APPLICATION OF HOST ROCK CLASSIFICATION AND ACCEPTANCE CRITERIA FOR REPOSITORY LAYOUT AND THE SAFETY CASE

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Abstract

In Sweden and Finland the spent nuclear fuel will be disposed of in a KBS-3 type repository in crystalline rock. Extensive surface based studies at Forsmark and Laxemar sites by SKB in Sweden and at the Olkiluoto site by Posiva Oy in Finland show that the bedrock in general will provide suitable and sufficiently stable conditions for a repository. Still, there are certain site specific features, e.g.: extensive deformation zones, volumes of relatively low mechanical strength in relation to the rock stress, sparse occurrence of highly transmissive fractures or very highly saline groundwaters that may affect the safety of the repository. The KBS-3 concept aims at long-term isolation and containment of the spent fuel assemblies in the copper canisters. Consequently, the safety functions of the host rock are a) to isolate the waste from the biosphere, b) provide favourable mechanical, geochemical and hydrogeological conditions for the engineered barrier system and c) to limit and retard inflow to repository and releases of harmful substances from the repository. This paper presents an approach, how to derive the criteria for selecting suitable canister positions from the general safety functions of the host rock. An intermediate step is definition of the safety function indicators and related criteria, which consider properties and conditions under which the barriers will fulfil the safety functions. Examples of the current status of the development work are given highlighting the different aspects of applying such criteria for design, safety assessment and practical testing in tunnel conditions.

Introduction

SKB and Posiva are responsible for the final disposal of spent nuclear fuel in Sweden and in Finland, respectively. In both countries the plan is to build a KBS-3 type repository in crystalline rock. In Sweden, site investigations are being carried out at two sites, Forsmark and Laxemar. The selection of the site is planned for 2009. In Finland, Olkiluoto has been selected as the site for the repository and currently an underground research facility, ONKALO, is being built at the site. ONKALO will later serve as an access route to the disposal facilities.

According to current understanding, the bedrock at all three sites will provide suitable and sufficiently stable conditions for a repository, but there are site specific features, e.g. extensive deformation zones, volumes of relatively low mechanical strength in relation to the rock stress, sparse occurrence of highly transmissive fractures or very high salinity groundwaters that may affect the safety of the repository. In order to mitigate the influence of such features various design measures, including formulating acceptance criteria for different aspects of the repository layout, are developed.

The programmes in both countries are approaching the licensing phase. This means that the Safety Case needs to cover all aspects from design, manufacturing, installation, control and long-term performance. An aspect emphasised in the development work is setting up the requirements for the design, manufacturing and implementation of the technical barriers. Also aspects related to operation of the facilities need to be considered. Appropriate quality assurance measures need to be developed to verify that the requirements will be met. Requirements on the host rock are being developed to guide repository design and layout adaptation as required by the regulators.

Regulatory requirements

The Finnish regulator, STUK (2001) requires definition of the performance targets for each of the barriers including the repository host rock. The performance targets should be defined taking into account deviations in or erroneous determination of the characteristics of the barrier, possible low performance of a single barrier and changes during the assessment period. In case of host rock, special emphasis should be put on the geological structures. The structures of the host rock of importance to groundwater flow, rock movements or other factors relevant to long-term safety, shall be defined and classified. The waste canisters shall be emplaced in the repository so that adequate distance remains to such major structures of the host rock which might constitute fast transport pathways for the disposed radioactive substances or otherwise impair the performance of barriers.

According to the Swedish Nuclear Power Inspectorate regulation SKIFS 2001:2, safety after the closure of a repository shall be maintained through a system of passive barriers and the function of each barrier shall be to, in one or several ways, contribute to the containment, prevention or retardation of dispersion of radioactive substances, either directly, or indirectly by protecting other barriers in the barrier system. Furthermore, the Swedish Nuclear Power Inspectorate's General Recommendations concerning the Application of the Regulations concerning Safety in connection with the Disposal of Nuclear Material and Nuclear Waste (SKIFS 2002:1) states: "*…The safety assessment should also aim at providing a basic understanding of the repository performance on different time-periods and at identifying requirements regarding the performance and design of different repository components. .. Based on scenarios that can be shown to be especially important from the standpoint of risk, a number of design basis cases should be identified. Together with other information, such as on manufacturing method and controllability, these cases should be used to substantiate the design basis such as requirements on barrier properties.*"

To meet these regulatory requirements Posiva has carried out a project called host rock classification (Hagros, 2006) and SKB are preparing reports on "Design and production of the KBS-3 repository" In its most recent safety assessment, SR-Can (SKB, 2006b), SKB introduced the concept of detailed safety functions, safety function indicators and safety function indicator criteria in order to identify and assess the safety critical components of the barriers. This is now forming the basis for developing the design basis for the safety critical repository and EBS components. This approach has also recently been applied in compiling the Safety Case for the horizontal alternative (KBS-3H) using Olkiluoto site as a reference site (Smith *et al.,* 2008).

