

Part II: Preserving the favourable properties of the bedrock during construction

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1 The construction process to meet design requirements

Potential impacts of construction processes and layout on long-term safety are covered by design requirements for the underground openings (DBR, Section 6.4), which are mostly qualitative. Section 2.5 of the UOPL describes the main long-term safety-relevant issues as controlling the drilling of boreholes from the surface and from the disposal area, groundwater flow, foreign (introduced) materials and EDZ effects. Overall, the quantitative dependences of long-term performance of the engineered barriers on the specifications and dimensions of the underground openings, especially of the deposition holes, are not explicitly set out in the UOPL. It provides outline descriptions of the construction processes but not at a level of detail that would be adequate for a technical expert to judge the practicability, especially taking account of the long duration of the construction and operation programme and the need for a certain level of consistency. Generally, the UOPL is not a satisfactory report in terms of the depth or scope of the information it provides.

1.1 Layout planning and adaptation during construction

The best description of the planned rock volumes for the repository is presented in WR 2013-17, which has six different layouts designed for a quantity of 9,000 tU of spent fuel. The plans take into consideration the two major deformation zones and the orientation of the deposition tunnels. The length of the deposition tunnels is limited to 300 m. The difference between the layouts is in the orientation of the deposition tunnels, reflecting different orientation of the maximum horizontal rock stress, which also leads to different orientation of the transport tunnels. The alternatives are based on the same bedrock model and ONKALO layout. The different layouts are appropriate considering the existing

uncertainty about the state of stress at repository level but, with respect to the bulk rock, it needs to be recognised that the detail level of the lithological model, was compiled for the scale of the whole site, rather than for these needs of repository/panel-scale construction.

Building the disposal facility begins with expansion and integration of the ONKALO space. A stepwise construction plan has been designed for extension of the repository with time. Space is reserved to enlarge the facility if the amount of waste were to increase. The feasibility and conformity of deposition tunnels and holes are based on the experience and outcome of the tunnelling work conducted during the ONKALO project, together with results from the Demonstration tunnels. The Design Report claims (p.90) that layout Alternative 3, with layout direction 126°/306° for the deposition tunnels, “*has been selected at this point (2012) for a more detail consideration*”. Hence, Posiva is far from presenting a quality verification test and layout of the repository.

Posiva propagates two different layouts for the repository into the safety assessment: the “*current reference layout*” (Figure 3-6 in the Synthesis report; Figure 1-3 in PAR and Figure 3-4 in DBR) and the “*layout adaption for a repository hosting 9000 tU SF*” (Figure 3-5 in the Synthesis report; Figure 3-17 in PAR and Figure 4-2 in Description of the Disposal System 2012). The major difference between the two layouts is the number of deposition tunnels and deposition holes in the area between the two major fracture zones BFZ020B and BFZ 146. Section 4.1 of the Disposal System report describes the constraints on the layout of the underground openings by the presence of geological structures that are classified as LDFs. Each LDF is given a respect distance that accounts for uncertainty in its location and characteristics. The stepwise adoption

of the larger layout variant for 9000 tU SF would give Posiva flexibility to redesign the repository, individual panels and main tunnels if needed.

Presentation of two different layouts is confusing, especially as Posiva mentions (p.45, Disposal System) that the adapted layout was used as input to the safety case. It seems likely that the current reference layout has a somewhat higher status. The deposition tunnels in both layouts have the tunnel axis oriented parallel with the present knowledge of the direction of maximum horizontal stress. Posiva is still trying to confirm the orientation of the principal stresses at repository level. This information will be very important for the overall stability of the repository. Also, orientation of principal stresses might change in the individual stress domains between the major brittle deformation zones, which could lead to reorientation of the tunnel axes. Throughout the documentation, information is meagre about practical operation and how the gradual expansion of the facility and its safety will be managed. For example (Synthesis, p.74): *“There is flexibility to adapt the layout according to the additional and more detailed geological information to be gained during construction”*.

The tunnel alignment for the transport and deposition tunnels should be in the direction of the maximum horizontal principal stress of the rock mass, which generates the most favourable stress distribution around the tunnel periphery. The stress model (which needs further work: see Part 1, Section 1.1.3 of this review) has to consider the reorientation of the principal stresses from major deformation zones and that the stress orientation in a repository area might change from one stress province to the next. During construction of the ONKALO access tunnel, Posiva observed that instability and noise from cracking in the rock mass developed when the tunnel was driven in a certain direction, at locations where the tunnel made a strong bend and where a large span was necessary at tunnel intersections. This information was used to align the tunnel direction at the deepest chain of the tunnel. Posiva has not presented a concise strategy and methodology by which the alignment of the tunnels will be determined.

The planned repository layout is reasonable for the operational safety of the facility. Posiva could consider excavating the central tunnels to full length and then backing out, filling the deposition

tunnels and corresponding parts of the central tunnel, so as to minimize stand-open time of the filled area. Account needs to be taken of the heat from the filled panels: Posiva 2012-23, Fig. 3-14 shows the maximum temperature increases in the disposal tunnel area will be about 35 to 40°C, around 60 years from the start of disposal. The central tunnels of the largest repository area (NE) have to stay open 50 to 60 years and their temperature just before backfilling will reach some 35 to 55°C (bedrock in-situ temperature about 14°C plus increase from the canisters some 20 to 40°C).

Occupational health and safety requirements relevant to underground construction are that the work-place temperature is not allowed to rise above 28°C without special measures taken to prevent heat stress. The most convenient way is to design the stoping and filling order in a way that minimizes the heating of the tunnels in use, This can be done, e.g., by stoping the NE area central tunnels directly to full length, and by starting the disposal and filling from the outer border of the area inwards. This also minimizes the time the central tunnels are open, which should be advantageous with respect to the upconing of deep saline waters. Also, the smaller temperature increase in deposition and central tunnel walls (roof, floor) diminishes possible thermal spalling before the tunnels are filled.

The OSD describes the geological situation at the site as *“heterogeneous and structurally complex”* (p.126), to the extent that the site lithological model has been of limited use, as detailed mapping in ONKALO shows most of the variability to be at a much smaller scale. Correlations from surface, or tunnels, to boreholes, and back, are highly uncertain. It suggests that the disposal panel excavations could encounter some poor or unusable rock (e.g. frequent or extensive greisens in the migmatitic gneiss, such as those described on OSD p.150), with predictability being difficult. The OSD does not give a quantitative account of the overall extent of alteration of all types in the total rock volume and Posiva rate uncertainty on the location of altered rock volumes as ‘high’ (p.169; p.223).

In some areas (water leakage, EDZ) requirements (VAHA L5-ROC-54, L5-ROC-56, L5-ROC-57, L5-ROC-62, Posiva 2012-24) are set to maximum acceptable for construction, in contrast to YVL D.5 §508a. Otherwise they are realistic and possible to implement. There is little information on the

response that will be made when construction is found to have entered unacceptably poor rock. For tunnels, one option is to increase the number of rock bolts per unit area and to increase the strength of the net, to prevent rock fall. Under these severe conditions the net and rock bolts would have to remain in a deposition tunnel during backfilling. One topic that is discussed in this respect concerns DH tolerances and whether Posiva will need to be more flexible in its DH requirements and specifications (UOPL, p.88). It is indicative of the current early development stage of the DH construction procedure and technology that the early results are suggesting that specifications may need to be relaxed (an example is given of allowing a minor amount of slabbing in the DH walls). Posiva is concerned that too rigorous VAHA-L5 specifications may lead to too many rejected DHs, which would challenge the overall disposal programme. This level of argument does not propagate into the rest of the CLA documentation, where it is simply assumed that DHs will meet specifications. A related issue is how Posiva will deal with DHs that are rejected and have to be backfilled. The type of backfill (e.g. UOPL, p.32), when it will be emplaced and the impact on flow around neighbouring DHs has not been documented in the CLA.

