Developing practical approaches to assess geological structures influencing repository design, operational procedures or assurance of operational / post-closure safety

Fractured Hard Rock

Experiences from the SKB and Posiva programmes

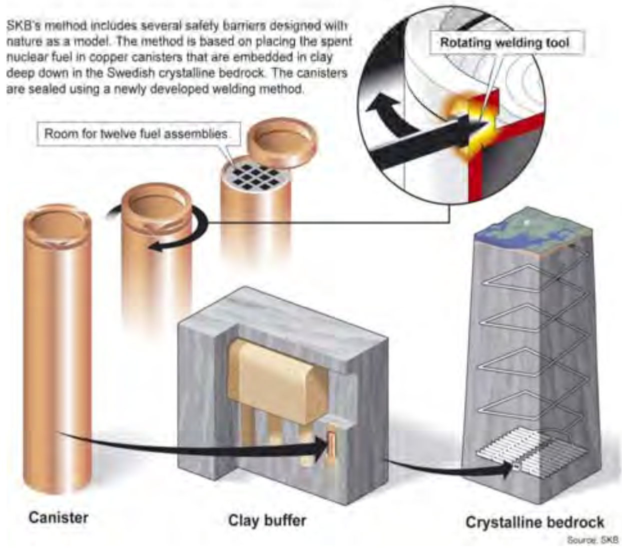
Johan Andersson

Outline

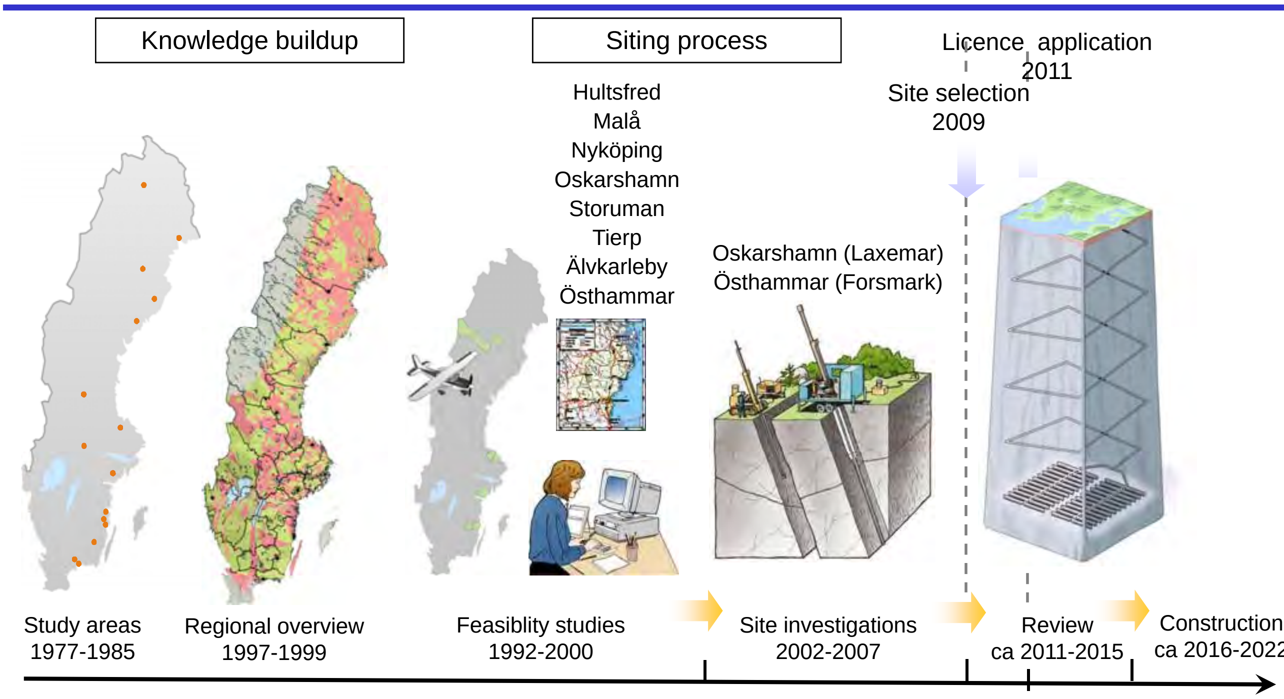
- General Approach
  - SKB's development of "Design Premises"
  - Posiva's "Rock Suitability Criteria" (RSC)
- Examples from the SKB Design Premises TR-09-22
- Practical application as a decision tool underground
- Future development