Site understanding

All the sites have been extensively studied by surface and surface based methods. In addition, the construction of ONKALO at the Olkiluoto site also provides a substantial amount of data from the underground, both from pilot holes drilled inside the tunnel perimeter prior to excavation and from mapping the tunnel after excavation. The investigation data are assessed into a Site Descriptive Model (SDM) of the site, i.e. a model describing the geometry, properties of the bedrock and the groundwater, and the interacting processes and mechanisms that are relevant for understanding the evolution of the site to the present day, and the potential for future radionuclide migration. Modelling involves interpreting data, extrapolating or interpolating between measurement points and calibrating the numerical models used to simulate the system against data, based on the various assumptions inherent in the conceptual model(s) being employed. Based on results from an initial phase of the site investigations, a preliminary SDM of Forsmark was presented in 2005 (SKB, 2005) and for Laxemar in 2006 (SKB, 2006a). These SDMs are currently being updated using all the data obtained from the site investigations. Andersson *et al.* (2007) present the most recent SDM of the Olkiluoto site. Also this model is now being updated to consider more recent information from the ongoing characterisation work.

Forsmark site

The bedrock in the Forsmark region has been affected by both ductile and brittle deformation, but the candidate area is situated within a tectonic lens enclosed between ductile high-strain zones. The bedrock inside the lens is relatively homogeneous, and is dominated by a metagranite with high content of quartz. Due to its rather high quartz content, the bedrock is characterised by high thermal conductivity and high mechanical strength compared to typical rock conditions in the Fennoscandian shield. Rock stresses are relatively high compared to typical values of the Swedish bedrock. Gently dipping and two sets of subvertical deformation zones have been recognised. These gently dipping zones are more frequent in the south-eastern part of the candidate volume. The gently dipping deformation zones have relatively high hydraulic transmissivity, and higher than the vertical and steeply dipping deformation zones at the site. The more fractured upper part of the bedrock overlying the repository target volume is highly transmissive in the horizontal plane and in good hydraulic contact over long distances, whereas at below 200 m depth the rock has very low permeability with a low frequency of connected transmissive fractures. Below 400 m depth there are only a few connected transsmissive fractures. Meteoric water is present only at shallow depths, below which salinity increases.

Laxemar site

The northern and central parts of the Laxemar area are dominated by Ävrö granite, whereas in the southern part of the area there are rock domains consisting mainly of quartz monzodiorite and diorite to gabbro. This results in relatively low and varying thermal conductivity, compared to typical values of Fennoscandian bedrock. The mean uniaxial compressive strength is comparatively low in most of the rock types and it also shows a quite large spread. Rock stresses are comparable to typical values of the Fennoscandian bedrock. The principal orientations of deformation zones are north-south and east-west. There is a high variability in the fracturing and it appears to be relatively independent of depth. Most deformation zones are transmissive, but some, including diabase dykes, appear to act as hydraulic barriers in their transverse direction. The upper part of the bedrock shows relatively high frequency of connected transmissive fractures, but this frequency decreases significantly with depth. Fresh (meteoric) water is found down to 800 m depths, whereas the interface is much shallower closer to the sea.

Olkiluoto site

The bedrock at Olkiluoto belongs to the Fennoscandian domain of Southern Finland and it comprises a range of high-grade metamorphic rocks and igneous rocks. The metamorphic rocks include various migmatitic gneisses and homogeneous, banded or only weakly migmatised gneisses. This results in relatively low and varying thermal conductivity, compared to typical values of the Fennoscanidan shield. The mean uniaxial compressive strength is comparatively low in most of the rock types and it also shows a quite large spread. Rock stresses are comparable to typical values of the Fennoscandian shield. The bedrock has been affected by ductile deformation, which is reflected by significant foliation. This results in anisotropy of thermal and rock mechanics properties. The fault zones at Olkiluoto are mainly SE-dipping thrust faults. In addition, NE-SW striking strike-slip faults are also common. Away from the near surface part of the rock, hydraulically connected transmissive fractures, especially those with transmissivities higher than 10^{-8} m^2/s are concentrated mainly in three regions of the SE dipping faults. Connected fractures with lower transmissivities occur outside these zones, but also tend to form clusters. Meteoric water is found only at shallow depths, in the uppermost tens of metres, brackish groundwater, with salinity up to 10 g/l dominates at depths between 30 m and about 400 m. Saline groundwaters (salinity > 10 g/l) dominate at still greater depths.

Safety functions of the barriers

In a KBS-3 concept the spent fuel will be placed in copper canisters with a cast iron insert. The canisters surrounded by the buffer material (bentonite) will be emplaced at several hundred metres depth. The concept aims for long-term isolation and containment of the spent fuel assemblies in the canisters, but in case of radionuclide release, the engineered barrier system and host rock should limit and retard the releases.

In order to ensure long term containment of the radionuclides, the canister should be corrosion resistant and have enough mechanical strength. The buffer protects the canisters and limits and retards radionuclide releases in case of canister failure. Therefore, the buffer should be impermeable enough, once saturated, that the movement of water is insignificant and diffusion is the dominant radionuclide transport process. Furthermore, the buffer should have a sufficiently fine pore structure such that microbes and colloids are immobile (filtered) and microbe- or colloid-facilitated radionuclide transport will not occur in the event of canister failure. The buffer should also damp any small rock displacements so that the canister would not be mechanically damaged.

