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ABSTRACT:

To verify the suitability of the plug demonstration tunnel locations in Underground rock characterisation facility (URCF) ONKALO and to select the location for the plug within the tunnels, the Rock Suitability Classification (RSC) -system developed by Posiva Oy has been applied. A short description of the RSC-system is given in Chapter 2 of this memorandum, with the host rock classification criteria pertaining to the plug summed in Chapter 3. The two suitability classifications carried out to determine a suitable location for the POPLU plug are presented in Chapters 4 and 5 with short concluding remarks made in Chapter 6.

RESPONSIBLE:

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REVIEW/OTHER COMMENTS:

The memorandum is reviewed by POPLU Experiment leader and POPLU project manager and approved by Posiva site manager according to the Posiva approval rules for documents. The DOPAS coordinator has reviewed the memorandum and approved for submission when document has been published internally in Posiva electronic archive system.

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Memo

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URCF RSC work memorandum (POPLU)

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1 Introduction

Posiva Oy will demonstrate the full-scale construction and performance of a deposition tunnel end plug during 2014. The plug, called POPLU, will be demonstrated in the ONKALO underground rock characterisation facility in Olkiluoto, Finland. The plug demonstration is carried out to fulfil the YJH-2012 (Posiva 2012a) plans to:

- Construct a full-scale deposition tunnel end plug (demonstration, workmanship, quality control)
- Develop detailed structural design, including concrete recipe development for plug
- Develop tunnel plug location excavation, with attention to the wire-sawing technique
- Produce a quality manual for quality control practices and risk mitigation for plug
- Develop instrumentation and performance monitoring techniques (mechanical load transfer, concrete shrinkage, water tightness), including models
- Observe and solve practical challenges prior to construction and implementation, related to occupational safety, documentation, quality assurance, practical work procedures etc.

The length of the plug is 6 meters, and it should be located in intact rock to fulfil its requirements (see Chapter 2.4 in Haaramo & Lehtola, 2007), set for ensuring water tightness around the plug and for preventing leakages from the surrounding rock, in order to protect the plug from the dissolving effect of ground water and to prevent the formation and transport of cement leachates in bedrock fractures.

The plug construction will be carried out in the ONKALO demonstration area, at -420 metres, where two plug demonstration tunnels are currently under construction, northeast of the current demonstration tunnels 1 and 2 (Figure 1). The excavation will be completed by the end of 2013. One tunnel, demonstration tunnel 4, will contain the plug and the second tunnel, demonstration tunnel 3 will contain the monitoring equipment. The tunnel lengths are approximately 21 and 25 metres from the centre line of the central tunnel, respectively. The dimensions of the tunnels are 4.35 metres height by 3.5 metres wide, with an area of approximately 14.46 m^2, similar to the demonstration tunnels 1 and 2 constructed with deposition tunnel specifications (Posiva 2012b, Mellanen et al. 2012).

To verify the suitability of the plug demonstration tunnel locations and to select the location for the plug within the tunnels, the Rock Suitability Classification (RSC) -system developed by Posiva Oy has been applied. A short description of the RSC-system is given in Chapter 2 of this memorandum, with the host rock classification criteria pertaining to the plug summed in Chapter 3. The two suitability classifications carried out to determine a suitable location for the POPLU plug are presented in Chapters 4 and 5 with short concluding remarks made in Chapter 6.

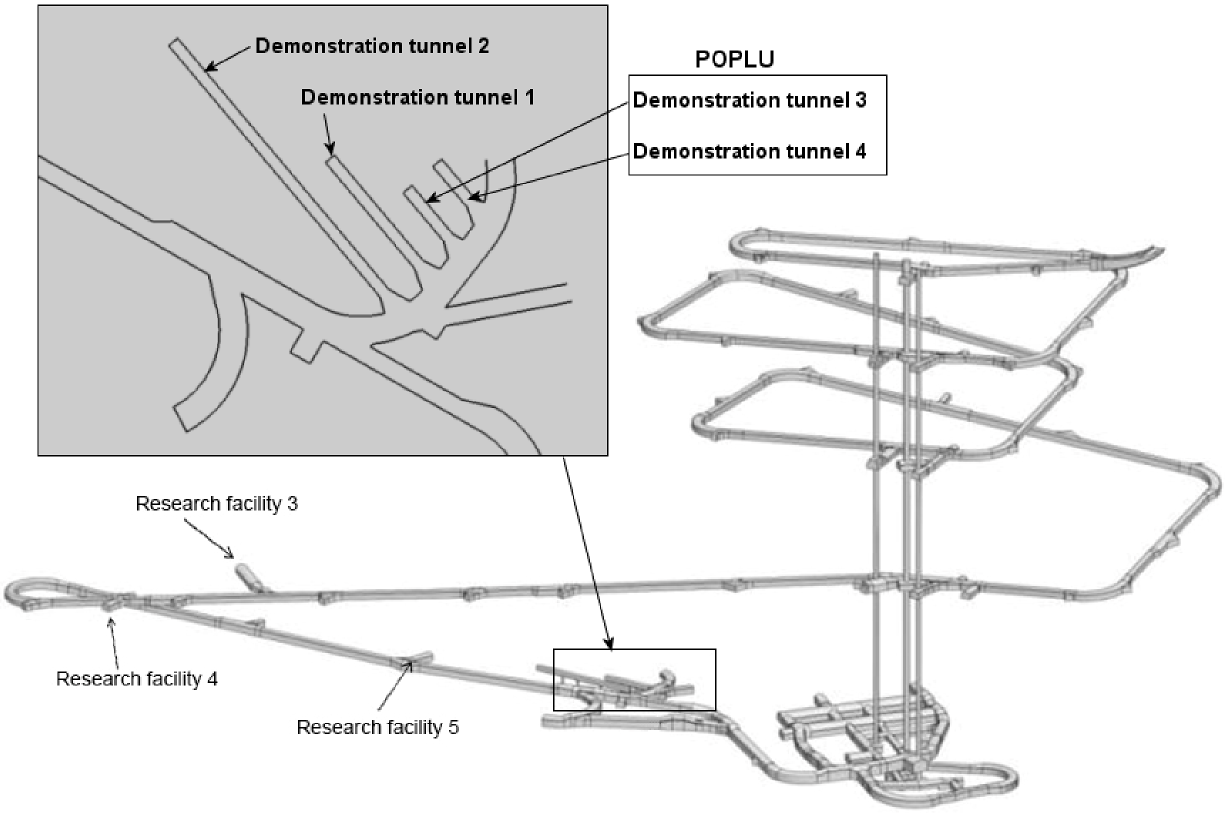

***Figure 1**. POPLU tunnel locations in ONKALO.*

2 Rock Suitability Classification (RSC)

Posiva's RSC-system comprises a stepwise procedure for identifying bedrock volumes suitable for hosting the various parts of the repository - such as repository panels, deposition tunnels, tunnel plugs and deposition holes - based on a series of suitability assessments carried out as construction proceeds and increasingly detailed data on the properties of the bedrock is collected through various investigations. The suitability of host rock volumes is evaluated using criteria defined for the different parts of the repository; for example, to be classified as suitable for hosting a deposition hole, a volume of rock has to fulfil every criterion (concerning host rock properties) set for a deposition hole. The criteria are based on requirements stemming from aspects of long-term safety, related to the functioning of the bedrock as a natural barrier as well as to ensuring proper conditions for the functioning of the EBS-system. The criteria pertaining to all underground rooms, deposition tunnels or deposition holes are described in McEwen et al. (2012); for criteria pertaining to deposition tunnel plugs, see Chapter 3 of this memorandum.

An overview of the implementation of the RSC-system and its relation to investigations, modelling, design and construction is given in Figure 2 and in the following paragraphs; a detailed description of the RSC-system and its implementation is found in McEwen et al. (2012).

The implementation of the RSC-system can be divided into four stages, which coincide with the stages of repository design and construction, proceeding from the design of the whole repository to the more detailed design and construction of panels, tunnels and, finally, deposition holes (Figure 2).

