author suggests that effects on the availability of sulphide by formation of iron sulphide minerals (e.g. FeS and $FeS_2$) should have been explored.

The evaluation of sulphide availability discussed above concerns the undisturbed bedrock environment, but issues have been raised regarding the possibility of preferential sulphate reduction occurring near canister surfaces (29). The electron donor may apart from methane (eq. 2) be dissolved hydrogen or reactive dissolved organic matter. Experiments related to this issue have recently been initiated by SKB (30). Forsmark groundwater generally contains very small amounts of hydrogen and methane, which imply a limited potential impact. However, significantly larger amounts of organic matter may originate from either buffer/backfill materials or are available as dissolved organic matter (DOC) in groundwater. SKB has accounted for the buffer/backfill part by mass-balances (31), but argues that DOC in deep groundwater is generally unreactive given long residence times on the order of thousands of years (32).

Corrosion of copper will occur in the presence of oxygen apart from the main sulphide route discussed above:

$$2Cu + ½O_2 \rightarrow Cu_2O(s) \qquad (3)$$

The early period of oxidizing conditions during operation and soon after the closure of the repository is accounted for by mass balance (31), but a more difficult question often raised in the past is whether the process could re-appear in the distant future by a rapid inflow of oxidizing glacial meltwater. This issue is dealt with by an analysis of how release of ferrous iron from rock minerals can counteract inflow of oxygen (33). SKB's analysis suggests that oxic corrosion of copper canisters (eq. 3) after the initial period of oxidizing conditions is unlikely but still a remote possibility for a small number of deposition holes. For the vast majority of the deposition holes with higher F-values (indicating more extensive contact between flowing water and rock surfaces) there appears to be a substantial safety margin. Due to the many conservative assumptions utilized in arriving at this conclusion SKB omits any risk contribution from this reaction. SSM conducted a thorough external review of this work during the main review (34) and here it was concluded that SKB's analysis is appropriate and no other factors that might affect the redox evolution apart from those that were dealt with by SKB were identified. The authors nevertheless recommended that further characterization of redox sensitive minerals should be conducted at the Forsmark site in order to establish an improved knowledge about possible redox transitions in the future.

## VII. ANALYSIS OF RISK CONTRIBUTION FROM THE ADVECTION CORROSION CASE

The risk contribution from the so called advection corrosion case is based on corrosion of copper by sulphide (eq. 1) and eroded buffer conditions caused by dilute but spatially variable groundwater chemical conditions. Eroded buffer conditions are eventually expected to result in copper canisters that are directly exposed to flowing groundwater. SKB has based the quantification of risk for this case on highly complex and sophisticated modelling methods involving extensive analysis of and interaction between site hydrology and site geochemistry.

SKB's analysis of the advection corrosion case relies on a simultaneous accounting of spatially variable conditions for both groundwater flow and groundwater sulphide content. According to the results canister failure could occur in the time frame of $10^6$ years if high flow conditions at deposition-hole scale coincide with positions in the bedrock with unusually high sulphide content. Because SKB arrives at the conclusion that such combinations are rare the risk contribution is quite small. Regulatory scrutiny is thus needed for spatial and temporal variability of both flow as well as groundwater sulphide, and not only for average or extreme values. A possibility of correlation between flow and sulphide content also needs to be considered.

The advection case with eroded buffer conditions can be compared with the diffusion controlled case with intact buffer conditions. Here the analysis is based on a fixed sulphide concentration and the rock/buffer boundary corresponding to the highest measurement value. Moreover, although the distribution of flow rates is accounted for also in this analysis, even the highest flow-rates are insufficient to cause canister failure in the $10^6$ years' time frame (31).

Because failure is anticipated by SKB only for a few of the most exposed deposition holes, repository risk could be reduced if such positions can be at least partially identified and avoided during repository construction. SKB has proposed that deposition-hole acceptance criteria should be further developed and formulated with the purpose of limiting the risk contribution from the advection corrosion case (6). There are limitations regarding the extent of unsuitable high flow position that can be avoided considering both cost and practicalities. This means that verification of suitable rock conditions for the Forsmark bedrock as a whole becomes very important. It could be mentioned here that limited risk analysis for the Laxemar site, the alternative site where SKB also carried out surface-based investigations, suggests that risk contributions related to the advection/corrosion case are substantially higher compared to Forsmark, mainly due to a higher frequency of flowing features at repository depth at this site (35).