The safety functions of the host rock are (a), to isolate the spent fuel from the biosphere and normal human habitat, (b), to provide favourable and predictable mechanical, geochemical and hydrogeological conditions for the engineered barriers, protecting them from potentially detrimental processes taking place above and near the ground surface such that they contain the spent fuel, and (c), to limit and retard inflow to and release of harmful substances from the repository (e.g. Vieno and Ikonen, 2005). The host rock properties enhancing the safety are thus related to groundwater composition and limited groundwater flow, which contributes to the stable chemical conditions, avoiding erosion of buffer and limiting and retarding radionuclide transport. To avoid canister corrosion, reducing, oxygen free conditions and groundwater with limited chloride and sulphide content are favourable. In order not to weaken the buffer and backfill performance, limited pH and salinity, limited contents of K^+ and Fe(II)/Fe(III) are favourable. To limit radionuclide transport in case of any leakages, low colloid and organics content are favourable. To provide mechanical stability, displacements in fractures intersecting the deposition holes should be limited.

SKB safety assessment SR-Can (SKB, 2006b) brings the issue of Safety functions one step further and also defines “safety function indicators” and “safety function indicator criteria”. According to SKB terminology:

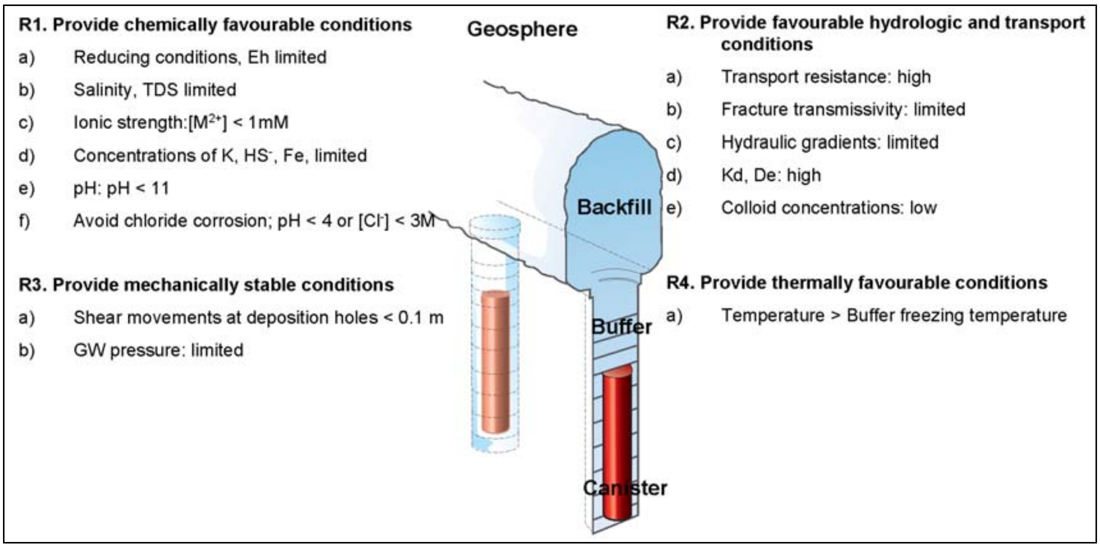
- A safety function describes how a repository component contributes to safety. (Example: The canister should withstand isostatic load.)
- A safety function indicator is a measurable or calculable property of a repository component that indicates the extent to which a safety function is fulfilled. (Example: Isostatic stress in canister.)
- A safety function indicator criterion is a quantitative limit such that if the safety function indicator to which it relates fulfils the criterion, the corresponding safety function is maintained. (Example: Isostatic stress < isostatic collapse load.)

The criterion should ideally be fulfilled throughout the assessment period. Meeting criteria implies that the barrier performance is as intended. Violation of the criteria does not necessarily mean reduced safety but a need for a more thorough analysis. Figure 1 presents the safety functions, associated indicators and criteria according to SR-Can (SKB, 2006b). Note, the safety functions applied by SKB and Posiva are identical on the overall level whereas Posiva is in a process to derive the performance targets corresponding to safety function indicators and related criteria.

Acceptance criteria and host rock classification

The safety functions for the barriers are derived from the disposal concept, whereas the indicators and related criteria already take into account the design specific issues. For example, material selection (e.g. buffer material) can also set requirements on the rock environment. Given the reference design and knowledge of the material properties, a range of conditions under which the barriers function as they should, need to be defined and formulated as the safety function indicators and the related criteria. To locate rock volumes where it is very likely that the safety function indicators will be upheld, host rock classification procedure and acceptance criteria have been developed. These criteria may be site specific, e.g. consider the most relevant parameters and the confidence in the models at the given site, whereas the safety functions and related criteria are in essence site independent.

Figure 1**. Safety functions, safety function indicators and indicator criteria for the geosphere as defined in SKB SR-Can** (SKB, 2006b)