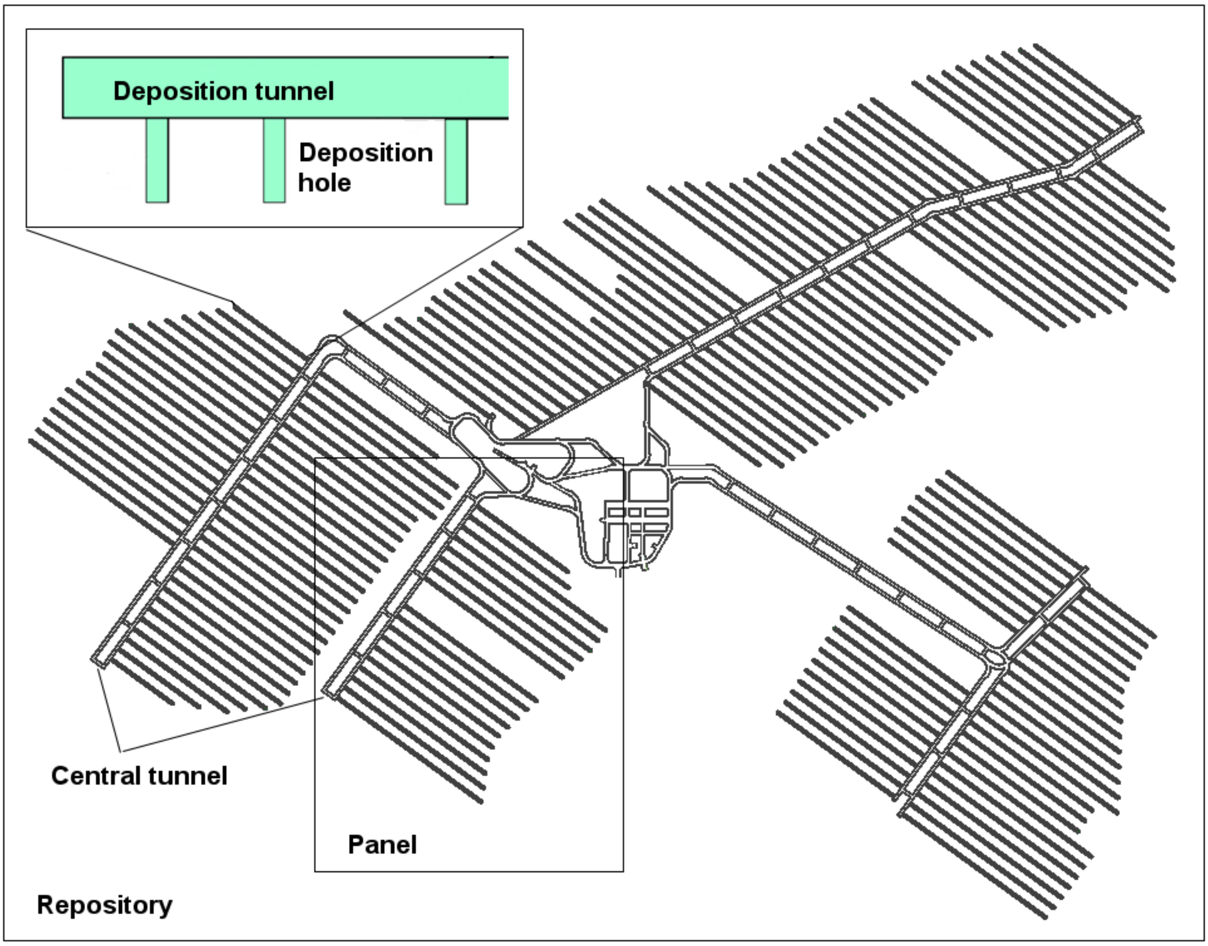

Figure 2. *The parts of a repository. The repository comprises several deposition panels composed of multiple depositions tunnels, which host the deposition holes. Each panel includes two central tunnels providing access to the deposition tunnels.*

A general outline of the stages of the repository construction and the flow of investigation, modelling, RSC, design and construction activities performed during them is presented in Figure 3. It should be noted that this is, of course, a somewhat artificial division, and that the starting point for each stage could be defined in several different ways. Therefore, a decision has been made to consider the commencement of pilot hole[1] drilling as the starting point for each consecutive stage.

[1] *Pilot holes* are cored drillholes drilled inside the profile of a planned tunnel (or deposition hole) prior to commencement of excavation. The purpose of pilot holes is to produce local information on the properties of the rock volume for example for the detailed modelling and further the rock suitability classification, as well as for confirming the quality of the rock mass for construction purposes.

The main function taking place at the ***repository stage*** is the layout design of the repository within the fixed host rock volume, including the overall design of the repository panels, as well as the access routes and other subsurface rooms needed for the operation of the repository. With respect to the RSC-system, the repository stage comprises two parts: classification of the known features of the Olkiluoto bedrock at the scale of the entire repository, and a preliminary classification of the rock volumes planned to host single repository panels (Figure 3). The first part of the classification at the repository stage aims at defining the rock volumes to be used for repository layout planning. Consequently, the so-called layout-determining features (LDF)[2] and their respect volumes[3] that are to be avoided when locating deposition tunnels and deposition holes are determined for the use of repository layout design. The LDFs are determined on the basis of the geological and hydrogeological structure models describing the Olkiluoto site (for the latest published versions, see Aaltonen et al. 2010 and Vaittinen et al. 2009). In the second part, a preliminary suitability classification of the rock volume planned to host a single repository panel is carried out to assess the locations planned for the two parallel central tunnels of the panel. There are no criteria specific to central tunnels, but the criteria set for deposition tunnels and holes, for example, are considered to enable optimal use of the rock volume designated for the panel. This classification, as well as the following ones, is based on a detailed-scale model of the bedrock features in the panel area, constructed on the basis of preliminary investigations of the host rock volume.

The ***panel stage*** comprises the construction of the central tunnels of a repository panel and the detailed design of the panel layout (Figure 3). At the panel stage, the aim of the RSC-system is, firstly, to verify the overall suitability of the selected rock volume for hosting a repository panel and to verify the optimal positioning of the central tunnels. This suitability assessment is carried out on the basis of the detailed-scale model updated with data from investigations of pilot holes drilled for the planned locations of the central tunnels. Secondly, the RSC-system aims at determining suitable areas for the deposition tunnels within the panel and at assessing the degree of utilisation[4] of the panel area for the detailed design of the panel layout. This second assessment is performed after excavation of the central tunnels and investigations therein.

The ***tunnel stage*** comprises the construction of deposition tunnels within a repository panel and culminates in selecting locations for deposition holes within the tunnels (Figure 3). The first suitability classification is again carried out after the drilling of pilot holes, one within each planned deposition tunnel profile, with the aim of verifying, the overall suitability of the selected tunnel locations, i.e. verifying the fulfilment of criteria pertaining to deposition tunnels, and producing a preliminary estimate on tunnel sections suitable for hosting the plug and deposition holes. An estimate of the degree of utilisation for each tunnel is also produced for making decisions on proceeding with tunnel excavation or, if necessary, updating the tunnel layout plans. The second

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[2] The term *layout determining feature* is used to describe a major geological or hydrogeological feature in the bedrock which may affect the long-term safety of the repository, and should therefore be avoided by deposition tunnels and deposition holes. For an overview on the LDFs, see Chapter 5.3 in McEwen et al. 2012; for a more detailed description, see Pere et al. 2012.

[3] The minimum distance to be maintained from the margins of a fault zone to the deposition holes, which is, at a minimum, equal to the width of the zone, is referred to as a *respect distance*. The *respect volume* is the 3D equivalent of the respect distance. For further information, see Chapter 5.3 in McEwen et al. 2012 as well as Pere et al., 2012.

[4] The *degree of utilisation* is determined by the number of suitable deposition holes with respect to the theoretical maximum number and is related to economy and efficiency of use of the rock volume.

classification is carried out after the excavation of the tunnels and the subsequent tunnel investigations, when the location of the plug is finalised and the deposition hole-specific criteria are applied in order to assess the suitability of the rock volume below the tunnels and to divide the tunnels into sections that are possibly suitable or possibly not suitable for locating deposition holes.