Introduction

- In the KBS method, copper canisters with a cast iron insert containing spent nuclear fuel are surrounded by bentonite clay and deposited at approximately 500 m depth in saturated, granitic rock,
- Swedish Nuclear Fuel and Waste Management Co. (SKB) will submit a license application for a final repository for Sweden's spent nuclear fuel in 2011
- Posiva Oy, Finland, will submit a construction license application in 2012

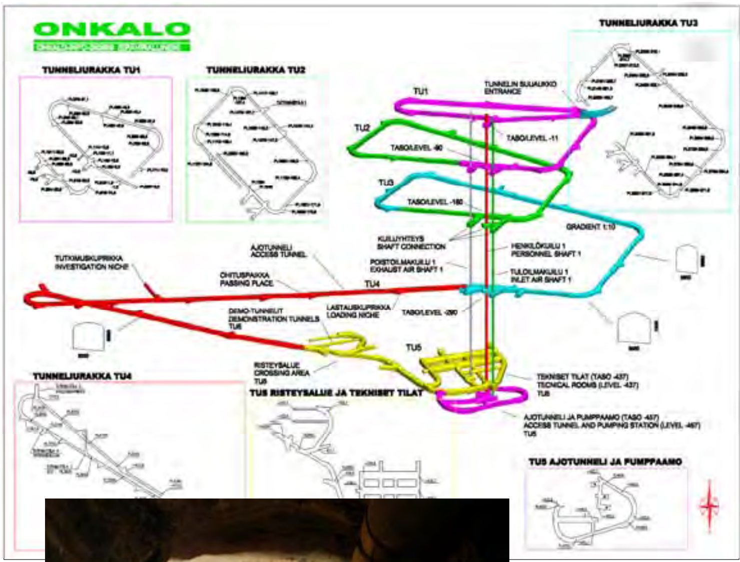


SKB road to a final repository



Posiva road to a final repository

- Site investigations since late 1980:s
- Detailed surface based investigations of 4 sites during the 1990:s
- Olkiluoto Site selected 1999
- General license and Decision in Principle in 2001
- ONKALO excavated since 2004
- Application for construction licence for the disposal facility by the end of 2012

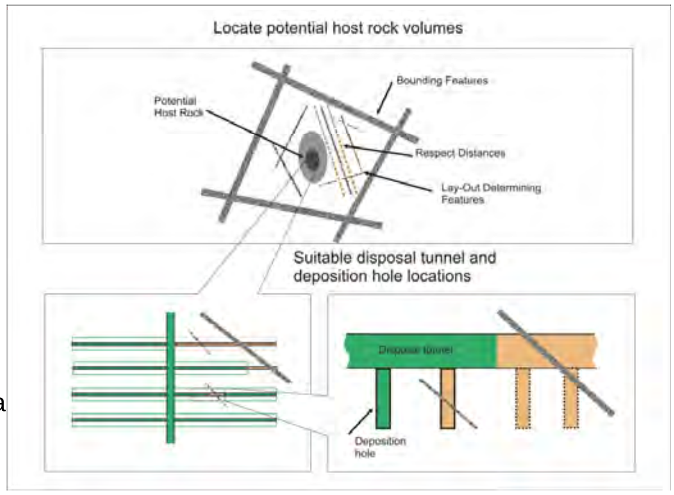


SKB: Design Premises Developed

- Provide requirements from a long term safety aspect
  - to form the basis for the development of the reference design of the repository
  - to justify that design
- Design premises typically concern
  - specification on what mechanical loads the barriers must withstand
  - restrictions on the composition of barrier materials or acceptance criteria for the various underground excavations
- The justification for these design premises is derived from SKB's most recent safety assessment SR-Can (SKB 2006a) complemented by a few additional analyses. (To be updated when safety case is revised)

Posiva: Rock Suitability Criteria

- Develop and describe a work process and methodology to locate suitable host rock volumes for a KBS-3 type repository in the Olkiluoto bedrock
- Definition of the performance targets on the host rock (TARGET)
  - define the performance targets
  - evaluate the safety consequences of the suggested criteria
- Development and testing of the criteria (DETECT)
  - "Translate" the performance targets to criteria that can be verified by observations, measurements and interpretations
  - Site specific testing
- Application of the criteria for layout design (DESIGN)
  - Provide input from construction and design by defining the needs of layout design.