It may be reasonable to assume that the potential for high groundwater flow in various part of the repository rock volume should remain more or less time invariant because it is related to the distribution of very old geological features in the bedrock. However, there appears to be no compelling arguments why sulphide concentrations should remain time invariant. Local perturbation of geochemical conditions can be expected to modify microbial sulphate reduction (MSR). Nevertheless, because corrosion failure results from accumulated mass transfer of sulphide, periods with temporarily either high sulphide concentrations or very low would only have a modest impact on canister life times provided that fluctuations are short in relation to canister life times. Such variations in time would most likely result in smaller probability of individual canister failure compared to the case with persistent sulphide distributions. An additional effect would however be a more evenly distributed partial corrosion damage in a larger fraction of the ensemble of copper canisters. Further assessment of the availability of sulphide and its connection to microbial sulphate reduction might be needed covering not just the current conditions but also for conditions after the repository has been established, for an extensive temperate phase, and for future glacial stages.

Even if a substantial amount of review results are available (by November 2014), the review of the advection corrosion case is still ongoing at SSM and it is thus not possible to draw any firm conclusions regarding SSM's position in relation to the analysis in SR-Site. It should be noted that other corrosion mechanisms apart from general corrosion by sulphide or oxygen is beyond the scope of this paper.

## VIII. OVERALL CONCLUSIONS

The paper presents an overview of scientific and regulatory issues related to SKB's modelling of hydrogeology and groundwater chemistry with the purpose of scrutinizing the basis for SKB's corrosion failure analysis in the post-closure safety assessment. The review findings presented in this paper mainly reflect the outcome of a number of external experts' reviews and from SSM's independent modelling of site hydrogeology.

The review of SKB's advection corrosion case in the SR-Site report has proven to be a challenging task considering its broad scope and multidisciplinary nature. The original analysis is based on a range of hydrogeological and geochemical measurements at the

Forsmark site as well as extensive and complex modelling work. Review and assessment of site characterization data and the reliability and performance of complex site models have proven to be time consuming and resource demanding.

Because of the high degree of complexity in SKB's analysis, it is only possible for SSM to conduct a partial and simplified verification of SKB's main results. Moreover, the application of rigorous quality assurance measures is necessary under such circumstances and SSM has thus also devoted efforts to review and understand SKB's quality assurance measures during both site characterization and modelling work.

The results of the external expert reviews, such as the one described above for the buffer advection corrosion scenario, have indicated strengths and weaknesses of the scientific and technical arguments underlying SKB's safety case. Generally the external experts review results agree to a large extent with the positions taken by SKB, for instance hydrological results concerning the order of magnitude of flows to deposition holes or flow wetted surface area distributions. The experts, however, recommend further exploration of alternative hydrological conceptual models to a degree that would allow SKB to confidently capture the conceptual uncertainties.

A limitation in the usefulness of subject oriented expert review is that such reviews may not capture all of the integration aspects. Some scientific questions are short circuited by conservative assumption in SKB's compliance analysis. Formulations of an appropriate regulatory position based on external expert reviews therefore require careful interdisciplinary analysis of the external experts' results by the authority. In SKB's safety assessment, some safety enhancing features are ignored but this on the other hand puts more emphasis on uncertainties related to the combination of safety enhancing features that are included. SSM has addressed the key compliance assumptions by organizing workshops covering closely related subject areas that are coupled to different parts of the safety assessment. A lessoned learned is that integration aspects are complicated and time consuming both regarding integrated modelling and coverage of closely related subject areas.

## ACKNOWLEDGMENTS

SSM's staff members of the GLS review group and SSM's external experts are acknowledged for identification of critical review issues and very valuable discussion during review meetings.

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