The ***hole stage*** comprises the construction of deposition holes within a deposition tunnel and culminates in the final acceptance (or rejection) of the constructed holes for deposition use (Figure 3). Hence, the aim of the RSC activities carried out at this stage is to verify, firstly, the suitability of the planned deposition hole locations and, secondly, to evaluate which of the constructed holes fulfil the criteria and can be accepted for deposition. The first suitability classification of the hole stage takes place after a vertical pilot hole has been drilled for each selected hole location and pilot hole investigations have taken place. The second, and final, classification for the acceptance (or rejection) of each deposition hole is carried out after investigations in the constructed holes.

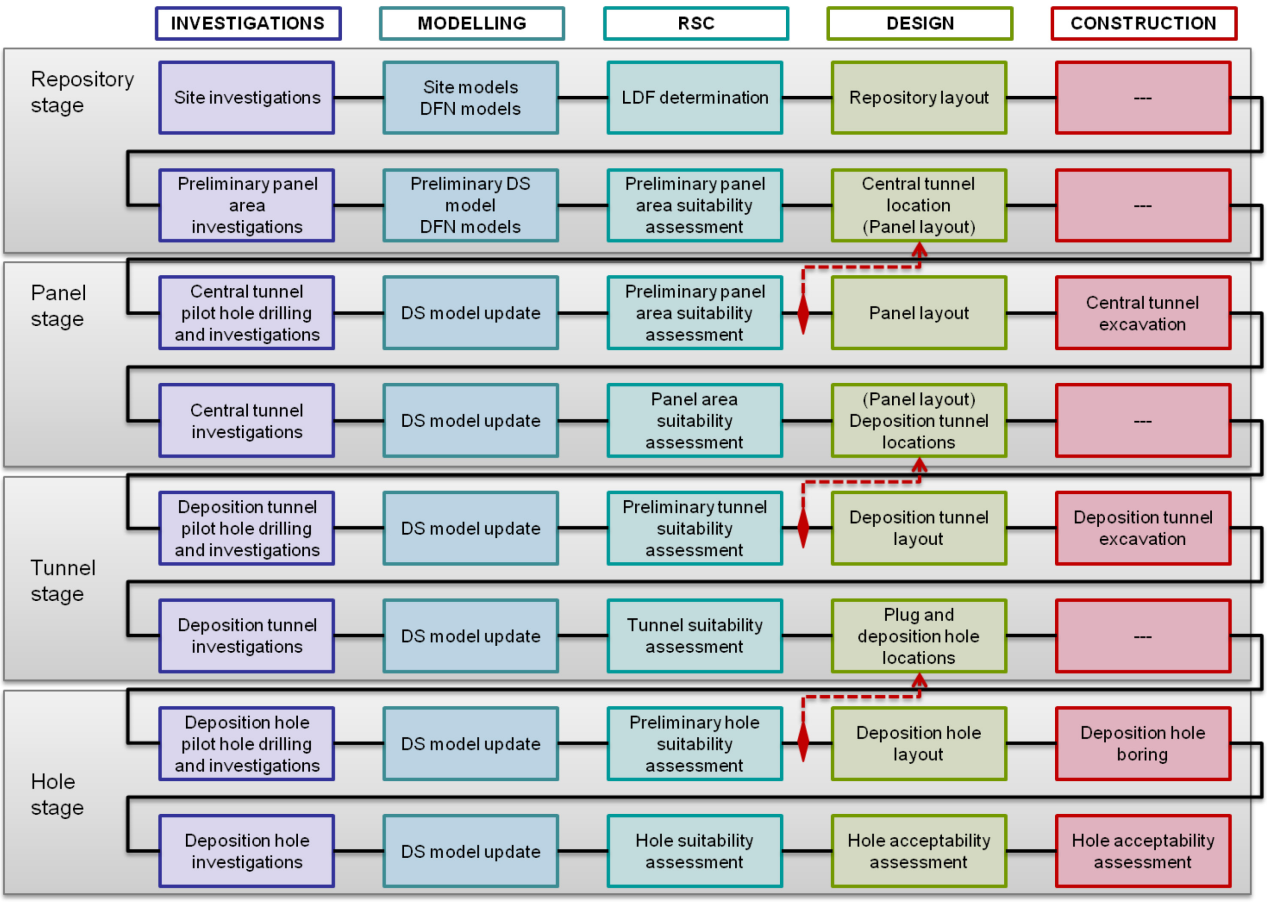

Figure 3*. A general outline of the repository construction process and the flow of investigation, modelling, RSC process, design and construction activities. The red diamonds represent main decision making points preceding the construction of new repository rooms, and the red arrows indicate return to the previous design step (the selection of a new location for a tunnel or hole) in the case of a negative decision. DFN (Discrete Fracture Network), LDF (Layout Determining Feature), DS (Detailed-Scale).*

3 Host rock criteria for the plug location

Currently, three host rock-pertaining criteria have been defined for the plug location, aiming at promoting fulfilment of the requirements set for the plug (see Introduction; Chapter 2.4 in Haaramo & Lehtola, 2007) and at ensuring good conditions for the construction of the slot (Table 1). The criteria specifically consider a wedge-plug design, and have formed the basis of the rock suitability assessments described in the following chapters. However, they are still somewhat preliminary in nature, and might be updated and complemented based on the experiences gained from POPLU and other ongoing tests. Any possible future changes in the plug design would, of course, also raise a need for re-evaluation of the criteria.

Table 1. *Criteria pertaining to rock volume hosting a plug location, as currently found in Posiva's requirement management system VAHA (Posiva 2012c).*

L5-ROC-59	The plug location shall not be intersected by the respect volumes[5] of hydrogeological zones.
L5-ROC-60	The plug location shall not be intersected by the respect volumes of brittle deformation zones.
L5-ROC-80	Hydraulically conductive fractures shall not intersect the entire length of the plug.

4 Suitability classification 1 - Preliminary assessment of the suitability of the demonstration tunnels 3 and 4

4.1 Background

The area immediately northeast of the existing demonstration tunnels 1 and 2 (see Figure 1) was considered a possible location for the POPLU demonstration on the basis of investigations and detailed-scale modelling of bedrock structures carried out earlier, during the construction of the two demonstration tunnels (see Chapter 7 in McEwen et al., 2012).

To further verify the suitability of the selected location, a pilot hole was drilled within the profile of each planned tunnel at the end of November, 2012 (pilot holes ONK-PH26 and ONK-PH27, see Figure 4), and Posiva's standard set of drillhole investigations was carried out in the holes. The standard set of investigations comprises geological logging of the drill core and sampling for rock mechanical tests, optical and acoustic drillhole imaging, as well as a set of geophysical surveys and hydraulic measurements (see for example Aalto et al. 2011 for a detailed description). During the geological logging, several parameters describing lithology, foliation, fracturing, deformation zones and weathering are recorded, and the resulting data are then utilised in the preliminary interpretation of data from the geophysical surveys (for example drillhole radar data) and the hydraulic measurements (for example flow log data). Once all data from a specific hole are ready, a so-called "single hole interpretation" is carried out, where integrated interpretation of the data from the various disciplines is performed with the objective of identifying and describing the general characteristics of major rock units and possible deformation zone intersections in the drillhole[6]. In

[5] See Footnote 3.
[6] An example of the single hole interpretation can be seen for example in Aalto et al, 2011.

addition, potentially significant (large) single fractures are identified from among all natural fractures present in the drillcore based on their geological, geophysical and hydraulic properties (see Joutsen, 2012; Heikkinen et al., 2011; Chapter 7 in McEwen et al., 2012). The data from the pilot hole investigations is stored in Posiva's databases, and is later published, together with the results of the single hole interpretation, as a Posiva Working Report (see Aalto et al., 2011 for an example)[7].