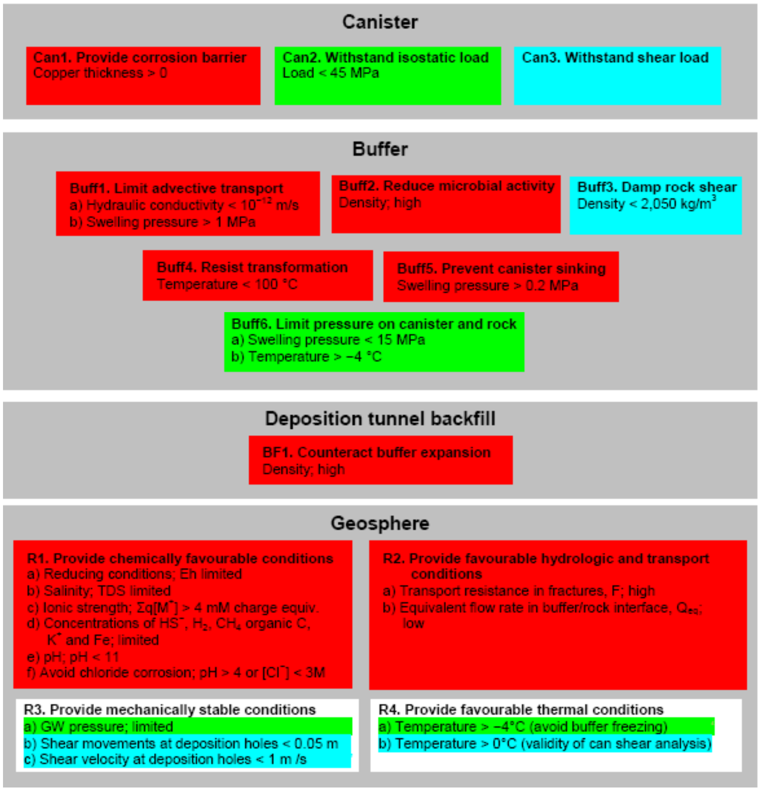


Role of safety assessment

- Iterative input to the formulation of requirements on barrier properties
  - Assess a specific repository design
  - Identification of the safety functions
  - Identification of the external stresses t potentially jeopardizing safety.
  - A quantitative analysis of how the identified external stresses affect safety for the established design.
  - Conclusions regarding the sufficiency of the chosen set of properties or recommendations regarding possible improvements.
  - Derivation of modified requirements on barrier properties.
- Few, if any, load cases on individual barriers
  - load on one barrier will depend on the design of other barriers and on the site properties
  - design premises must be determined for the entire barrier system in an integrated manner, and in some respects also site specifically
  - there is a range of different combinations of barrier and site properties that could provide a similar performance of the repository
- Beyond scope of safety assessment to develop the specific design.

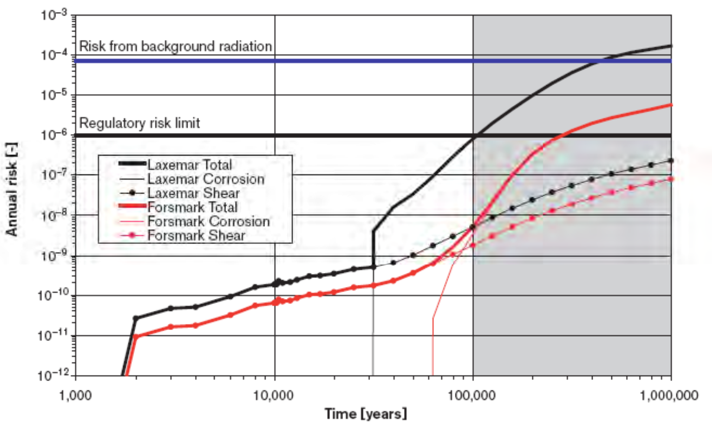
SKB Approach to develop design premises

- Reference design assessed in safety analysis starting point
- A few design basis cases - mainly related to the canister
  - and the implied conditions being part of the design basis case
- Safety function indicator criteria
  - Design premises refer to the initial state - must be defined such that they give a margin for deterioration over the.
- Other feedback on the analysed reference design.
- Some additional analyses