An important input to layout planning with respect to rock suitability will come from pilot holes, whose utility in guiding rock acceptability has been tested using prediction-outcome tests. In general terms, it seems clear (e.g. OSD, Section 9) that for predictions to be of any value in decision-making about deposition volumes, they must be based on the maximum amount of data available, which means always using pilot holes, plus all other available information. The simplest application of the P-O studies has been to attempt predictions of lithology ahead of excavation. Together with predictions of rock alteration, this has not been very successful (OSD p.744, 755). Prediction of BFZs is also poor (p.758). This will increase Posiva's project risk, as potentially mediocre to average deposition volumes will not necessarily be identifiable based before tunnels are excavated. Predictions of fracturing in the 'normal' rock mass seem only to have looked at orientations (i.e., which fracture sets are present) and not at fracture intensity, which falls short of the full range of information that could be most useful. Overall, the P-O experience seems to be

rather negative. The prediction of 'spalling zones' in the excavations "do not seem to fit" the observations (OSD, p.766). Attempts to condition borehole RQD measurements using excavation data did not allow 'correction factors' to be established (p.775).

In Section 4.1 of Posiva 2012-05, Posiva refers to the option of extending the repository to a second storey beneath the -420 m level. This option requires a careful study of the effects of increasing rock stresses at greater depth. In addition the increasing salinity at greater depth and the logistics of the disposal activities in a two-storey repository would also need to be taken into account.

Conclusion: There is insufficient information in the CLA documentation to conclude that adequate procedures are in place. The P-O work to date does not give confidence that Posiva will be able to deploy predictions in any serious manner ahead of decisions on tunnel excavation. The stress model and stress data are currently inadequate for decision-making. These appear to be areas that Posiva has under development. Information might emerge in the Site Engineering Report (Posiva 2013-23), 'Design of the Disposal Facility 2012' or the 'Underground Openings Line demonstrations Stage 1, 2012' (Posiva 2012-33), but none is yet available. The introduction of a process called *Management of the Disposal Concept* (UOPL, p.16) is interesting. The new process must interface closely with the deployment of RSC and should be monitored by STUK, at least over the initial period, so see how decisions are made and what controls them. A plan for the whole area of construction management and decision-making needs to be presented to STUK before construction can commence.

1.2 The construction process and methods

The UOPL only briefly outlines the construction process, at a high level. Posiva has developed a reference method for constructing the underground rooms, but it is not clear what this means. Design requirements lead to individual steps in the production of the underground openings, such as reference methods for construction of tunnels. Section 5.2 notes that reference construction methods are presented in more detail in the Site Engineering Report (Posiva 2012-23), which is not yet available. For example, it is not clear whether Posiva aims to apply EUROCODE 7 for geotechnical design

and construction. One important part of the code is the application of the Observational Method to underground construction. The EUROCODE is mainly used for soil and construction work in soil. The application to rock and rock structures is under development and the International Society for Rock Mechanics has established a commission to assist the development of the code.

An area that is not covered in any of the CLA documentation is the interaction between data gathering, layout planning and the construction process. There is a lack of flow charts and diagrams that illustrate these interactions. Managing the interactions will be vital with respect to the safety class, foreseen service life and environmental conditions in the repository. Hold-points are expected when key decisions are to be made. The UOPL describes the meaning of the term hold points, where employees are not allowed to proceed before getting permission from the supervisor and gives a few examples applied in the work conducted in the Demonstration Tunnel, e.g., hole drilling with the special DH machine and silica grouting. These examples do not demonstrate how Posiva will use the RSC in defining hold points. In more general terms, Posiva's experience in building ONKALO should have provided ample experience of how the integration of a large rock engineering project should be done. During the ONKALO project the responsibility of the design work of the access tunnel and the repository was given to an external consultant firm. To integrate the design work of the repository into the Posiva own organisation might lead to a better integration and interaction of the design work with data collection and construction.

The UOPL briefly describes the interface between pilot holes, tunnel mapping and excavation. There is little information about the necessary information flow to and from construction and when this was raised at the RSC workshop Posiva said that a handbook was planned. At present, it is not clear how the different levels of management decision will be managed, from day-to-day routine decisions underground to high level decisions on programming, deadlines, panel locations, disposal strategy etc. They are all closely linked, so there needs to be a comprehensive plan for them. Experience with the RSC was that the testing programme was subordinate to construction needs. How this type of problem is managed in future will be an im-

portant area in which STUK will need to have good confidence in Posiva's approach, as almost all topics could have some bearing on either operational or post-closure safety.

There is a lack of information about the basis of the tolerances that have been set for construction of tunnels and deposition holes. For example, Figure 6-1 of the UOPL shows impressive scans of the excavation geometry over a 40 m length of Demonstration Tunnel 1. The tolerance for the cross-sectional area is up to a maximum of about 30% more than the designed nominal area, but the basis on which this tolerance has been specified is not discussed, nor how these specifications will be propagated into the deposition tunnels. Management of situations where tolerances are exceeded (e.g. remedial action) needs discussion. On the other hand, the geometrical tolerances may not always challenge the functionality of the tunnels and it is necessary to separate the tolerance of a tunnel and the EDZ of a tunnel. If, with bigger geometrical tolerances, the contour holes can be set apart in a way that their EDZs do not coincide, the EDZs in the walls will be discontinuous and the final tunnel wall less transmissive. The documentation gives an impression that the acceptability criteria set for the underground construction will be equal to and take as a reference the successful production of the underground openings of ONKALO, implying that using the same construction methods will mean that the repository will fulfil the requirements and acceptability criteria. There are no guarantees that this will be the case. As noted previously, YVL D.5, 508a requires: "*...rock construction methods shall be used that limit disturbances in the rock surrounding the emplacement rooms to a level as low as reasonably achievable*". This does not appear to be the case: the standards have been Class 2 or 3 of InfraRYL2010, when Class 1 is still considered "reasonably achievable" in Finnish underground construction.

In terms of construction methods, Finland and Sweden have long experience of mining and underground construction and an advanced and active mining machinery industry, well qualified to take on the design and construction programme. The construction method is drilling and blasting, with the deposition holes being drilled with a special drilling machine, which has been tested in the ONKALO demonstration area and by drilling large diameter

experimental boreholes. Two of the ONKALO shafts will be drilled and the same technique is suggested for construction of the remaining ventilation shafts. Drilling and blasting is by far the most common method for tunnelling in hard rocks worldwide. The international trend towards more use of tunnel boring machines (TBM) was discussed earlier in this review (Part 1, Section 4.3.1) along with a recommendation that Posiva keep the technology under review.

Conclusion: As discussed in the previous section, there is insufficient information in the CLA documentation on the construction process itself, but the forthcoming documentation indicates that Posiva has plans to develop its management procedures. These plans need to be monitored by STUK and need to be seen before construction begins. The construction methods applied in ONKALO and the suggested methods for the excavation of the tunnels and deposition holes are well known, robust and viable. During the construction of ONKALO Posiva has used different contractors and knows that existing contractors on the market in Finland have the skills, personnel and equipment to construct the repository in the Olkiluoto gneisses. Integration of the design function into Posiva's own organisation appears to be an important requirement to consolidate their core competencies as a repository licensee.