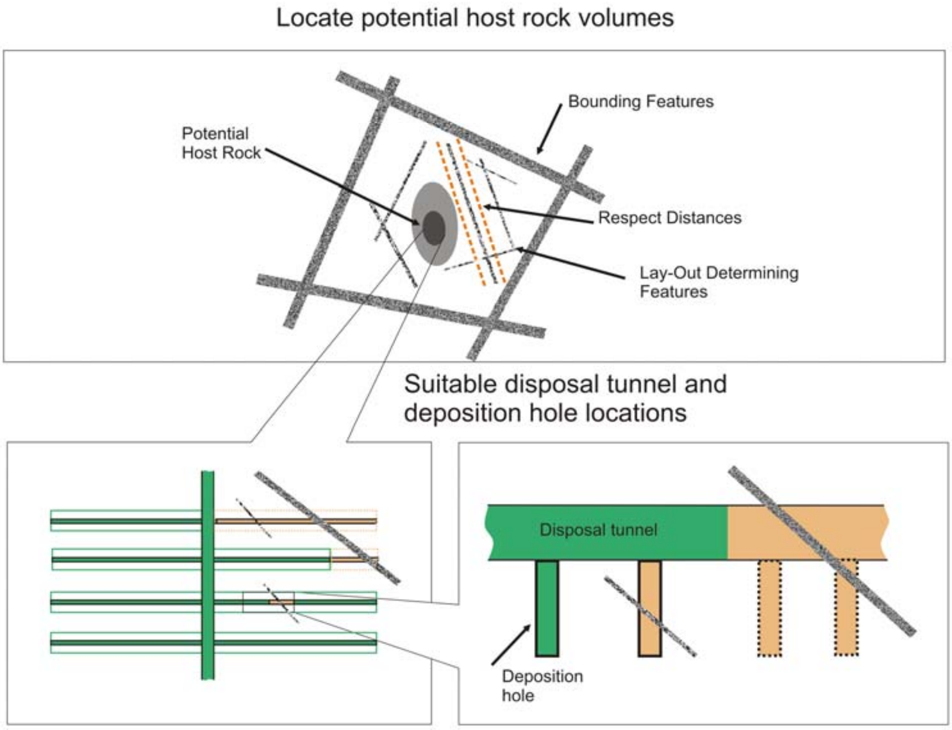


Acceptance criteria consider observable, measurable present day rock properties that will contribute to fulfilment of the safety functions especially in the canister near field. Interpretation and modelling are needed to understand the importance of these observations in the context of general site understanding. The parameters and criteria need to be defined in a way that fulfilment of the criteria can be demonstrated. In defining the criteria, there is a need to assess that the current rock properties will give sufficient information on the future conditions. The challenge is to have the predictive capacity in the models and the ability to observe and measure the most relevant properties at the site and in the excavated tunnels under disturbed conditions. Part of this work is the selection of the proper measurement techniques. Testing at the site will give important information on the practical aspects of applying such criteria and help to estimate uncertainties related to observations.

Definition of the criteria ultimately aims at decisions whether to use a certain location for canister disposal based on data observable from the potential locations. In addition to this, host rock classification (HRC-system) introduced by Posiva (Hagros, 2006) addresses also questions of how to locate rock volumes to host panels with several tunnels and select repository tunnels with a high probability of hosting suitable canister positions. It considers thus also larger scales and more averaged rock properties, which need to reflect the acceptance criteria for the deposition holes. Figure 2 shows the principle of applying a classification procedure at different scales.

Applying the criteria on models can be utilised for design and safety assessment. Simulations can be carried out to estimate the utilisation rate and the range of potential conditions around the deposition holes for the description of evolution and for selecting cases for radionuclide transport calculations. Application of the criteria can be utilised in the layout design and it can also guide the needed design measures e.g. thermal dimensioning. Analysis of the impact of the criteria on the radiological consequences will give feedback to development of the criteria itself, site characterisation activities and design.

Figure 2. **General principle of applying host rock classification and acceptance criteria scheme**
Colour green notes rock volumes, tunnels and deposition holes accepted for disposal and brown unaccepted parts of the tunnels (after Hagros, 2006). In the figure only deformation zones and fractures with certain properties are considered as restricting, but the acceptance criteria can include also other parameters



Acceptance criteria for limiting shear movements in deposition holes in the SKB safety assessment SR-Can

The only rock mechanics process that could cause a direct breach of the containment safety function would be a large shear displacement along a fracture that intersects a deposition hole. If a fracture shear displacement is fast and the fracture intersects the deposition hole at an unfavourable angle, the load transfer across the buffer may damage the canister. The canister and the buffer is therefore designed to withstand a 0.1 m fracture shear displacement across a deposition hole, but to design these barriers for even larger loads is judged impractical.

For all time-continuous mechanical, hydro-mechanical and thermo-mechanical load scenarios forecasted in the 1 million year SKB safety assessment timeframe, a fracture shear displacement of that magnitude would require rock fractures with dimensions of about 500 m or more (Hökmark *et al.*, 2006). Fractures of such dimensions will be reliably detected during repository construction (Munier, 2006a, 2006b). Seismic loads, however, may potentially generate shear displacements larger than the damage threshold on fractures too small to be detected or identified with 100% certainty. Reactivation of fractures in response to seismic events is therefore a potential risk that needs to be addressed in the safety analysis.

The fracture reactivation issue has been addressed in a number of SKB studies (La Pointe *et al.*, 1999, Munier and Hökmark, 2004 and Fälth and Hökmark, 2006). At present the Swedish bedrock is seismically stable with most earthquakes being observed in the southwest and along the northeast cost. Moment magnitudes have very rarely exceeded 5.0 in historical time. However, large earthquakes have occurred in connection with the retreat of the Weichselian ice cover some 10 000 years ago. While all large unambiguous postglacial fault traces are found in northern Sweden, it cannot be excluded that some may have taken place also in southern Sweden. This means that there is a potential risk of large earthquakes occurring close to the candidate repository sites Forsmark and Laxemar in connection with future glaciation cycles.