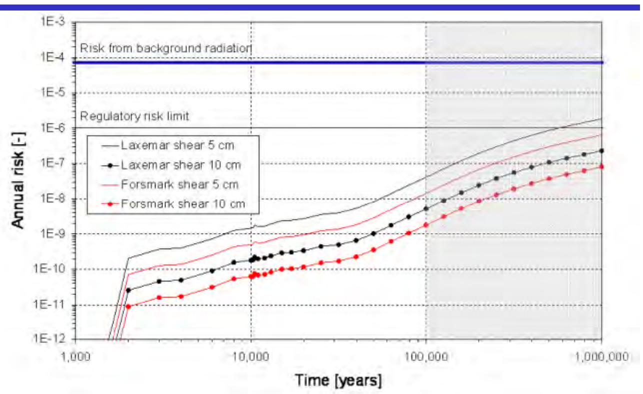
External loads that need to be considered

- Selection
  - Only shear movements and corrosion load after lost buffer contributed to risk in SR-Can
  - Also some other important external loads the barrier system will be exposed to that need to be considered when the design premises are developed
- Design basis cases:
  - Canister; Isostatic load
  - Canister; Shear movements
  - Canister; Corrosion load
  - External loads on the buffer



Example Design Basis Case: Shear load 1(2)

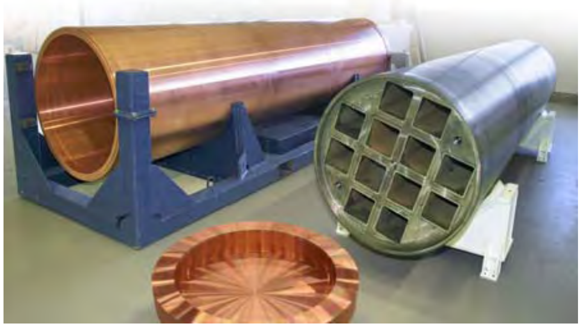
- In rare cases, earthquakes could induce secondary movements in fractures intersecting a deposition hole.
- Stability of copper canister?
  - Magnitude and location of earthquake;
  - Shear length of intersecting fracture
  - Velocity of shear movement;
  - Angle of intersection
  - Buffer mechanical properties (density)
  - Canister geometry and properties
  - Temperature
- SR-Can findings
  - Canisters may sustain shear loads of up to 10 cm at shear velocities up to 1 m/s without failing.
  - Mean number of canisters in unsuitable positions ≈0.5 out of 6,000
  - Due low probability of earthquakes, this corresponds to less than 0.12 failed canisters over 1,000,000 years.
  - But possibly oversimplified material models

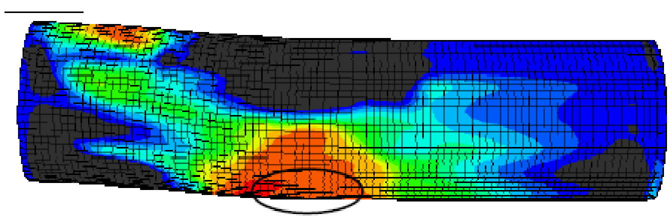


- Risk contribution
  - SR-Can assumed 10 cm shear limit – risk orders of magnitude below risk limit
  - 5 cm shear "only" 8 times increase in risk compared to SR-Can
  - Earthquake risk overestimated.
- Current standpoint
  - 10 cm shear load case is a non-trivial load
  - Failure at 5 cm – a more reasonable design requirement

Example Design Basis Case: Shear load 2(2)

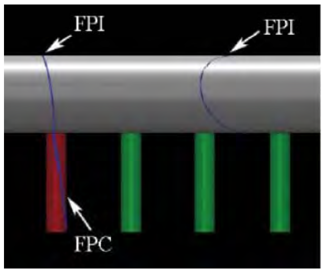
- Design Premises:
  - The copper corrosion barrier should remain intact after a 5 cm shear movement at 1 m/s for buffer material properties of a 2,050 kg/m^3 Ca-bentonite, for all locations and angles of the shearing fracture in the deposition hole and for temperatures down to 0° C. The insert should maintain its pressure-bearing properties to isostatic loads.
- Indirect requirements due to assumptions in analyses
  - Maximum buffer density<2050 kg/m^3
  - Avoid large fractures in deposition holes





Additional means of deriving design premises - Conditions assumed in design basis cases: Example