1.3 Estimated construction properties & preliminary design of 1st panel

Kirkokomäki (2013) states that the first disposal panel will be constructed to the area SW of the ONKALO main characterization level at -420 m. The 6 deposition tunnels are to be about 300 m in length. The SER estimates the bedrock to consist of veined gneiss (50%), pegmatitic granite (22%), diatexitic gneiss (14%) and granite and mica gneisses (12%), with the orientation of the foliation estimated to be ca 50° in direction 137 degrees and three fracture sets, of which two are vertical and one sub-horizontal. N-S striking BFZ045b intersects all the tunnels in the panel. Posiva estimates the stresses to agree with the second stress model, with average magnitudes: $\sigma_H=33-34$ MPa, $\sigma_h=19-20$ MPa and $\sigma_v=13$ MPa and the maximum stress and deposition tunnels oriented NW-SE. Based on experience from the ONKALO rock mechanics investigations, the rocks belong to ground type GT1.

WR 2014-32 describes a detailed modelling study of the effect of heating by the spent fuel on the virgin stress field, focussing on any potential rock failure of the transport tunnel during the time of operation and the rock support strategy for the transport tunnels. Coupled, 3-D thermo-mechanical analyses using 3DEC and the most recent rock mechanics and rock thermal input data from the OSD shows that a maximum temperature increase of 13°C will take place in the central tunnel of the NE panel. After 120 years of deposition in the panel the maximum horizontal stress perpendicular to the axis of the central tunnel increases by about 10 MPa and reaches about 35 MPa. Somewhat lower temperature and thermal stresses were obtained for the transport tunnel of the SW panel and for the first panel close to the central area of the repository.

Stress-induced damage analysis used the 3-D FEM software, Midas GTS NX, applying the calculated rock stresses from 3DEC calculation as boundary condition for the damage analysis. For all three locations analysed, the maximum compressive stress in the roof of the transport tunnels (where the profile changes, close to the connecting tunnel) are in the range of 54-58 MPa and exceeds the crack initiation value of 52 MPa for the gneiss. Adding the thermal stresses generated during the disposal period to the Midas modelling, the maximum stress across the transport tunnel varies between 75 and 78 MPa and the arc of the tunnel is likely to suffer damage. The modelled temperature in the tunnel after 120 years is 28°C. However, ventilation of the tunnel will reduce the temperature and lower the thermal stresses.

A Cohesion Softening-Friction Hardening (CSFH) material model was applied to model the failure of the intact rock around the periphery of the central tunnel, using Midas GTS NX. The elastoplastic material model is new and, to date, has been applied in stability analyses of underground mines. The modelling indicated a maximum shear failure depth of 900 mm in the crown of the transport tunnel in the NE panel and tension failure in the wall of the tunnel.

In the third step of the modelling sequence Posiva conducted detailed tunnel reinforcement modelling for the central tunnel of the NE panel, using the Phase² computer code and the depth and extension of the failed rock block in the crown of the tunnel calculated by the Midas program and the

CFSH material model. Two different tunnel profiles were simulated to illustrate the influence of the tunnel geometry on the stress distribution around the tunnel periphery and the need for rock support. The reinforcement structures used in the modelling were 25 mm diameter rock bolts of 3 m length and 40 mm shotcrete. The layer of shotcrete is assumed to transmit the load bearing forces via the normal and shear stiffnesses of the contact between the rock and the shotcrete. The result shows that 25 mm rock bolts and 40 mm shotcrete are strong enough to provide a stable tunnel during the peak of the long term stress state. To guarantee the long term safety and stability of the repository, Posiva suggests a reinforcement strategy in two steps. In the first step, the rock support is installed to sustain the initial stress from the start of deposition together with a monitoring programme to record displacements in the rock mass, bolts and shotcrete. When failures are observed and displacements in the structure reach or exceed given stoppers, additional support elements are installed until the structure remains stable. This approach is in agreement with the so-called Observational Method and is a method included in the regulations of Eurocode 7 that Posiva intends to follow.

The tunnel designers have presented a tunnel section where the stress concentration from the maximum horizontal virgin stress, with or without thermal loading, exceeds the damage strength of the intact rock. The suggested rock support can mitigate the damage of the tunnel roof and achieve a safe tunnel during operation and for long-term safety. Another approach is to modify the tunnel profile to achieve a stable tunnel profile, both in the roof and tunnel walls, without damage or with limited damage. By increasing the radius of the arc in the tunnel roof, the tangential compressive stress will reduce. The space required for the transport vehicles in the tunnel might lead to an increase of the height of the walls. When the walls of the tunnel get higher the tensile stresses in the centre of the walls may exceed the tensile strength of the rock and therefore demand additional reinforcement. Hence, knowing the effect of thermal stresses over the lifetime of the transport tunnels (knowledge that has arrived late in their design phase: Posiva WR 2014-32), there is room for another iteration of the transport tunnel design for the different panels so that the optimum tunnel shape and related

reinforcement are determined. Posiva should be encouraged to perform such an analysis.

The modelling of thermally induced rock stress increment and its response of the rock reinforcement for the transport tunnels and shafts (WR 2014-32) was conducted in three steps, with four different modelling schemes and three different methods; 3DEC (discrete element method), Midas GTS NX and Phase² (finite element method) and Examine 2D (boundary element method). The Posiva team has made a careful selection of methods to solve the different steps in the analysis. The approach is innovative and the selection of material properties has been done using the latest knowledge of the Olkiluoto site. The many steps and computer codes applied to derive the final statement show the need for a unified computer code that can solve capacity and response of different rock support methods for different rock types and anisotropy and can integrate several support methods in one and the same code. Posiva has the need and the capacity to take a lead in such development.

Conclusion: Posiva has conducted innovative modelling of the thermally induced increment of rock stresses at three locations of the transport tunnels in three different storage panels. The heat from the canisters generates an extra stress that will be superimposed on the virgin rock stresses. For the transportation tunnel in the NE panel, Posiva has used three different computer codes to derive the temperature distribution in the repository, the intact rock failure and the bearing capacity of the rock reinforcement of systematic rock bolting and shotcrete. The analysis shows that crack initiation strength is exceeded in parts of the roof of the transport tunnels and Posiva will need to apply the Observational Method according to Eurocode 7 to monitor the failure development and install additional rock support, if needed. Exceeding the rock damage strength in parts of the transportation is new information. Posiva should be encouraged to perform an additional modelling phase, where the geometry of the crown of the roof of the tunnel is flattened and the wall of the tunnel is made slightly higher. Also, Posiva should be encouraged to take a leading role in developing a unified rock reinforcement code that can analyse the load bearing capacity for different support systems emplaced in anisotropic gneissic rocks.

2 Consequence mitigation during construction

2.1 Bedrock stability with respect to thermal loads at disposal depth

Although the Design report has several sections describing the need for bedrock stability in the design and construction of the repository tunnels and other underground openings, the acceptance criteria and measurement procedures for bedrock stability are not sufficiently described and discussed in the UOPL.

2.1.1 Thermal properties and anisotropy of the rock mass

The OSD explains that there are about 400 laboratory measurements of thermal properties, indicating a generally high thermal conductivity (2–4 W/m/K) for most of the rock lithologies (with in-situ measurements generally about 0.4 higher than the lab values), which should thus not present problems with thermal dimensioning. The migmatitic rocks show distinct anisotropy caused by the foliation, with a mean anisotropy factor of 1.4 (OSD, p.316) and with a significant scatter, so orientation with respect to foliation will be a factor in spacing of tunnels and deposition holes. Posiva uses a mean value of K of 2.91 for all the rocks for thermal dimensioning, which is conservative enough that a single value for DH spacing based upon it will accommodate actual conductivity values in most rock volumes. A statistical analysis using variograms and 2-D stochastic realisations of conductivity distribution (OSD, p.329) suggests a generally very low (<1–2%) probability of 10 m³ blocks of rock in the repository having conductivity less than 2.2 W/m/K, somewhat less than could be estimated simply from the histogram of lab sample data. This suggests that an RSC to test routinely for thermal properties in all DHs is not required. Nevertheless, care will be needed if other rock types are encountered in deposition volumes, as some (e.g. amphibolites)

could have low conductivities. The lower tail of the thermal conductivity distribution is thus of outmost importance for the design of the repository and these data are not presented. In addition, Posiva has not carried out any specific modelling of the effects of the observed anisotropy.