The current handling of the earthquake issue in the safety analysis is based on recent results of dynamic distinct element simulations of Magnitude 6 and Magnitude 7.5 earthquakes (Fälth and Hökmark, 2008). The consequence for the repository layout is that there must be a respect distance between canisters and potential earthquake faults (see Figure 3). The respect distance is set at 100 m, provided that canister positions intersected by fractures with extensions less than 150 m are rejected. At 200 m distances and larger from potential faults, positions intersected by 300 m fractures and larger should be rejected. These numbers may, however, be subject to revision in the ongoing SR-Site safety assessment.

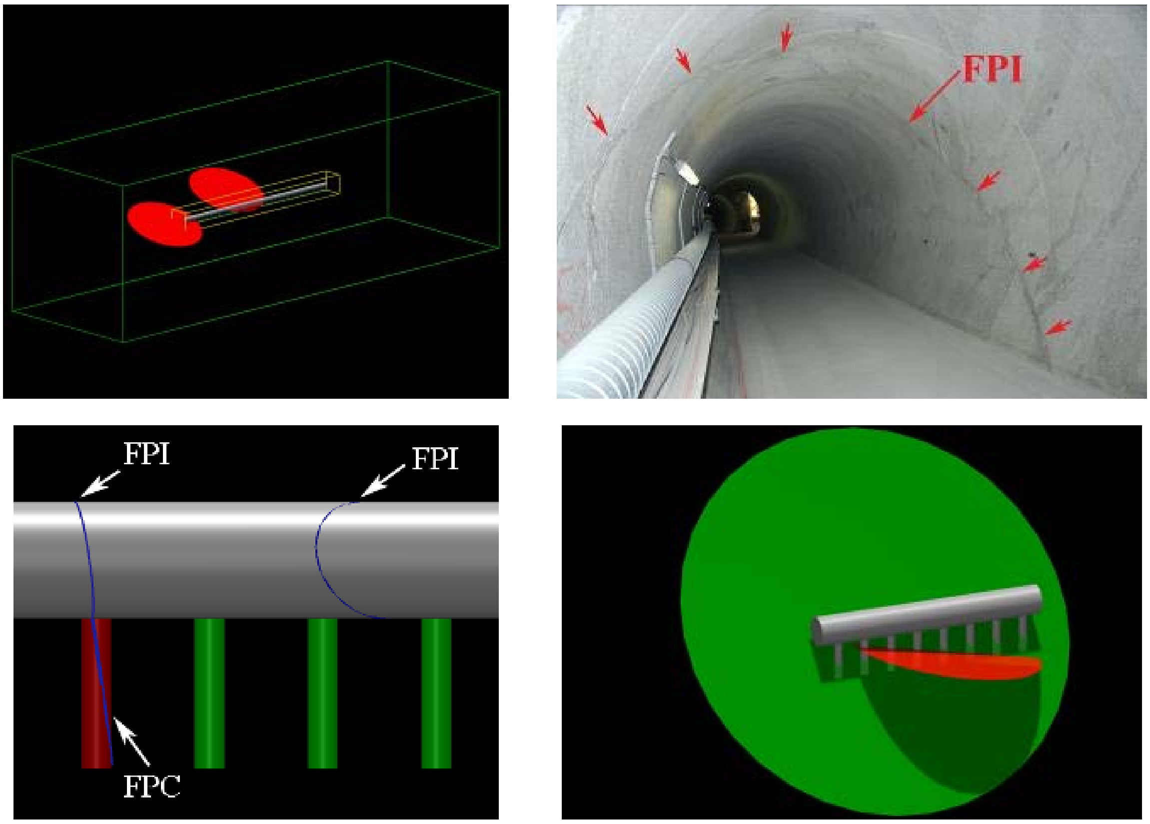
A great problem with the criteria resulting from the modelling is that they are based on fractures size, a parameter that is notoriously difficult to measure, even under the most favourable conditions. There have been attempts to address fracture sizes by the use of surrogate properties (Bäckblom *et al.*, 2004), such as width or mineralogy, but these did not turn out sufficiently reliable for the intended usage. This was later confirmed by an elaborate study of Cosgrove *et al.* (2006) the main conclusion of which was that it is imperative to make use of a collage of mapped fracture properties and remote methods to be able to address the fracture size, which, for the fractures of interest, still only can be quantified in relative terms.

An approach using proxy for large fractures, based on full tunnel perimeter intersections, was proposed by Munier (2006b) (see Figure 3):

- Deposition holes intersected by the extrapolation of a full perimeter intersection should be disregarded (FPC).
- Five or more deposition holes that are intersected by the same fracture should be disregarded (EFPC).

The main outcome of the study was that the proposed criteria could indeed be used to identify large fractures potentially hazardous to the repository function, but at a cost of the degree-of-utilisation. Yet, the computed degree-of-utilisation were judged reasonable and the methodology was applied in the safety assessment SR-Can (SKB, 2006b and references therein).

Figure 3. **Suggested criteria for avoiding large fractures**



An application to earthquake hazard was presented in SKB, 2006b (p 327-332). First the average number of canisters that are intersected by discriminating fractures (r≥75 m, r≥150 m) needs to be computed, assuming blind deposition. This can be done using a method proposed by Hedin (2005). Thereafter, the FPI criteria (FPC and EFPC) are applied using the DFN model, and tunnel orientations provided from the repository layout. The yearly probability of an earthquake is computed for the area covering the repository and the bounding deformation zones. This probability is weighted over all zones within the area. Assuming, then, that each earthquake will trigger all critical fractures and, additionally, that all critical fractures will reach their maximum slip, the average number of canister failures is computed.