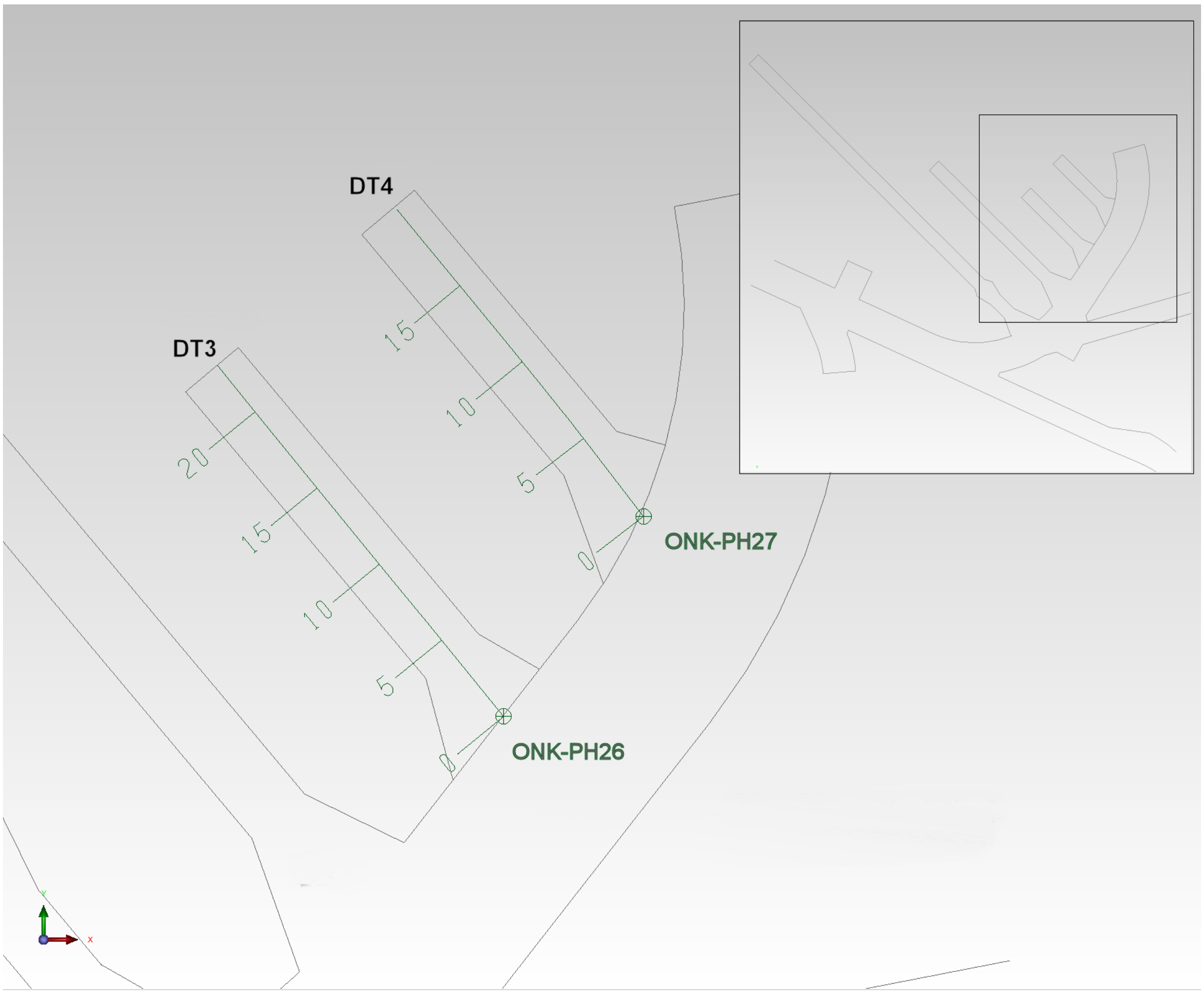

Figure 4. *The planned demonstration tunnels 3 and 4 (DT3 and DT4, respectively), and the locations of pilot holes ONK-PH26 and ONK-PH27. The numbers denote the length of the pilot holes in metres.*

Based on the data obtained from the pilot hole investigations, the detailed-scale model of the demonstration area was updated (see Section 4.2), and in February 2013, the first assessment evaluating the suitability of the planned tunnels for a plug location was carried out (Section 4.3).

[7] The reports published by Posiva are available for free download in PDF format from the Databank accessible through Posiva's web page: http://www.posiva.fi/en/databank

4.2 Significant bedrock structures in the vicinity of the demonstration tunnels 3 and 4

4.2.1 Summary of the RSC-relevant pilot hole data

The data from the pilot holes ONK-PH26 and ONK-PH27 is not yet available as Working Reports, so a short summary of the RSC-relevant data used to update the detailed-scale model and to carry out the suitability classification is given here.

During the geological logging of the drill cores, a total of 75 natural fractures were observed and described from the pilot hole ONK-PH26 (DT3) and 21 from the pilot hole ONK-PH27 (DT4) (Appendix 1). A brittle deformation zone intersection was recorded from the pilot hole ONK-PH26 during the geological logging at the depth of 6.85-8.32 metres (Table 2); no zone intersections were observed in the pilot hole ONK-PH27.

Table 2. *The brittle deformation zone intersection logged from the pilot hole ONK-PH26 drillcore.*

Hole Id	Metres from	Metres to	Intersection Id	Intersection type	Description
ONK-PH26	6.85	8.32	ONK_PH26_BJI_685-832	Brittle joint intersection	A fractured section with a ~7 cm section of crushed core or core loss. No well-developed core, just broken sections and a 1 cm thick clay filling in one fracture. Possibly the fault zone OL-BFZ297 identified in the demonstration tunnels. The rock surrounding the center part of the zone is moderately altered and fractured, the fractured area extends from 6.85 to 8.32 m but it is possible that the fractures slightly ahead and behind from the zone also belong to the same structure. Slight alteration extends further. Based on expert judgement, at least one very probable large fracture exists within the section.

Flow logging of the pilot holes ONK-PH26 and ONK-PH27 was carried out using the PFL DIFF probe (Posiva Flow Log, Difference Flow method) developed by Posiva, which - unlike conventional drillhole flowmeters that measure the total cumulative flow rate along a drillhole - measures the flow rate into or out of defined drillhole sections. This enables improved detection of small incremental changes of flow along the drillhole (see for example Chapter 5.2 in Aalto et al. 2011 for further information on the PFL).

In the pilot hole ONK-PH26, the measured fracture flow directions were negative, out of the hole into the bedrock, indicating a possible connection between the conductive fractures and open tunnel space. Typically, the flow directions in ONKALO are positive, out of the bedrock into the hole. The total measured outflow from ONK-PH26 was 10.3 ml/min, no flowing fractures were found in the pilot hole ONK-PH27 (Table 3). The tabulated results from the flow logging of the pilot hole ONK-PH26 are shown in Table 4.

Table 3. *Outflow measurements and the measured sum of flows with the PFL DIFF probe, drillholes ONK-PH26 and ONK-PH27.*

Drillhole	PFL DIFF Measurement date	The measured sum of flows with the PFL DIFF probe	Drillhole outflow, measured during flow loggings, 2012-12-04 (PH26) and 2012-12-11 (PH27)
ONK-PH26	4.12.2012	-10.3 mL/min **	0 mL/min, *
ONK-PH27	11.12.2012	0 mL/min	0 mL/min ***
* ONK-PH26 drillhole water was leaking in to the bedrock during the flow measurement. The drillhole was filled during the measurement. Accuracy of the drillhole water loss into the bedrock could not be measurec			
** ONK-PH26 flow direction in to the bedrock (fracture area about 6.6 m - 8.2 m).			
*** ONK-PH27 No measurable outflow detected.			