It should be noted that the thermal properties of the rocks above the -350 m level have not been characterised. This information will be needed for evaluating the large-scale thermal response of the total rock mass above the repository.

Conclusion: OSD introduces a thermal block model that corresponds with lithologies from which it can be inferred that available rock volume should be more than adequate. Thermal dimensioning work has adopted a conservative approach that means that detailed thermal characterisation in all deposition regions will not be required. More data are needed in order to carry out a large-scale thermal response model for the rock volume above the repository.

2.1.2 Thermal dimensioning and thermal impacts on construction

The thermal dimensioning report (WR 2012-56) presents the analytical and numerical method for determining the distance between the deposition tunnels and the canisters spacing for different canister thermal properties. The dimensioning is governing by the maximum allowed temperature 95°C at the surface of the canisters. The methodology for determining the temperature distribution with time for single deposition holes and the whole panels when all the canisters are deposited in the panel is demonstrated. Comparison of the calculations performed by Posiva and SKB using different methods gives good agreement and full confidence in the results. Posiva has demonstrated that simple superposition principal can be used in determining

the temperature interaction between panels and the calculations have shown that there are minor differences in temperature, whether the canisters are loaded sequentially (36–50 canisters/year) or whether all canisters of a panel are loaded simultaneously. Long delays between filling adjacent panels need to be avoided, otherwise the rock heats up sufficiently that the new panel would need to be farther away or its DHs would need to be significantly further apart than ‘standard’, thus affecting available space. This seems not to be an issue, provided the operational gap is less than about 20-40 years, but will clearly have to be taken into account over the c.100 year operational period.

WR 2014-32 (p.127) presents results of a rock engineering modelling of thermally induced rock stress increment and rock reinforcement of the transport tunnels.

The UOPL notes that during the operational phase there will be more open rooms and higher temperatures than currently exist, due to the heat from canisters that have already been emplaced. These elevated temperatures will result in increased stresses in the bedrock that could result in slabbing or spalling into the tunnels and holes. Posiva notes that this phenomenon is not fully understood and research is currently taking place in ONKALO.

Conclusion: The thermal analysis is well founded and useable for planning. There are no issues at the CLA stage, but further evaluations will be required at the time of the OLA. For thermal issues, STUK needs to check that the sequence of panel use has been included in the planned staging of panel filling that Posiva already proposes. Closer to operations, Posiva should demonstrate the temperature distribution in the most likely repository layout for the complete deposition before closure. In due course, Posiva should present an analysis of the tunnel and deposition hole stability as a function of the temperature distribution for the individual panels and the completed repository.

2.1.3 Analysis of fracture response to thermal and mechanical loads

Posiva’s analysis of fracture propagation concerns shear displacement on fractures intersecting DHs as a result of an earthquake and uses a distinct element analysis with the 3-D code, 3-DEC. The earthquake scenario is discussed elsewhere in this review (Part 1, Section 2.3.3). Posiva has found that

the stress increase at a target fracture in the DH will not generate a deformation that exceeds the limit of 5 cm.

An ongoing modelling project at GFZ Potsdam for SSM is using the discrete element method and the Particle Flow Code (PFC) to simulate the same effect (for the Forsmark site) but from the perspective of thermally induced strain and induced EQs on fracture zones. At the peak temperature for the repository the thermal stresses plus the virgin rock stress and induced EQs on existing fracture zones generate shear displacements that exceed the limit of 5 cm. As time progresses, more and more fractures (with fractures >100 m and <562 m) displace more than 5 cm, with the shorter fractures showing the largest displacements. This new modelling approach indicates that the specified upper limit of displacement on existing target fractures will be exceeded by the combination of thermal stresses generated by the spent fuel and EQs that are initiated at any of the large deformation zones inside or outside the repository area.

Posiva has studied fracture propagation due to thermal and mechanical loading in the POSE project (WR 2011-23). Posiva has used FRACOD for the two-dimensional fracture mechanics analysis (MDR, p.240-251). Posiva needs to apply this, using a realistic fracture network, to evaluate TM fracture initiation and propagation in the area around the top of the deposition holes, at the floor of the deposition tunnel.

Conclusion: Along with several other aspects of the earthquake scenario (discussed elsewhere) and the strain response of the rocks mass, where Posiva is planning more work, combined thermo-mechanical fracture response is an area where further work would improve confidence in future iterations of the safety case. Posiva should be encouraged to continue and extend their work in this area.

2.2 Construction materials introduced into the repository

A range of materials will be used in the disposal rock volume to facilitate construction and operation and it is important that these ‘introduced’ materials do not affect the long-term safety performance of the rock barrier. The principal ‘foreign’ materials involved are rock bolts and meshes for roof support, grouts used in fracture zones and ‘process water’ used for drilling and cleaning activities.

2.2.1 Amounts of 'foreign' material and their control

WR 2011-32 estimates the amount of foreign material left in the repository during backfilling of the tunnels and closing the repository after all the excess material has been removed. During construction of ONKALO, the majority of foreign material introduced has consisted of cement and steel. The total amount of cement that will be used in the final repository is estimated to 2,366 tons, of which half will be located in the access tunnel. About 90% of the cement will be used in constructing the plugs for the deposition tunnels. The amounts of material, geometry and volumes are likely to change from the current stage of plug design. At the time of WR 2011-32, the floor of the deposition tunnel had a concrete floor. Recently, Posiva has used a road-header to even the floor in the demonstration tunnel, with positive results, so the proposed 120 to 150 mm thick concrete floor (which later has to be removed before backfilling) might not be necessary. It is acknowledged (WR 2012-46) that, although some (e.g. 20 to 25% of cementitious materials) might eventually be removable, the actual amounts are not currently known. Hence, the required amount of cement to be used in the repository is not known at the present time.

Two types of rock bolts will be used: support and anchor bolts. Supports bolts are used to reinforce the rock in the access tunnel, transport tunnel and the excavations in the central area of the repository. They are made with rebar, with a steel plate, washer and nut, grouted with cement mortar. Support bolts will remain in the rock mass after installation but will not be used in deposition tunnels. The design life of the central tunnels is specified to be 100 years (UOPL, p.41), which calls for permanent reinforcement and stainless steel. It is not clear from any of the reports dealing with design of the repository for the LA if the reinforcement will remain in the central tunnels. Anchor bolts are used to attach items such as nets or electrical cables and pipes to the roof and walls. Rock support in the deposition tunnels will be removed prior to backfilling and closure of the tunnels. WR 2011-32 (p. 19) notes that the one-meter long anchor bolts will be cut and a part of the steel will be left in the drill hole. Posiva might consider using a friction anchor type to support the net: a split-set dowel with steel plate or expanded dowel with faceplate. Another option could be a

mechanically anchored, ungrouted expansion shell bolt. The removal efficiency of these types of bolt is better than the estimated 40% for conventional grouted rock bolts. Section 6.4.1 of WR 2012-46 describes the following procedure: *“After the making the deposition holes, the reinforcement (except rock bolts) together with all the tunnel infrastructure is taken away in disposal cycle of four canisters. Tunnels must be scaled mechanically and the rock blocks need to be taken out from the tunnels prior to the backfill is emplaced. In some parts of the tunnel, such as when passing through a fracture zone, the mesh must be left in the tunnel for occupational safety reasons. In other rooms the shotcrete is also extracted, and the same safety judgement is applies as for the disposal tunnels”*.