Testing host rock classification in ONKALO

Posiva has carried out a programme to evaluate existing rock classification schemes aimed for rock construction purposes and developed a host rock classification system (HRC, Hagros *et al.* 2005 and Hagros, 2006) which is also incorporating aspects related to long term safety. The system aims to provide relevant information for the decision making of whether to excavate disposal tunnels or deposition holes at given locations. Consequently, three scales: repository, tunnel and canister scale are considered. Classification is based on avoiding fracture zones (classified in terms of their transmissivity (T), rock quality, length and thickness) and rock mass properties like strength/stress ratio, rock quality (Q'-value, Barton *et al.*, 1974), hydraulic conductivity (K) and salinity (TDS). In the canister scale also single fractures (width and trace length) are considered.

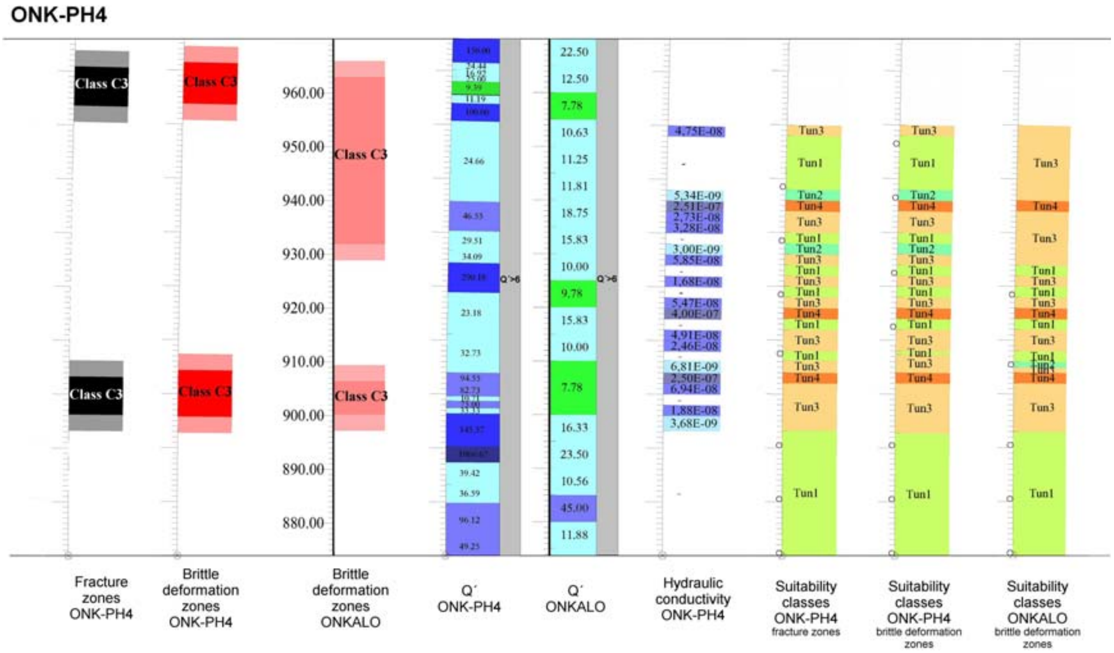
The parameters considered in HRC link to the safety functions of the geosphere in the following way:

- Avoiding fracture zones and leaving a certain distance to them contributes to favourable mechanical, geochemical and hydrological conditions for the engineered barrier system and limiting and retarding flow and transport of radionuclides and other harmful substances.
- Stress/strength ratio and rock quality contribute to mechanical stability.
- Hydraulic conductivity of the rock is considered because of its importance for the hydraulically and geochemically stable conditions and for limiting flow and transport.
- Salinity is an indicator for geochemically stable conditions.
- Fracture trace length is considered in order to avoid risk of shear displacements and also along with fracture width (including both aperture and fracture fillings) to limit groundwater flow and transport of radionuclides and other harmful substances.

Tunnel scale classification scheme has been tested by the mapping geologist using ONKALO data both from pilot holes and the tunnel to gain experience of applying the scheme in practice (Lampinen, 2008). Testing included the characterisation of the pilot holes ONK-PH2 – ONK-PH5 (all together 566 m of drill core in the depth range 10 m – 110 m from the ground surface) and the tunnel length (from the chainage 135 m to 1 192 m) covered by these drill holes in the first spiral of the ONKALO tunnel. Testing was done based on the logging of pilot holes, mapping of tunnel walls and hydraulic data from the pilot holes. The intersections of fracture zones and deformation zones were defined based on definitions used in the bedrock model by Vaittinen *et al.* 2003 (used in the definition of the HRC) and geological model by Paulamäki *et al.* 2006 (in use while testing was done). The orientation of the fracture zone or brittle deformation zone is not dealt within this study. In practice the classification result is determined by the main parameters used, i.e. rock quality value (Q´) and hydraulic properties of the features (K- and T-value).