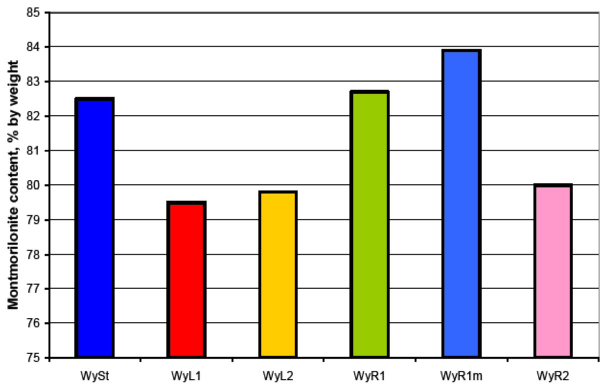
- One of three identified failure modes of the canister is that due to a rock shear movement across a deposition hole.
  - Can only occur in fractures with radii> about 100 m
  - Need also to avoid large deformation zones
- Can we find the critical positions?
  - A crude method is to apply the EFPC criterion and apply respect distance to long deformation zones
  - Additional studies are warranted for devising more efficient means of avoiding large fractures
  - It may be possible to reduce the respect distance of 100 m to some deformation zones based on an a site specific detailed and individual assessment of their properties
- Design premises
  - Deposition holes are not allowed to be placed closer than 100 m to deformation zones with trace length longer than 3 km.
  - 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.



- Indirect requirements due to assumptions in analyses
  - None

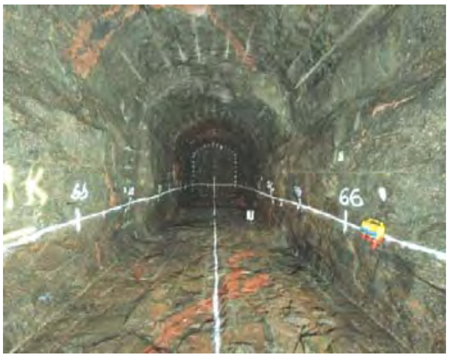
Simplifying assumptions based on feedback from SR-Can: Example

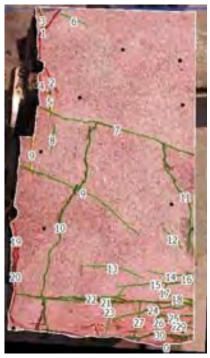
- Safety assessment simplified if various detrimental processes can be neglected
  - Sometimes the basic justifications for these simplifications are based on assumptions on the design.
- Mineralogical criteria for the buffer material.
  - Montmorillonite content has to be sufficiently high, and
  - Content of harmful accessory minerals has to be low enough
- Is assessed in detail in /SR-Can Buffer and backfill process report section 2.5.6/.
- Design Premises
  - *The montmorillonite content of the dry buffer material shall be 75-90% by weight.*
  - *The content of organic carbon should be less than 1 wt-%*
  - *The sulphide content should not exceed 0.5 weight percent of the total mass, corresponding to approximately 1% of pyrite.*
  - *The total sulphur content (including the sulphide) should not exceed 1 wt-%.*



Additional means of deriving design premises – Results of sensitivity calculation

- EDZ example
- SR-Can /Main report section 10.5.7/
  - 10-100 times higher conductivity than the surrounding rock – only a limited impact
- May still be hard to prove that the EDZ has such a low conductivity.
- A further sensitivity study has been undertaken /Jocye el al. 2008/.
  - Even with a connected EDZ transmissivity up to 10^{-8} m^2/s the impact is negligible.
  - Analyses suggests that an even higher transmissivity would be acceptable.

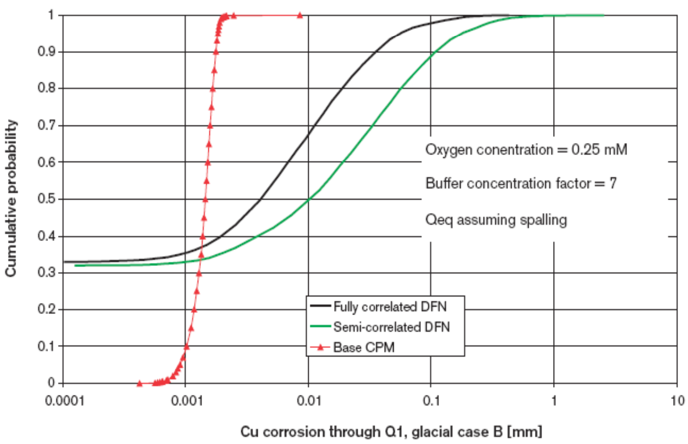




- Design Premises
  - *Excavation induced damage should be limited and not result in a connected effective transmissivity, along a significant part (i.e. at least 20-30 m) of the disposal tunnel and averaged across the tunnel floor, higher than 10^{-8} m^2/s. Due to the preliminary nature of this criterion, its adequacy needs to be verified in SR-Site.*