Monitoring of process waters by analyses of sedimentation pond water is mentioned in WR 2012-46 and 2012-43. Process waters have been tagged with fluorescein, so the relative proportions of process waters and natural groundwater inflows in the pumped discharge into the sedimentation ponds can be calculated. The nitrate contents of these waters are elevated, at around 200 mg/l, which presumably originates in part from blasting residues. The pH of these waters is moderately high, which derives from grouting materials. The high nitrate contents would have a localised impact on redox conditions and could also locally stimulate microbial activity.

Outside the disposal volume, the Closure Production Line report (Posiva 2012-19) describes the use of stored rock debris from excavations in backfilling various other parts of the repository. The central working areas at disposal depth, plus much of the shaft and inclined adit back to the surface, will use crushed rock backfill. This material will be treated before emplacement (additional crushing and grading). Care will be needed to ensure that processed materials from spoil heaps that have been exposed to surface biological processes over decades do not introduce large amounts of biological and organic material into the deep environment.

Comparisons of the amounts of foreign materials from current and previous (WR 2003-72 and WR 2007-17) studies shows that substantial differences have arisen due to the changes in design and construction over time. Technical guidance and strategy should be in place to make consistent decisions about management and optimisation of these

materials, based on reliable data, which are already being acquired in the monitoring programme.

The control and monitoring of Foreign Materials is discussed in WR 2012-46, where the documentation base is explained. The impression is that, while the amounts of important materials are well known, the quality of the procedures for controlling them are not well stated. Audits have led to 'stray' materials being removed. For grouting the composition and material use in a grouting campaign is specified but the total volume or injected amount per volume rock has no pre-set acceptability criteria. Often, it is difficult or impossible to predict and forecast the amount of grout needed to tighten the rock, or the amount of rock stabilisation with rock bolts and nets that will be needed in an area of instability and low strength. Based on the Hydro-DFN, WR 2012-48 presents an approach to modelling the amount and spread of grout to achieve specified levels of inflow on individual fractures and to each deposition tunnel. However, at its present state of development, the model is highly idealized and needs to be validated by comparison with data from underground. Posiva has thus not pre-set acceptability criteria for the maximum amount of steel from rock bolts and nets that can be inserted in a deposition tunnel.

Conclusion: The problem posed by foreign materials is clearly well recognised by Posiva and a programme is in hand to control them. The discrimination of allowable from forbidden materials appears soundly based. The amounts of some materials are considerable. The available information does not allow conclusions to be drawn about the adequacy of Posiva's control procedures.

2.3 Mitigation of hydraulic and hydrogeochemical disturbances

Disturbances due to ONKALO have been used for parameterising/calibrating the site-scale hydrogeological models to achieve consistency. The hydrogeological background reports (WR 2012-32 and 42) incorporate physically realistic and adequately

detailed models of the repository tunnels for assessing this effect, as part of the hydrogeological base-case calculation case.

Hydrogeochemical disturbances during the excavation and operational phases are considered in Section 5.1 of the PAR. They are modelled in terms of (a) potential salinity changes due to perturbation of groundwater flows, (b) consumption of dissolved oxygen by reaction with pyrite in fracture zones, and (c) concentrations of HS^- and Fe^{2+} in groundwaters entering repository tunnels. The model outputs are shown in Figures 5-10, 5-12 and 5-14. These are adequate and comprehensive modelling treatments of these issues. However, it would be valuable for Posiva to monitor whether deposition tunnel excavation induces any significant local changes in key redox parameters in the deposition volume.

There is clearly a possibility that the cement-based LILW repository at 180 m depth could chemically interfere with the spent fuel repository. The Hydro-DFN report (Section 7.7, WR 2012-42) looks in some detail at possible interactions between water that has passed through the cement-filled LILW and the SF deposition holes. The analysis is important for the safety case as a whole, but it is not propagated. The considerable importance of having a high quality backfill and good seals in the access shafts and tunnels to prevent interactions is highlighted (e.g., Figure 7-28 and p.179) and is an issue for STUK to track in future. This study also highlights the significance of the transmissive HZs (particularly 19B and 20A) in controlling inflow paths.

Conclusion: Hydrochemical impacts of excavation have been considered and modelled by Posiva. It would be useful to confirm the modelling by observations during the early stages of construction. The impact of the LILW repository on the deeper SF repository needs to be more fully evaluated as part of an integrated safety case for the joint facility. This should be a requirement for the OLA safety case documentation.

3 Meeting design targets and initial state

3.1 The VAHA system

The VAHA requirements management system is an essential and well-structured feature of Posiva's plans. It is clear that Posiva is still developing this system with respect to its practical application and this will need to be a focus for STUK scrutiny, as there are identifiable difficulties with the current formulation, as discussed below.

All the specified performance targets belong to Level 3 of VAHA. Level 4 of the VAHA system specifies the more detailed requirements that are derived from the performance targets and target properties. The text in the design specifications on Level 4 and the target properties defined on Level 3 for the host rock are very similar in level of importance for the long-term safety of the repository. From the text of the specifications at Levels 3 and 4 it is not possible to discriminate a target property from a design requirement. Design specifications occur at Level 5 and are unambiguous. There is no information presented on the tolerances that Posiva will allow for any of the quantitative criteria.

Overall, the way Posiva presents VAHA makes it difficult to grasp the overall design approach and the system appears not to be viable, measurable and practical. The situation becomes more difficult to grasp when one considers that suitable RSC criteria have to be satisfied for the design of the panels, deposition tunnels and deposition holes.

Within VAHA, there is both overlap and lack of clarity in the definitions and poor traceability, for example, how do definitions get made? Some examples are given below:

- a. Each diagram that presents the VAHA levels uses slightly different words: compare RSC, Fig. 5-1, with DBR, Fig. 6-1, for different ways of presenting the rock.
- b. Level 3 has General Requirements and Target properties. In fact, there is only one General

Requirement and that is 'depth', but this is not justified in the documents.

- c. It is not clear in almost all the documents that the rock (and the biosphere) do not have 'Production Line' reports, like all the other components of the system. It seems that the OSD and the biosphere reports are regarded as the equivalents.
- d. It is not clear that the RSC are supposed to cover both L4 and L5, except in one diagram in the RSC report (5-1).
- e. There is complete overlap between some of the L3 and L4 definitions, for example: subsystem requirement L3-ROC-21 "*Inflow of groundwater to deposition tunnels shall be limited to ensure the performance of the backfill*" and its derived L4 design requirement L4-ROC-9 "*Inflow to deposition tunnels shall be limited to ensure the installation of the backfill and to limit piping and erosion*".
- f. The L3 requirements are often vague. For example the flow and transport properties of the DH rock (see Design Basis report, Section 6.3.4) use phrases like '*in the vicinity of a DH*', '*at the most*', and '*for most of the deposition holes*'. The latter phrase is important, as Posiva implies that not all accepted DHs need to meet certain quantitative criteria. Other examples of vagueness include: L3-ROC-33 ("*The properties of the host rock shall be favourable for matrix diffusion and sorption*") and L3-ROC-23 ("*The location of the deposition holes shall be selected so as to minimise the likelihood of rock shear movements large enough to break the canister*"), which cannot really be audited.
- g. The next step (L5, which comprise quantitative specifications) is not justified in any CLA documentation: for example, the L5 RSC for (e) above is the 0.25 l/min inflow criterion to tunnels. The DBR (p.80) mentions that it could be from 0.1 to

- 0.5. The RSC report establishes the value of 0.25 and (p.78) refers back to the DBR for ‘detailed discussion’. In fact, going back to the main cited justification (WR 2009-129), there is no mention of a value of 0.25 being identified as a criterion – the conclusion must be that this is not traceable.
- h. There is also a traceability problem with the 0.1 l/min inflow L5 criterion for DHs. First, it is not reported how the L3 requirement of “*the flow rate in such a fracture shall be in the order of one litre of flow per one meter of intercepting fracture width in a year (l/(m*year)) at the most. In case of more than one fracture, the sum of flow rates is applied*” is converted to the 0.1 l/min DH inflow criterion. The origin of this 0.1 value is not defined in the CLA documentation: we are referred back to Hellä, 2009. Here there seems to be a lot of uncertainty. The original number comes from Swedish work and it is assumed that erosion only occurs for a period of 12 weeks until tunnels are plugged. Hellä notes that the tunnels will be open for much longer (up to 10 months) and cites evidence that significant erosion would occur after ‘several weeks’ at the 0.1 l/min limit. The value has not really been set using careful logic and does not appear to be definitely conservative.