In Figure 4, the results of HRC tunnel scale classification of the pilot hole ONK-PH4 and respective tunnel lengths are shown as an example. In the first two bars the classification of fracture zones and deformation zones along the pilot hole ONK-PH4 are shown. The core of fracture/deformation zones can be detected by this classification method, especially if it is water conductive. The third bar represents the classification of the deformation zone in the ONKALO tunnel, which clearly differs from the pilot hole classifications because the orientation of the zone is affecting the length and location of the zone intersection (the other zone was in a low angle to the tunnel). The following two bars represent the Q’-classification of the pilot hole and the respective tunnel length. The place for the different classes varies somewhat probably because of the effect of the orientation being more visible in the tunnel classification. In addition the difference in fracture frequency measured from a pilot hole and tunnel wall may affect this parameter. So far there is no clear explanation for the difference between hole and tunnel wall. A common phenomenon throughout the testing was the good rock quality in the ONKALO tunnel and as a consequence it could not be tested if the Q’-classification could be useful for identifying less useable portions of the tunnel. The sixth bar represents the hydraulic conductivity measurements in the pilot hole. The tunnel has been grouted before the construction after the pilot hole drilling and but there are no comparable, continuous measurements from the tunnel because. However, the hydraulic conductivity measurements from the pilot hole classification became the main defining factor for the classification scheme. The three bars in the right represent the final result of the classification, four suitability classes, defined for the pilot hole and finally for the ONKALO tunnel [Tun1/Tun2 (suitable for deposition, shown in green in Figure 4) or Tun3/Tun4 (unsuitable for deposition, shown in red in Figure 4)]. However, with the current tools and knowledge, it seems reasonable to reduce the number of categories. Based on testing the beginning of this tunnel length is suitable for the deposition, the area in the middle is questionable and the end of the tunnel is not suitable.

Figure 4. **The result of HRC tunnel scale classification of ONK-PH4** (Lampinen, 2008)
The depth bar represents the chainage (m, equal to the tunnel length).
The pilot hole and tunnel section starts from the lower line.



The HRC-classification parameters take the long fractures into account first in the canister scale and not in the tunnel scale. In the classification based on drill hole logging long fractures are not detectable and other parameters are needed to indicate possibility for them. In tunnel mapping long fractures are observed in the tunnel wall, but in classification based mainly on parameters like Q´ and K_{2m} (conductivity measured in 2-metre intervals) in the tunnel scale, the location of the fracture is not clear. Based on testing and the outcome of the tunnel mapping the long fractures should be taken into the classification scheme already in tunnel scale.

As a conclusion of the testing the site understanding is needed to put the results of the classification into the right context. The usage of the site descriptive models is essential to understand the significance of a feature observed in a pilot hole regarding the suitability of the tunnel based on pilot hole information. The main deformation and hydraulic features need to be interpreted and classified based on the models and the model should be updated directly after pilot hole drilling before the tunnel will be excavated. In addition, there is a great need to validate and standardise the source data and its processing to be applied in the classification. The final classification needs to include concrete parameters, which are in practice measurable both from the drill hole and the tunnel. These parameters need to be included in the routinely collected data in logging and mapping procedures.

Although the general structure of the classification scheme is usable, the testing has pointed out needs for development of the system. These include enhancing further the link between the criteria and the repository safety and design and leading thus to re-assessment of the parameters and cut-off values as well as issues related to practical application of system e.g. data availability.

Conclusions

This paper presents an approach how to derive requirements on the host rock from the general safety functions of the barriers. The paper discusses experiences gained in applying the developed criteria as part of safety assessments and practical testing in tunnel conditions at Olkiluoto. Based on the experiences, we consider the presented approach as a useful and practical tool to incorporate site data for design and safety assessment and thus enhance safety. The main benefits of the presented approach are:

- The iterative nature of the approach; the concept specific safety functions are defined clearly at different level than the safety function indicators including already design specific issues and criteria on host rock, which can have site specific components, thus enabling changes in the relevant parts if e.g. design changes.
- It provides a way to communicate with different functions thus increasing understanding and transparency and contributing to meeting of the safety requirements.
- It helps to make efficient use of the site data.
- It helps to structure the work by pointing out what is important.
- It gives guidance in decision points.

For the licence application both organisations need to (formulation according to SKB, 2007):

- Present the engineered part of the repository system, in a form of a reference design, that should be assessed in the safety assessment.
- Show how the reference design has been developed and adapted to meet the design premises stemming from the repository safety functions of containment and retention of the radioactive waste within the spent nuclear fuel.
- Describe how to produce/construct and quality control the repository based on this design.
- Justify the property data on the engineered system used as input in the long term safety assessment.

For this purpose SKB is preparing a set of "Design and production reports" for the spent fuel, the canister, buffer, backfill, sealing and rock. Posiva will publish similar information in design reports and assessment basis reports and specifically, Posiva has launched the Rock Suitability Criteria (RSC) programme to develop criteria for the host rock further. The discussion and formulation of the requirements and constraints on design arising from the safety functions [for SKB these are defined in SR-Can (SKB, 2006b)] will be key contents in the above mentioned reports. Examples of such restrictions include minimum distances from deposition holes to long deformation zones to ensure mechanical stability, need to avoid large fractures in deposition holes in order to ensure mechanical stability and minimum distances between canisters to control buffer temperature. Other restrictions will also apply, but are currently being formulated. It is noted that criteria addressing a certain safety function may also have implications for other safety functions. For example, avoiding large fracture also implies that many water conducting fractures are avoided as well. This will be explored further, when defining the criteria that take into account the flow conditions.

References

Andersson, J., H. Ahokas, J.A. Hudson, L. Koskinen, A. Luukkonen, J. Löfman, V. Keto, P. Pitkänen, J. Mattila, A.T.K. Ikonen and Ylä-Mella, M. 2007. Olkiluoto Site Description 2006. Eurajoki, Finland: Posiva Oy. POSIVA 2007-03.