Table 4. *Fractures detected with the PFL DIFF probe in ONK-PH26. T = transmissivity.*

Drillhole: ONK-PH26						
Elevation of the top of the hole (masl):	-420.04					
Elevation at the bottom of the tunnel (masl):	-458.812					
Inclination (degrees):	-1.8					
Depth of fracture along the drillhole (m)	**Flow (mL/h)**	**Fracture elevation (masl)**	**Drawdown (m)**	**T (m2/s)**	**Hydraulic aperture of fracture (mm)**	**Comments**
6.6	-10	-420.2	-38.772	7.09E-11	0.005	*, **
7.8	-85	-420.3	-38.772	6.02E-10	0.010	*, **
8.2	-532	-420.3	-38.772	3.77E-09	0.019	**
* Uncertain fracture. The flow rate is less than 30 mL/h or the flow anomalies are overlapping or they are unclear because of nois						
** Flow direction in to the bedrock.						

During the single hole interpretation, the fractures detected with the flow log probe (Table 4) were correlated to fractures observed during the geological logging to obtain a more accurate location as well as orientation for them. Also, two potentially large fractures were identified based on fracture properties, both in the pilot hole ONK-PH26 (see Appendix 1). In addition, the width of the core and influence zone[8] of the brittle deformation zone observed in the pilot hole ONK-PH26 (see Table 2) was re-determined in more detail taking into account also the results from the flow log and

[8] A widely accepted conceptual model for brittle fault zone architecture includes a fault *core*, representing the localisation of strain during slip events, and an associated *damage zone* mechanically related to the growth of the fault, surrounded by relatively undeformed host rock. In Posiva, the term *influence zone* is used instead of the damage zone, as additional features, such as higher hydraulic conductivity and elevated likelihood of exhibiting alteration, are included. For further explanation, see Section 5.3.2 in McEwen et al., 2012. For the purposes of suitability classification, the *respect volumes* in criteria L5-ROC-59 and L5-ROC-60 are considered equal to the influence zones.

geophysical investigations. The influence zone was determined to start at the depth of 6.29 metres and end at 9.22 metres with the core located at 7.76 - 8.04 metres.

4.2.2 Detailed-scale modelling

The detailed-scale model of the demonstration area was updated on the basis of the pilot hole data and the single hole interpretation. The natural fractures logged from the drillcores were modelled as disks using the observed depths and orientations, except the fractures within the interpreted brittle deformation zone intersection, which was modelled as a solid using the orientation of the main fracture within the zone core (fracture at the depth of 8.04 metres, see Appendix 1) (Figure 5).

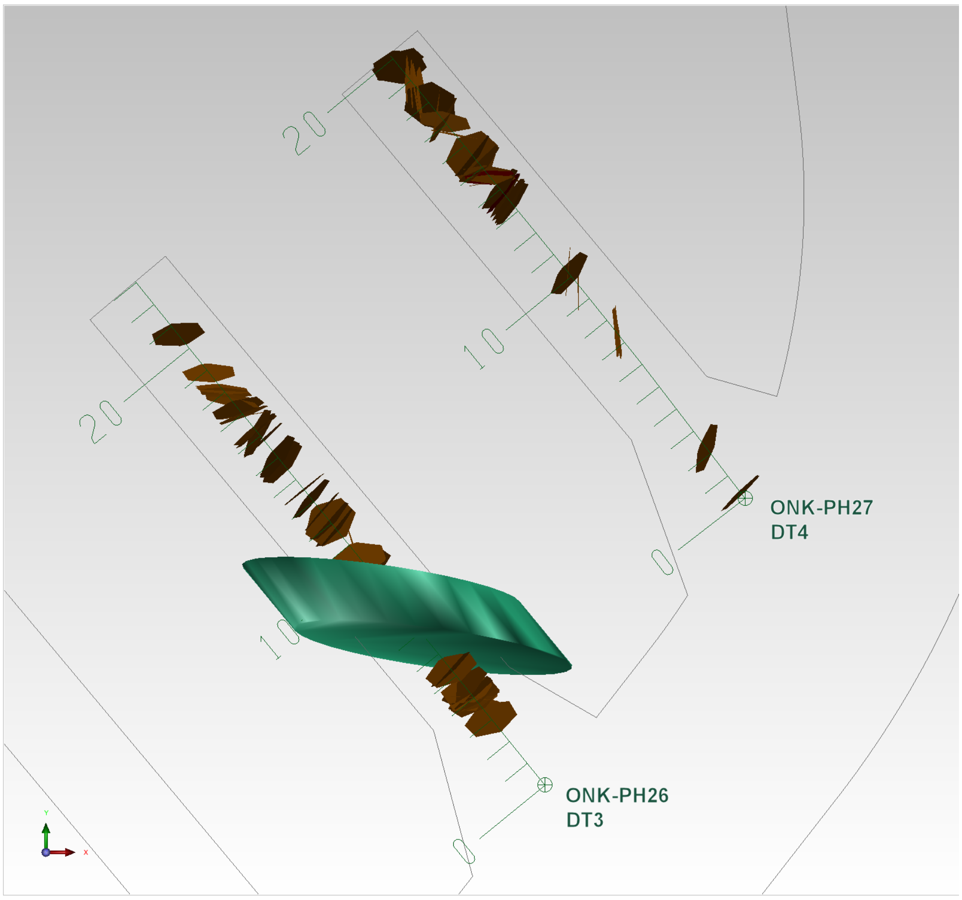

Figure 5. *Structures observed in the pilot holes; the brown disks depict single natural fractures, the green solid is the interpreted brittle deformation zone intersection.*

The brittle deformation zone intersection observed in the pilot hole ONK-PH26 could be correlated to a known brittle fault zone[9], OL-BFZ297, which was updated to fit the new observation. The zone intersects the planned demonstration tunnel 3 at the approximate tunnel chainage 8 - 16 metres

[9] If a *brittle deformation zone* (as in the criterion L5-ROC-60, Table 1) displays evidence of having experienced slip during some point in its history, it is called a *brittle fault zone*. Thus, brittle fault zones form a subcategory of brittle deformation zones.

(Figure 6). The zone is hydraulically conductive with inflows measured from nearby intersections ranging from 4.8 ml/min (demonstration tunnel 1) to 115 ml/min (a probe hole bored prior to the excavation of the central tunnel of the demonstration area). In the pilot hole ONK-PH26, the flow direction was out of the hole into the bedrock, with a measured outflow of 10.3 ml/min.