Conclusion: Traceability within VAHA is difficult and frustrating and no single document brings everything together. Some RSC values cannot be traced to origin. VAHA definitions are entities that can be regulated and it is hard for STUK to do this if it means consulting reports of different age and importance level and sometimes having to make assumptions about Posiva’s meaning or intentions.

3.2 Acceptable initial state

The expected and desired initial states of the excavated openings are defined in several of the key reports Posiva 2012-22, Chapter 6; Posiva 2012-04 Chapter 3, Posiva 2012-05, Chapter 4. The text in each of the reports differs slightly. The repetition makes it difficult to judge the completeness of the long-term and operational safety issues. In addition, the description of the initial state of the excavated openings and other components of the repository is very brief.

The initial state of the underground openings refers to the as-built geometry of the underground spaces, as well as the properties of the of the host

rock after the excavation and prior to the emplacement of the buffer, backfill and closer of the system with plugs according to Posiva. The RSC work for the panels, tunnels and deposition holes and the thermo-mechanical parameter determinations and analyses are done before or during the underground construction. An acceptable initial state of the underground openings is dependent upon the quality of the RSC work and the determination and analyses of the thermo-mechanical characterisation.

A key issue will be the initial state of the DHs. The DBR discusses the VAHA L3 requirements on verticality and straightness of the DHs and the tolerances needed for buffer emplacement, but the Demo work so far has not been sufficient to be able to provide a robust test of Posiva’s ability to meet these. The UOPL goes much farther and defines the L4 design requirements for the underground openings as well as the L5 design specifications. The latter are under development and the UOPL Appendix includes preliminary updates and additions to both L4 and L5. Together, these define the required initial states of the openings and, with the exception of the problems identified in the previous section, they are clear, well defined and relate to obvious operational or post-closure safety issues. Section 3.6 of the UOPL identifies the need to have an agreed procedure with STUK to agree that an acceptable initial state has been achieved prior to disposal operations and that this will be based on extensive documentation produced during construction.

Section 6 of the UOPL identifies qualitative risks associated with achieving the specifications (and thus the initial states). This is a general discussion and simply identifies potential problems. It would be a focus for future STUK evaluation that these issues are being kept under review by Posiva. Much is currently being learned from the DT work and this is necessarily work-in-progress at the moment.

Conclusion: With the exception of the problems (identified in the previous Section) associated with some of the current RSC criteria for acceptable initial states of deposition tunnels and DHs, Posiva has a clear definition of what it wishes to achieve and is at the stage of testing methods for how to achieve it. This must continue and be subject to STUK inspection and STUK also needs to have a dialogue with Posiva about the interaction envisaged and the data that will be required in order to progress to an operational stage.

4 Demonstration and monitoring activities

In general terms, Posiva has not presented a plan that outlines how its further demonstration work (technologies, RSC development etc.) will tie in with the early stages of construction, such as the first panel access tunnel and the first deposition tunnels. Clearly, some of this demonstration work can only continue during construction, so it is important that STUK sees these plans before construction starts.

4.1 Demonstration of grouting methodology

As described in the UOPL, Posiva has cooperated with SKB on different grouting materials, techniques and equipment. This R&D programme has led to a better understanding of the fundamental mechanism of grouting and further development of grouting materials. After tunnel chainage 1000 m in ONKALO, the need for grouting is very low and limited to areas of tunnels intersecting deformation zones or brittle deformation zones. The use of normal cement grouting is not permitted below a depth of 290 m because its presence might affect the performance of the bentonite. This has required Posiva to participate in international projects developing low-pH grouting cement and colloidal silica grouting material. Posiva continues to carry out experiment related to stability and long-term behaviour of silica grout.

The general approach to where and why to use these ‘novel’ grouting materials is described in the UOPL and is also discussed in Part 1, Section 4.4.3 of this review. A description of the most recent demonstration work on colloidal silica grout is provided in WR 2012-84. Generally, the tests seem to have been difficult and the results are rather uncertain and inconclusive. It was possible to demonstrate that the equipment functions (albeit with some problems), but there were also problems with the quality of drilling of the grout holes. An already

‘tight’ volume of rock was used for one test and it was possible to make it even ‘tighter’, with the minimum aperture able to be penetrated by the grout being estimated as 10 microns. A conclusion of the tests is that flow is channelled, which has implications elsewhere in this review with respect to the representativity of the Hydro-DFN, including, in particular, the use of the Hydro-DFN to model grouting effects (WR 2012-48, Section 3.10). A series of recommendations has been made for further R&D (see p. 71-72).

Conclusion: It is clear from the report that the tests were regarded as preliminary and raised a lot of questions. It is not clear whether there is a forward programme for further testing. Clearly the technique does need more work and testing, and STUK should press for this during the construction stage. Development and testing of models for grout penetration and effectiveness should proceed in parallel.

4.2 Demonstration of excavation stability

With few exceptions, Posiva has constructed more than 4 km tunnels and large rooms for the central area of the repository with good to very good stability, with only light rock reinforcement being applied. The instabilities of the tunnel roof and the roof and walls of the rock chambers in ONKALO appear when excavation span increases or decreases and the direction of the excavation makes sharp bends. These instabilities are related to major changes in the stress state in the walls of rooms and tunnels. The other type of instability is governed by the local fracture geometry and its ability to generate blocks that can fall free.

UOPL Sections 6.4.1 and 6.5.1 describe potential hazards relative to the design premises for tunnels and deposition holes, respectively. Proper drilling and careful and smooth blasting is the most

effective drill and blast method to produce stable tunnels. The quality of the drilling and blasting is determined from the visual half-pipes at the surface of the excavation. Laser scanning of the surface or sections of the tunnels and rooms provide information about the amount of under- and over-excavation. GPR measurements provide data on the depth of the damage zone, although they cannot yet be used independently for this purpose (see Part 1, Sections 4.1.2 and 4.3.1). Manual scaling with a metal rod from the floor of the excavation or from a special scaling boom remains the most effective and safe way to secure the stability of roof and walls of the excavation. Following blasting and prior to mucking, mechanical scaling is made with special scaling equipment. Posiva has learnt not to use too high a scaling force against the rock surface, which has a tendency to destroy the stability of the tunnels and rock chambers.

In Section 4.2.4.1 of YJH 2012, Posiva presents results from extensometers installed to determine deformation in the rock mass that can give indications of time dependent deformation and/or instability. These extensometers are in the ONKALO access tunnel, the pillar between technical rooms and the parking hall in the central area. LVDT instruments record the deformation of the shafts at the end of drilling one section and are considered more reliable. Extensometers tend to have poor accuracy and are sensitive to humidity, as well as being challenged by the relatively small deformations in the hard gneiss. It is difficult to judge how successful the current installations will be for monitoring the stability of reinforcement.

Conclusion: Posiva has demonstrated that it can build stable openings. There are residual questions discussed elsewhere in this review concerning how Posiva will implement roof support in some areas, how it will respond to the improvement of the site stress model and how it will manage stand-up times in different operational areas, but there are no problems identified with the ability to construct a stable repository.