Favourable hydrological conditions

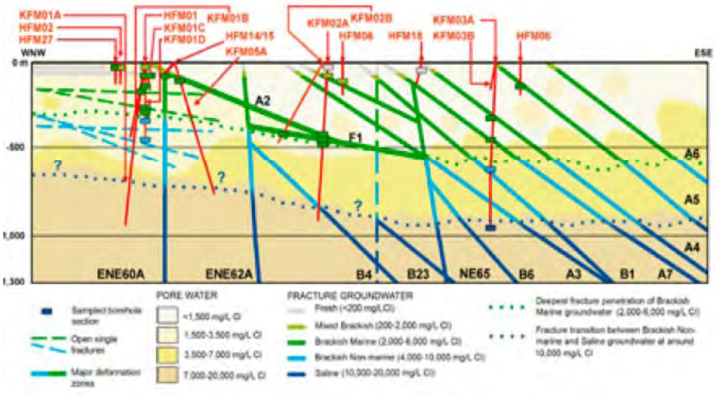
- Flow in deposition holes
  - Affects: piping and erosion during the water saturation phase, colloid release; effects of oxygen penetration; inflow of corrodants, potentially leading to canister failure; and outflow of radionuclides (in both cases in particular for eroded buffer).
- Risk contribution
  - Will not accept piping corrosion
  - Likely to be a strong correlation between the inflow to open deposition holes and flow conditions during saturated conditions.
- Design premises
  - The total volume of water flowing into a deposition hole, for the time between when the buffer is exposed to inflowing water and saturation, should be limited to ensure that no more than 100 kg of the initially deposited buffer material is lost due to piping/erosion. This implies, according to the present knowledge, that this total volume of water flowing into an accepted deposition hole must be less than 150 m^3.



- Fractures intersecting the deposition holes should have sufficiently low connected transmissivity. This condition is assumed to be fulfilled if the conditions regarding inflow to deposition holes are fulfilled.
- Practical inflow limit: 0.1 L/min (corresponds to $T<310^{-9}$ m^2/s)

Provide favourable chemical conditions

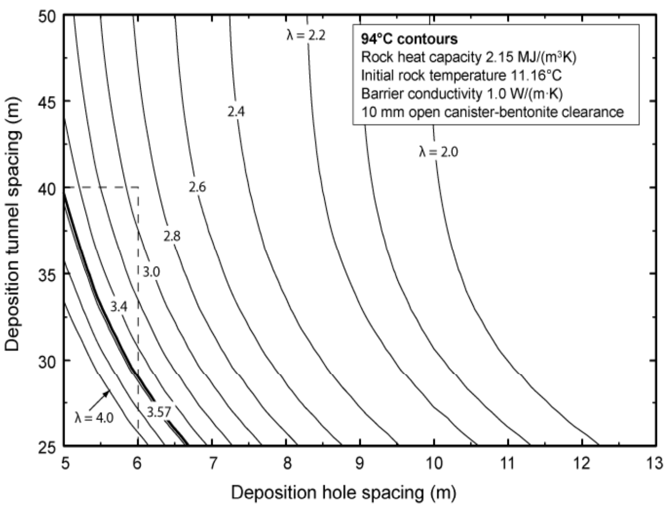
- The groundwater composition in rock volumes selected for deposition holes should, prior to excavation, fulfill the SR-Can function indicator criterion R1 on favourable chemical conditions.
  - /SR-Can Main report section 7.5 (Figure 7.2)/ and following the conditions expected for the buffer, see section 3.2.1
- Design premises
  - Reducing conditions; Salinity; TDS limited Ionic strength; [M2+] > 1 mM Concentrations of K, HS−, Fe; limited pH; pH < 11 Avoid chloride corrosion; pH > 4 or [Cl−] < 3M.



- Indirect requirements due to assumptions in analyses
  - These geochemical conditions are assured by selection of appropriate repository volumes and depth, see section 3.4.5. These conditions cannot be checked for individual deposition holes since the water composition there will be temporarily disturbed.
  - Justification of suitability for selected deposition areas is given in the Site engineering report (SER) and should be confirmed in SR-Site.