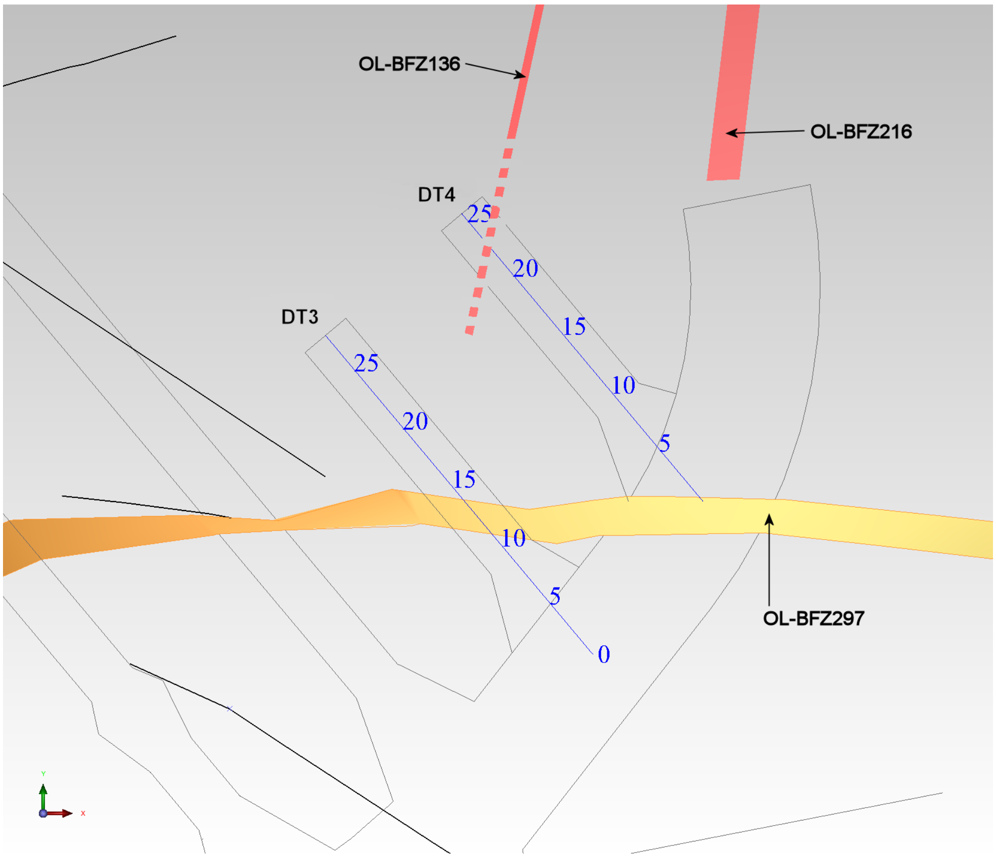

Figure 6. *Significant bedrock structures in the vicinity of the demonstration tunnels 3 and 4 (DT3 and DT4, respectively), horizontal cross-section at tunnel floor level. Red = a brittle fault zone based on the geological model of the Olkiluoto site v. 2.0 (Aaltonen et al., 2010); yellow = a brittle fault zone based on the detailed-scale model, including the zone core and influence zone; black = a large fracture. The centre lines and chainages of the tunnels are shown in blue.*

The geological model of the Olkiluoto site v. 2.0 (Aaltonen et al., 2010) suggests the brittle fault zone OL-BFZ136 to intersect the planned demonstration tunnel 4 at tunnel chainage 23 - 24 m (Figure 6). However, no indications of the expected intersection were observed in the plot hole ONK-PH27, and the zone most likely does not extend as far south as predicted by the site-scale model.

The interpreted possibly large fractures as well as all hydraulically conductive fractures (observed in the pilot hole ONK-PH26) are related to the brittle fault zone OL-BFZ297, and lie within the structure's modelled influence zone (see Appendix 1). Thus, they were not modelled as separate features.

4.3 Suitability of the demonstration tunnels 3 and 4

For carrying out the suitability assessment, the plug slot was modelled in 3D. The created solid was then used, together with the solids representing the relevant bedrock structures from the detailed-scale model, to define the tunnel sections where the criteria set for the plug location (see Table 1) would be fulfilled. The suitability assessment only considered those parts of the demonstration tunnels where the tunnel profile would allow for the construction of the plug slot, ie. the funnel-shaped tunnel profile transition zones were omitted.

Chainage 9.00 - 16.20 m of the demonstration tunnel 3 was classified unsuitable for a plug, due to the water conductive brittle fault zone OL-BFZ297 and to criteria L5-ROC-59 and L5-ROC-60 (Figure 7). All the criteria were fulfilled in the demonstration tunnel 3 chainage 16.20 - 27.30 m, where no zones or water conductive fractures were expected on the basis of the detailed-scale model and the pilot hole data, and the section was classified suitable for hosting a plug.

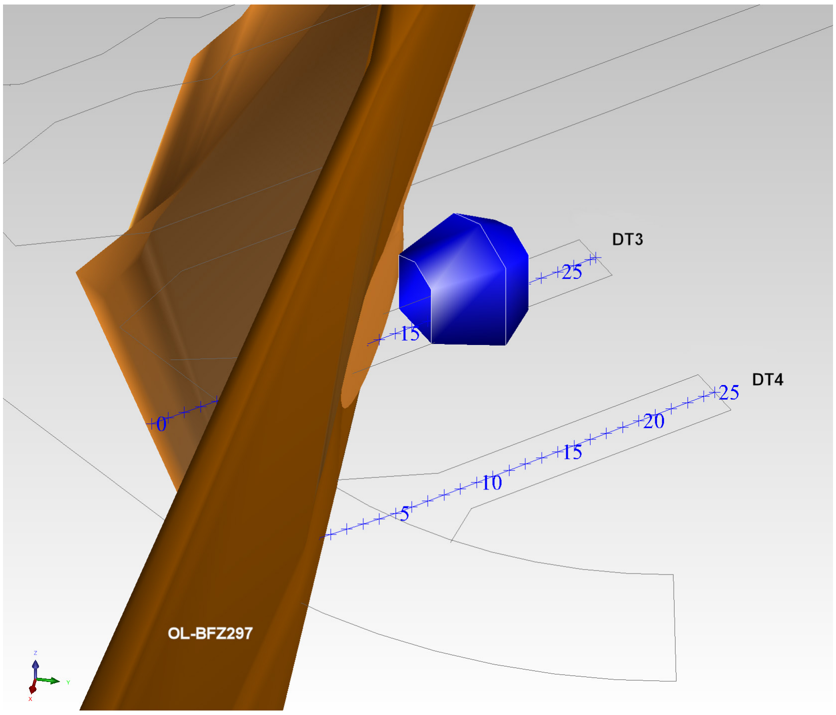

Figure 7. *The brittle fault zone OL-BFZ297 (brown) intersecting the demonstration tunnel 3 (DT3). The solid representing the plug slot (blue) is placed in the first suitable location in the tunnel (starting at chainage 16.20 m). The centre lines and chainages of the tunnels are shown in blue. View to Southeast.*

If the brittle deformation zone OL-BFZ136 would, contrary to the pilot hole data, intersect the planned demonstration tunnel 4, the chainage 17.20 - 25.00 m would be rendered unsuitable (Figure 8). However, the probability of such a situation was considered to be low, and as no other relevant structures were to be expected in the tunnel, the entire length of the demonstration tunnel 4 was classified suitable for hosting a plug.

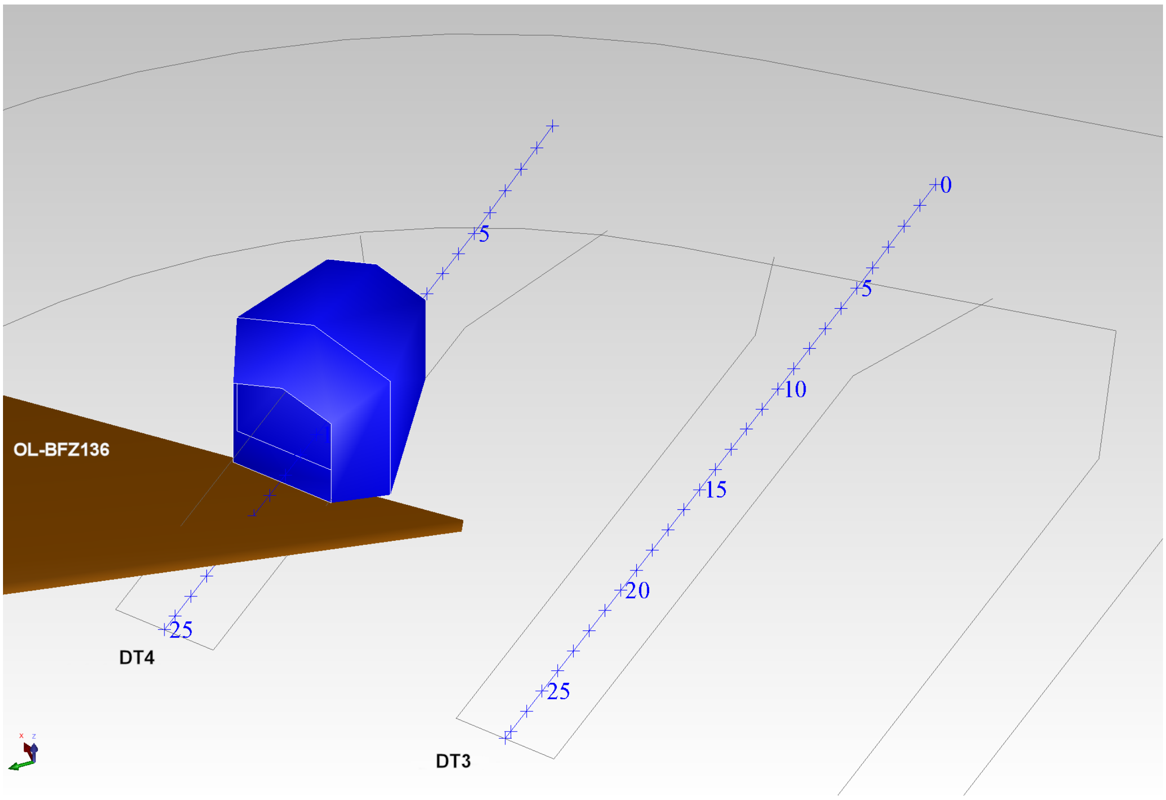

Figure 8. *The brittle fault zone OL-BFZ136 (brown) according to the geological model of the Olkiluoto site v 2.0 (Aaltonen et al., 2010) and the farthest suitable location for the plug slot (blue) in the demonstration tunnel 4 (DT4), ending at chainage 17.20 m. However, no sign of the zone was observed in the pilot hole ONK-PH27, and the likelihood of the intersection is considered low. The centre lines and chainages of the tunnels are shown in blue. View to Southeast.*

A summary of the suitability of the demonstration tunnels 3 and 4 for hosting a plug is shown in Figure 9.