4.3 Demonstration of plugs and seals

Sealing of drill holes is mentioned in Posiva 2012-19 and YJH-2012. A further report (Closure of the investigation boreholes, WR 2012-63) is not available. YJH 2012, Section 4.5.4 describes the method to be used, which is to seal the sparsely fractured

sections of the boreholes down to about 500 m with bentonite. Below 500 m depth and for fractured sections with high hydraulic conductivity, low-pH concrete will be used. The bentonite will be inserted into the boreholes in perforated copper tubes. The cement material for deeper sections and highly fractured sections will be pushed down in water-tight steel cylinders from which the cement paste will be pushed out. The development of backfill and plugs for borehole sealing is at an early stage of development and Posiva will have to present more thought-through solutions to make sure that erosion and short cuts are avoided.

Posiva 2012-19, Facility Closure Report, Section 3.7 and 4.4, describes the design and production of tunnel closure plugs. The plugs are of two types: mechanical plugs and hydraulic plugs. The installation is described in general steps. Plug locations will not be identified finally until the time at which closure of a section of the repository takes place, so plug notches will be constructed only at the time of plug emplacement. This approach (Posiva 2102-19, p.68) seems sensible, as it avoids deterioration of the plug seating over the decades before closure of any given section. There is no indication that any demonstration of plug emplacement has been carried out and none in any other national programme is referenced. Posiva was involved in a joint shaft backfilling exercise in Canada. Even though this is called 'shaft plug emplacement', it appears to have been shaft backfilling, rather than experience in constructing multi-component, notched plugs.

The production line report gives the impression that the key report on closure design, which would be presumed to provide more detail of why the closure designs were selected and what the frequently-mentioned available alternatives are, is WR-2012-09. This was found to refer *forwards* to the Production line report. This circular referencing shows poor quality checking, especially when neither report actually provides the expected information. It appears to be an omission that neither report refers to the planned DOPAS plug demonstration test in the DTs.

Additional information is available about the specific plugs to be used to seal the disposal tunnels in the Backfill Production Line report (WR 2012-18: note that this report only covers the disposal tunnels and not the whole repository backfill requirements). However, the information is mainly about

the materials to be used (plug, filter etc) and their properties, rather than about emplacement, and there is no description of practical experience in this respect. These plugs only have a design life of about 100 years. They should be tested at full scale before installation of the first deposition tunnel plug.

Conclusion: There is growing experience of repository closure activities. None of these will be needed by Posiva for many decades. Even though the current reporting is rather unsatisfactory in terms of looking to future development and demonstration, at this stage STUK needs to be confident simply that techniques are available that could be developed and adapted when the time come to deploy them. Even in an emergency closure scenario, for a part-filled repository, this will not be for at least 20 years. Detailed practical studies of all closure types can be carried out now, but it is inevitable that each methodology will change before the first closures are needed and also inevitable that the repository, which will be progressively closed over a period of around 100 years, will use adapted and modified procedures for similar requirements in different regions at different times, as technology advances.

4.4 Demonstration of reinforcements

Posiva will base the amount of reinforcement in the tunnels on the calculated Q-value from the tunnel mapping. Posiva has to present the type design of reinforcement – rock bolt and net in the deposition tunnels, rock bolts and shotcrete and net in transportation tunnels - for different Q values and for different type section about the orientation of the foliation of the rock mass. For the operational rooms and transport tunnels shotcrete, rock bolts and net are allowed. The degree of conservatism in the method of rock support is governed by the thickness of the shotcrete, the amount of fibres added to the shotcrete, the type, length and spacing of the rock bolts the type, dimension and strength of the net. Posiva has not presented design rules of rock reinforcement for different tunnels and rooms in the repository. It is not clear if Posiva intend to apply a systematic net and bolt reinforcement of all the tunnels and openings in the repository, or if spot-bolting and net installation will be applied.

Posiva has classified the rock masses in the ONKALO area in four classes, GT1 to GT4, according to Q-classification system (Posiva 2012-23, p

74-77). Deposition tunnels in classes GT1 and GT2 can be used for DHs. The current span width for deposition tunnels is 3.5 m (Posiva 2012-23, p 126). Combining Fig. 4-1 (Posiva 2012-23, p. 78) and the GT1 and GT2 class descriptions it can be seen that deposition tunnels belonging to classes GT1 and GT2 need not be supported, with the exception of some local blocks, where spot bolting may be needed.

In the YJH-2012 Report, Posiva mentions that a new type of rock bolt (Fin-Bolt) will be manufactured and used in the tunnelling work for the repository. There is no description of the new bolt presented in the CLA documents, nor in the SER. Section 6.3.2 of the SER briefly describes the procedure of rock support in the two DTs where the new Fin-Bolt was installed. One bolt per 200 installed bolts was tested with pull-out test when the grout was partly cured. Posiva claims that the pull-out test was passed if the grout annulus was complete without gaps. A new type of rock bolt cannot be introduced for the underground support work without extensive testing under realistic conditions and the feasibility of introducing the new bolt into the Olkiluoto repository schedule needs to be confirmed to STUK. Posiva will need to install a number of rock bolts in the ONKALO tunnel, central area, DTs and the transport tunnels of individual panels to be able to test the long-term bearing capacity and integrity versus time. Also, Posiva will need to test the dismantling of reinforcement, as the bolts and net will be removed before backfilling the tunnels.

Rock support and the performance of shotcreting, wire mesh and rock bolting are described in Sections 5.3 and 8.8 of the SER. Section 5.5 describes the different rock support measures and the equipment used to perform rock support. For chainage 0-2080 m, non-systematic bolting and partial shotcrete, together with spot-bolting, was used. After chainage 2080 m, systematic bolting was used, in a 2.2 x 1.8 m grid, together with 40-90 mm shotcrete. The SER does not mention how many rock bolts were used or the area of shotcrete made along the ONKALO tunnel with the purpose of testing the support quality and bearing capacity with time.

Conclusion: There is further demonstration work required with respect to the removal of reinforcement and if new bolting technology is feasibly to be introduced. Over the very long operational

lifetime of the repository, it is to be expected that new techniques will have to be introduced periodically, as technology improves.

4.5 Future demonstration activities

The first planning together with aims and needs of testing and demonstrations in ONKALO for the CLA was presented in WR 2009-24. The objective of the report was to outline the plans for testing and demonstrations for more detailed operational activities and their schedule for the period to 2018-19 or longer. Chapter 4 of YJH 2012 gives a comprehensive description of the present status and a new YJH Report will be produced in 2015.

For rock mechanics and rock engineering Posiva says that if the third phase of the POSE test on spalling of deposition hole is found to be useful, a similar test can be carried out in veined gneiss at the repository depth under the influence of relevant rock stresses. There is certainly the need for an additional test similar as POSE to give confidence in the result of zero spalling during drilling of the deposition hole and minor to zero spalling due to heating the rock mass. It might be possible to combine the extension of the POSE test with the test programme of scale dependent thermal and thermal-mechanical data with and without the TERO76 test equipment in operation. The characterisation of the strength and deformability of BFZs and laboratory testing of the BFZs at Olkiluoto is correctly of high priority for the Olkiluoto site and of great interest for other deep geological sites for spent fuel and HLW in other countries. Also, the determination of the state of stress at depth in ONKALO is a high priority research field together with the production of an updated version of the rock mechanical model RMM v. 3.0.

Conclusion: Posiva has an impressive plan for future demonstration work, which should be encouraged. The execution of the suggested R&D activities in the demonstration tunnels or other areas should aim to be conducted and reported within the allocated time plan before the OLA.

4.6 Monitoring to ensure preservation of favourable bedrock properties

Posiva's overall proposals for monitoring the site and the excavations are presented in the 'Monitoring at Olkiluoto' report (Posiva 2012-01), upon which all of the comments in this Section are based.