Provide favourable thermal conditions

- Thermal requirements on the buffer
  - Controlled by heat load, buffer material and dimensions, but also
  - on rock thermal conductivity and canister spacing
- Design premises
  - The buffer geometry (e.g. void spaces), water content and distances between deposition holes should be selected such that the temperature in the buffer is <100 °C.
- Indirect requirements
  - Since the buffer geometry and canister heat output is selected for other reasons, this criterion essentially concerns the adaptation to site properties by selecting the spacing of deposition holes and the repository depth.



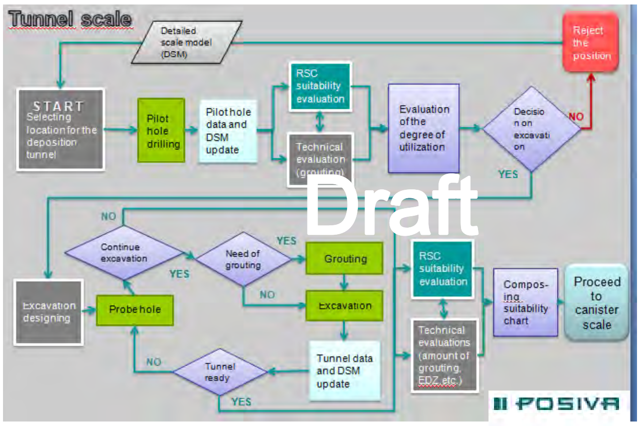
Further Design Premises on the Rock

- EDZ Deposition holes
  - 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.
- Repository depth and location
  - The repository volumes and depth need to be selected where it is possible to find large volumes of rock fulfilling the specific requirements on deposition holes, see section 3.3.
  - With respect to potential freezing of buffer and backfill, the requirement of temperatures favouring the mechanical properties of the canister (see section 2.3), surface erosion and inadvertent human intrusion the depth should be considerable. Analyses in the SR-Can assessments corroborate that this is achieved by prescribing the minimum depth to be as specified for a KBS-3 repository i.e. at least 400 m.
- Impacts on barrier functions from grouting, reinforcement and foreign materials
  - The following restrictions apply for grouting and reinforcement in deposition tunnels: Only low pH materials (pH<11) No continuous shotcrete Continuous grouting boreholes outside tunnel perimeter should be avoided
- Main tunnels, transport tunnels, access tunnels, shafts, central area and closure
  - Below the location of the top sealing, the integrated effective connected hydraulic conductivity of the backfill in tunnels, ramp and shafts and the EDZ surrounding them must be less than 10^{-8} m/s. This value need not be upheld in sections where e.g. the tunnel or ramp passes highly transmissive zones. There is no restriction on the hydraulic conductivity in the central area. The top sealing has no demands on hydraulic conductivity. The depth of the top sealing can be adapted to the expected depth of permafrost during the assessment period, but must not be deeper than 100 m above repository depth

More than 26 design premises stated by these means

Practical application as a decision tool underground

- Observational method
  - Guide decisions of the detailed design based on detailed undeground investigations
- Deposition tunnel example
  - Decide to drill pilote based on Site SDM
  - Drill pilot hole – detailed scale model
  - Decide to excavate
  - Mapping and characterisation
  - Decide to use tunnel and identifty locations for deposition holes
- To be tried in Posiva's ONKALO (DEMO-tunnel)



Current design premises will evolve!

- The resulting design premises
  - constitute design constraints, which, if all fulfilled, form a good basis for demonstrating repository safety, according to the analyses in SR-Can and subsequent analyses.
  - However, some of the design premises may be modified in future stages of SKB:s programme, as a result of analyses based on more detailed site data and a more developed understanding of processes of importance for long-term safety.
- We need to show that we can follow the currently stated design premises
  - Is provided in license application underway!
- SR-Site, as well as subsequent understanding and assessments gained e.g. during excavating the access will form a basis for revising the Design Premises for the Detailed Design Stage
  - Next Update in September 2011
  - Likely to be more sharp conditions on flow in deposition holes

Conclusions

- Methodology has been applied
- About 26 different design premises on the canister, the buffer, the deposition holes, the deposition tunnels and backfill and on the main tunnels, transport tunnels, access tunnels, shafts, central area and closure.
- The resulting design premises constitute design constraints, which, if all fulfilled, form a good basis for demonstrating repository safety