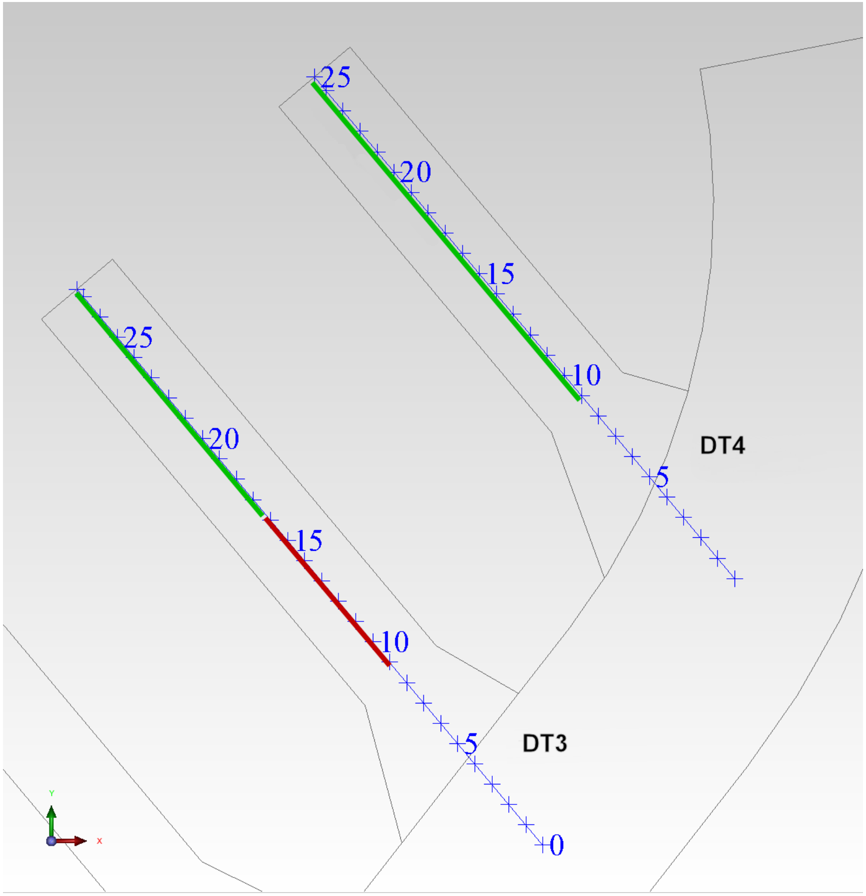

Figure 9. *Suitability of the demonstration tunnels 3 and 4 (DT3 and DT4, respectively) for hosting a plug. Red = unsuitable, green = suitable. The centre lines and chainages of the tunnels are shown in blue.*

4.4 Suggestion for the plug location

The criteria set for bedrock hosting a plug were determined to be fulfilled in the demonstration tunnel 3 chainage 16.20 - 27.30 m and in the entire length of the demonstration tunnel 4. Based on the pilot hole data, the first eighteen metres of the demonstration tunnel 4 were deemed to be less fractured than the rest of the tunnels (see Figure 5). It was therefore suggested that chainage 11 - 17 m would preliminarily be chosen for the location of the POPLU plug, as the tunnel section in question would likely be the best in rock quality (Figure 10). It was also noted that the section would be suitable for the plug even in the unlikely case that the zone OL-BFZ136 would turn out to intersect the tunnel (see Figure 8). Based on the pilot hole, the suggested section was observed to be mainly composed of the veined gneiss typical of the Olkiluoto area.

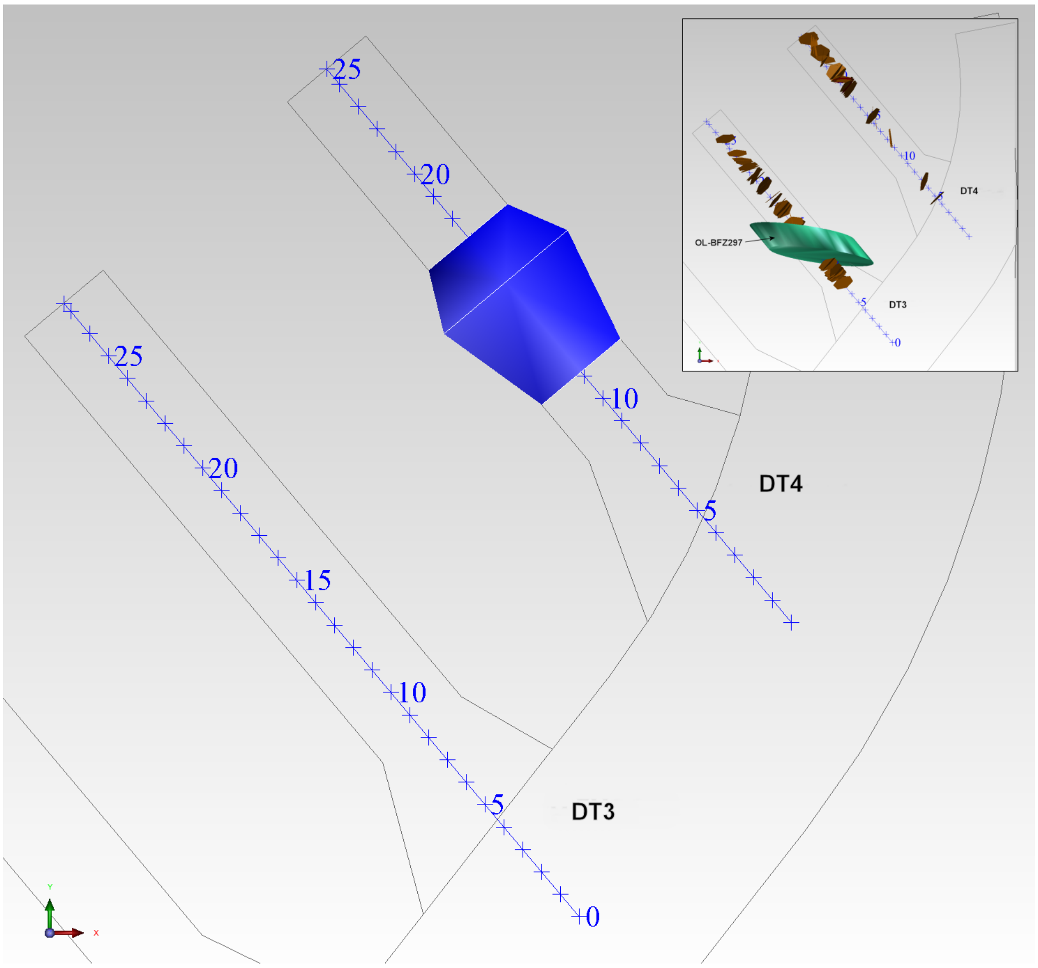

Figure 10. *The suggested plug location in the demonstration tunnel 4. The centre lines and chainages of the tunnels are shown in blue. The insert shows the structures observed in the pilot holes: the brown disks depict single natural fractures, the green solid the intersection of the brittle fault zone OL-BFZ297.*

5 Suitability classification 2 - Assessment of the suitability of the suggested plug location in the demonstration tunnel 4

5.1 Background

Based on the first suitability classification, and other factors not within the scope of RSC or this report, the approximate chainage 11 - 17 m in demonstration tunnel 4 was selected as the primary candidate for the plug location, and the excavation of the tunnel commenced in September, 2013. During excavation, geological mapping was carried out after each 3.5 metre round to obtain information on the possible significant bedrock features.