The highest level response to this report is that Posiva has adequately identified the processes, targets and parameters that need to be measured for each subject area, but does not present sufficient information on the programme itself to allow the monitoring to be subject to regulation by STUK. Section 3, which describes the history of development of monitoring ideas is confused and gives an impression of lack of integrated thinking on monitoring.

4.6.1 Managing the monitoring programme

Although the report describes frequencies of measurements for most parameters, it is vague on the 'where' and the 'when' of measurements and, in a few places, it is equally vague on 'how' measurements will be made. The report reads much more as a 'Concept of Monitoring' description (which is reasonably well presented), but it is a long way from being a Programme of Monitoring. It is clear that decisions have not been taken yet on many aspects of the underground measurement programme. Some specific points are:

1. It does not link with the proposals made in the RSC report, so that parameters measured during panel construction for RSC purposes become an element of the integrated monitoring programme. There should be convergence between design specifications, RSC criteria, and monitoring action thresholds. One issue that STUK may wish to discuss is whether the hydrochemical monitoring programme described here might provide an adequate substitute for specific VAHA L5 hydrochemical RSC measurements, which seem not to have been tested yet in demonstration work. An argument could be made that the repository scale chemical monitoring programme is sufficient for ensuring appropriate hydrochemical disposal conditions throughout the whole facility.
2. There is one sentence on microbiological monitoring, yet biological activity and niche occupation could be a major management issue in the long operational life of the repository.
3. Some historic monitoring programmes (especially the geodetic, GPS, scan line, levelling etc) are excellent bases for the future, but the report does not consider realigning or extending them to match the latest structural model in the OSD, to ensure that measurement stations and lines

are focussed on tracking the dynamic behaviour of specific structures or rock blocks.

4. Because the report is vague about the ‘wheres’ and the ‘whens’, it is not always possible to reach a view on whether potential opportunities to gather data (e.g. by locating more measurement stations, such as microseismics) are being missed.
5. There is no discussion of how monitoring data will be analysed, modelled, integrated and used. A brief description (Section 10) considers publication, project management and response to out-of-scale data. In all of these areas the report is not adequate for regulation purposes.
6. Appendices 1 to 4 define Action Levels. They are not discussed or justified and consequently cannot be evaluated properly. Only Appendix 4 mentions ‘justification’. This is a significant omission, as STUK cannot regulate action levels without knowing why Posiva has set them at the levels chosen.
7. Almost nothing is said about safety and the improvement of safety. An operating experience feedback programme, from the monitoring results to the internal SUKO and ORT leading group, is missing.

Conclusion: STUK needs to ask Posiva for a better developed and integrated Monitoring Programme and monitoring data management scheme. Posiva will need to provide a more detailed description of the management of monitoring information. The monitoring programme needs to be better established before construction goes any further.

4.6.2 Rock mechanics monitoring

Posiva has performed rock mechanics monitoring in ONKALO consisting of continuous microseismic monitoring, measurement of relative block movement of the bedrock by GPS, electronic distance recording and precise levelling technique and extensometer and convergence measurements of excavation rooms and tunnels. The rock mechanics monitoring schedule for 2012 to 2018 contains about 5 additional processes that will be recorded, such as reactivation of existing deformation zones, rock creep, spalling, thermal evolution and stress redistribution, where integrated stress analysis is applied. Recent modelling has shown that microseismic activity will develop during the thermal

phase. Hence, microseismic monitoring will become an important issue in constructing the repository. This extended monitoring programme mentioned above is targeted to important parameters for the safety and constructability of the repository. The suggested frequency of measurements (Table 4-2) and natural fluctuation and action limits as stated in Appendix 1 are adequate at this stage of the planning. The suggested programme can certainly be transferred to the construction period after year 2018.

Conclusion: The number of monitoring actions is compatible and extensive enough but the target for the action needs to be mentioned. Recent studies by SSM have shown that the thermal load from the spent fuel is likely to generate low and intermediate earthquakes, so temperature measurements and microseismic monitoring has to be performed well in advance of loading the waste in the first repository panel. In addition Posiva has to perform modelling campaigns to find the optimum location of measuring points to record reactivation of existing deformation zones and fractures, and possible areas for recording creep and stress redistribution.

4.6.3 Hydrogeological monitoring

There has been a comprehensive programme (OSD, Section 9.3) to monitor the hydrogeological effects of ONKALO excavation since 2004 and compare it to model predictions of the impact on heads. The predictive model uses an EPM approach, with property values upscaled from the Hydro-DFN. Salinity distribution was included in the model. This Section is unsatisfactory because it makes inflow rate predictions for the sparsely fractured rock up to end-2010, which could have been checked and included in the draft report issued in 2013 to strengthen the conclusions.

The monitoring/modelling results for perturbations to groundwater salinity are presented on OSD, p.821. They show that the excavations promote groundwater mixing and cause progressive dilution of waters to increasingly greater depths, as pumping proceeds. At the same time, saline waters begin to rise below the excavations, being greatest at 435 m depth and in HZ20B. The most pronounced effects of dilution and upconing seen in the models are in volumes of rock with no boreholes, so they could not be verified. Nevertheless, the impacts are slight enough for Posiva to conclude that the salinity field

has not been significantly disturbed and can be considered to be stagnant. This must be monitored as future excavation progresses.

Conclusion: The hydrogeological monitoring/modelling programme appears well conceived, robust and informative, and should continue throughout repository construction and operation. Posiva suggest improvements (e.g. OSD, p.811), which they should be encouraged to implement.

4.6.4 Monitoring foreign materials

Foreign materials monitoring is carried out by rules and checks on what enters the repository, then mainly by monitoring the chemistry of wastewater in the facility. The 2011 'Foreign Materials' report (WR 2012-46) gives a clear description of the requirements for controlling foreign materials and which materials are permitted and forbidden for use in ONKALO and the repository. The rationale and link to long-term performance is made (e.g. not using organic chemicals that could adversely complex with radionuclides and increase their solubility or mobility). The 'Material Handbook' referred to (Section 2.2) is said to provide all the information on this, although it appears to be a set of documents and data sheets. In 2011, three internal audits were carried out, which it is said led to the removal of some materials from the facility. It is not clear whether the procedures are adequate to fulfil requirements. So far, collection, compilation and reporting have been performed by external consultants and therefore have not been properly integrated into Posiva's process scheme.

Conclusion: From the information available the procedures and the data being produced appear to be appropriate for controlling the use of and the amounts of foreign materials, although

the frequency and rigour cannot be assessed based on the information presented. However, this is an area that is clearly open to inspection and audit by STUK, both now and in the future.

4.6.5 Monitoring the EBS

The EBS monitoring programme presented in 2012-01 is brief and lacks detail, except for the buffer monitoring work in niche TU1. The preliminary character of the EBS monitoring programme also means that the interaction between the bedrock and the technical barriers are lagging behind. In the section related to plugs and seals (p.145), Posiva states: "*The engineered barrier monitoring systems output (data files, database and data transfer) must be totally compatible and coordinated together with all other monitoring tasks, including present and future needs.*" The proper coordination of the monitoring programmes for the individual disciplines and between the disciplines is a task for the existing Site Research Planning and Coordination Group (SUKO) within Posiva's management organisation.

A particular vagueness concerns the use of a 'pilot repository' in which total EBS monitoring could be carried out (including canister). This is presented so weakly that it is not clear whether it is a plan or merely a possibility. If Posiva intends to move from 'demo tunnel' work to a pilot repository, this will occur over the construction period.

Conclusion: The EBS monitoring, continued demo tunnel work and the hinted pilot repository are mentioned but not properly covered in the Posiva CLA documentation. These possibilities raise many questions related to instrumentation, response to observations, whether or not there is an actual need to monitor the EBS and, if so, how etc. More information is required from Posiva.