Bäckblom, G., P. La Pointe, E-L. Tullborg, 2004. Äspö Hard Rock Laboratory. Preliminary study for developing a practical, stepwise field methodology for determining the acceptable proximity of canisters to fracture zones in consideration of future earthquakes. SKB IPR-04-44, Svensk Kärnbränslehantering AB (SKB) Stockholm Sweden. 676529/ipr-04-44.pdf

Barton, N., R. Lien, J. Lunde, 1974, Engineering classification of rock masses for the design of tunnel support. Rock Mechanics. December 1974. Vol. 6 No. 4. Springer Verlag. Wien, New Yourk. 189-236 pp.

Cosgrove, J., K. Röshoff, R. Stanfors, 2006. Geological characteristics of deformation zones and strategy for their detection. R-06-39, Svensk Kärnbränslehantering AB

Fälth, B., H. Hökmark, 2006. Seismically induced slip on rock fractures. Results from dynamic discrete fracture modeling. SKB R-06-48. Stockholm: Svensk Kärnbränslehantering AB.

Fälth B., H. Hökmark. 2008. Seismically induced slip on rock fractures – Expanded study with particular account of large earthquakes. In progress.

Hagros, A. 2006. Host Rock Classification (HRC) system for nuclear waste disposal in crystalline bedrock. Publications of the Department of Geology D8, University of Helsinki.

Hagros, A., T. McEwen, P. Anttila, K. Äikäs, 2005. Host rock classification. Phase 3: Proposed Classification System (HRC-system). Olkiluoto, Finland: Posiva Oy. Working Report 2005-07.

Hedin, A. 2005. An analytic method for estimating the probability of canister/fracture intersections in a KBS-3 repository. SKB R-05-29, Svensk Kärnbränslehantering AB (SKB) Stockholm Sweden. 948998/R-05-29webb.pdf

Hökmark H., B. Fälth, T. Wallroth, 2006. T-H-M couplings in rock. Overview of results of importance to the SR-CAN safety assessment. SKB TR-06-88, Stockholm: Svensk Kärnbränslehantering AB.

Lampinen, H. 2008. Test use of the Host Rock Classification (HRC) in the tunnel scale. Performed in the ONKALO access tunnel sections covered by pilot holes ONK-PH2, ONK-PH3, ONK-PH4 and ONK-PH5. Eurajoki, Finland: Posiva Oy. Working Report 2008-15.

Munier, R. 2006a. Demonstrating the efficiency of the EFPC criterion by means of Sensitivity analyses. SKB R-06-115, Svensk Kärnbränslehantering AB (SKB) Stockholm Sweden.

Munier, R. 2006b. Using observations in deposition tunnels to avoid intersections with critical fractures in deposition holes. SKB R-06-54, Svensk Kärnbränslehantering AB (SKB) Stockholm Sweden. 1125094/R-06-54webb.pdf

Munier, R., H. Hökmark, 2004. Respect distances. Rationale and means of computation. SKB R-04-17, Svensk Kärnbränslehantering AB (SKB) Stockholm Sweden. www.skb.se/upload/publications/pdf/R-04-17webb.pdf

Paulamäki, S., M. Paananen, S. Gehör, A. Kärki, K. Front, I. Aaltonen, T. Ahokas, K. Kemppainen, J. Mattila, L. Wikström, 2006. Geological Model of the Olkiluoto Site. Version 0. Olkiluoto, Finland: Posiva Oy. Working Report 2006-37.

La Pointe P., T. Cladouhos, S. Follin, 1999. Calculation of displacements on fractures intersecting canisters induced by earthquakes: Aberg, Beberg and Ceberg examples. SKB TR-99-03. Stockholm: Svensk Kärnbränslehantering AB.

SKB (2005), Preliminary site description. Forsmark area – version 1.2. SKB R-05-18, Svensk Kärnbränslehantering AB.

SKB (2006a), Preliminary site description. Laxemar subarea – version 1.2. SKB R-06-10. Svensk Kärnbränslehantering AB.

SKB (2006b), Long-term safety for KBS-3 repositories at Forsmark and Laxemar – a first evaluation. Main report of the SR-Can project. SKB Technical Report TR-06-09. Stockholm: Svensk Kärnbränslehantering AB.

SKB (2007), SKB TR-07-12, Svensk Kärnbränslehantering AB.

Smith, P., F. Neall, M. Snellman, B. Pastina, H. Nordman, L. Johnson, T. Hjerpe, 2008. Safety assessment for a KBS-3H spent nuclear fuel repository at Olkiluoto – Summary report. Olkiluoto, Finland: Posiva Oy. Working Report 2007-06.

STUK (2001), Long-term safety of disposal of spent nuclear fuel. Radiation and Nuclear Safety Authority (STUK). Guide YVL 8.4.

Vaittinen, T., H. Ahokas, E. Heikkinen, P. Hellä, J. Nummela, P. Saksa, E. Tammisto S. Paulamäki, M. Paananen, K. Front, A. Kärki, 2003. Bedrock model of the Olkiluoto site, version 2003/1. Olkiluoto, Finland: Posiva Oy. Working Report 2003-43.

Vieno, T., A.T.K. Ikonen, 2005. Plan for Safety Case of spent fuel repository at Olkiluoto. Posiva Oy, Olkiluoto, Finland. POSIVA 2005-01.