In Posiva, geological mapping of the excavated tunnel surfaces comprises three stages: round mapping, systematic mapping and supplementary studies. The round mapping is carried out as soon as possible after each excavation round for the purpose of obtaining data for the geotechnical assessment of the rock mass and for the detailed-scale modelling. Thus, the deformation zone intersections (including the core and the influence zone) and significant fractures are defined, described and measured with a tachymeter during the round mapping. The systematic mapping is performed tens to hundreds of meters behind the ongoing excavation (or in short tunnel, after completion of excavation) and is the main geological mapping stage, during which detailed information on lithology and all natural fractures over 20 cm in trace length is recorded. The supplementary studies include for example detailed descriptions of deformation zone intersections and hydrogeological mapping. For further information on Posiva's geological mapping procedure, see Enström & Kemppainen, 2008; note however, that the report is somewhat outdated concerning for example the round mapping procedure (update is in preparation). The resulting data is stored in Posiva's databases for further use, and overviews of the results are published periodically as Posiva Working Reports (see for example Nordbäck, 2010).

Once the excavation had reached chainage 17.2 m (slightly past the end of the prospective plug location, see Figure 10), the detailed-scale model was updated using the data obtained from the tunnel (see Section 5.2). The second suitability assessment based on the updated model and the data from the tunnel was carried out in October to verify the suitability of the chosen tunnel section (Section 5.3).

5.2 Significant bedrock structures in the demonstration tunnel 4

5.2.1 Summary of the RSC-relevant tunnel data

During the geological mapping of the demonstration tunnel 4, five significant fractures (with relatively long tunnel-surface traces) were observed in the chainage 4.5 - 17.20 metres (Table 5, Figure 11). None of the fractures crosscut the entire perimeter of the tunnel, and all of them were observed to be dry.

No intersections of brittle deformation zones or hydrogeological zones were observed in the tunnel.

Table 5. *Orientation and water-conductivity of the significant fractures mapped from the demonstration tunnel 4, chainage 4.50 - 17.20 metres. Some fractures were mapped in two parts denoted by the fracture codes.*

Fracture	Fracture code	Orientation		Water leakage
		dip	dip dir.	
1	D4-4_1	81	319	Dry
2	D4-4_2	74	228	Dry
3	10.5_M2	86	249	Dry
	10.5_M3	87	79	Dry
4	10.5_M1	87	103	Dry
	13.9_M2	89	270	Dry
5	13.9_M1	89	261	Dry

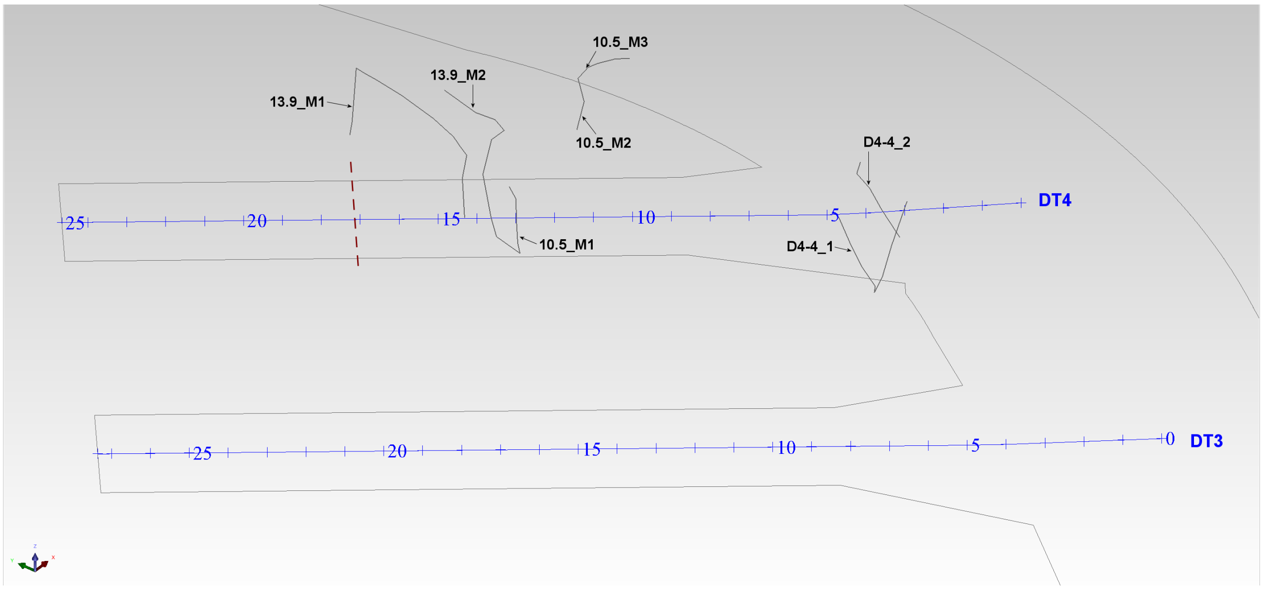

Figure 11. *Tachymeter-measured tunnel-surface traces (black lines) of the significant fractures observed in the demonstration tunnel 4, chainage 4.50 - 17.20 metres. The black text denotes the codes given to the fracture (or fracture section) during the geological mapping (see Table 5). The centre lines and chainages of the tunnels are shown in blue, the dashed red line denotes the extent of the excavated tunnel section (17.2 metres).*

5.2.2 Detailed-scale modelling

Once the data from the geological mapping of the excavated demonstration tunnel 4 was available, the need for updating the detailed-scale model was assessed. As no brittle deformation zone, nor hydrogeological zone, intersections were present in the tunnel, there was no need to update any of the zones in the model.

None of the largest fractures observed in the tunnel crosscut the entire perimeter of the tunnel (Figure 11), and was therefore not considered to be potentially large[10]. Also, none of the fracture traces could be correlated to the large fractures already in the model or other data that would have indicated them to be of significant size. Therefore, no updates were made to the detailed-scale model.

5.3 Suitability of the suggested plug location

The second suitability classification was carried out for the demonstration tunnel 4, up to chainage 17.2 m (the then excavated part), excluding the tunnel profile transition zone, with the purpose of verifying the suitability of the location suggested for the plug on the basis of the pilot hole data.

[10] A fracture (trace) crosscutting the entire perimeter of a tunnel is considered to be an indication of a fracture with an extent large enough to be taken into account in the RSC, especially when assessing the suitability of a rock volume for hosting deposition holes. Therefore, these so-called "tunnel-crosscutting fractures" or TCF (in RSC, the term "full-perimeter intersection", FPI, is used instead) are modelled in the detailed-scale model. For further discussion on the issue, see Chapters 4, 5 and 7 in McEwen et al. 2012)

Based on the detailed-scale model (and the tunnel observations), no hydrogeological or brittle deformation zones are present in the assessed tunnel section or the suggested plug location (Figure 12), thus fulfilling the criteria L5-ROC-59 and L5-ROC-60, respectively (see Table 1). Also, no fractures are present - hydraulically conductive or not - that would intersect the entire length of the plug (criterion L5-ROC-80 in Table 1); the largest fractures observed in the tunnel are shown in Figures 12 and 13, in relation to the suggested plug location.

It was therefore concluded that the criteria set for the plug location are fulfilled in the demonstration tunnel 4 in general and that the suggested chainage 11 - 17 m is suitable for the plug location.

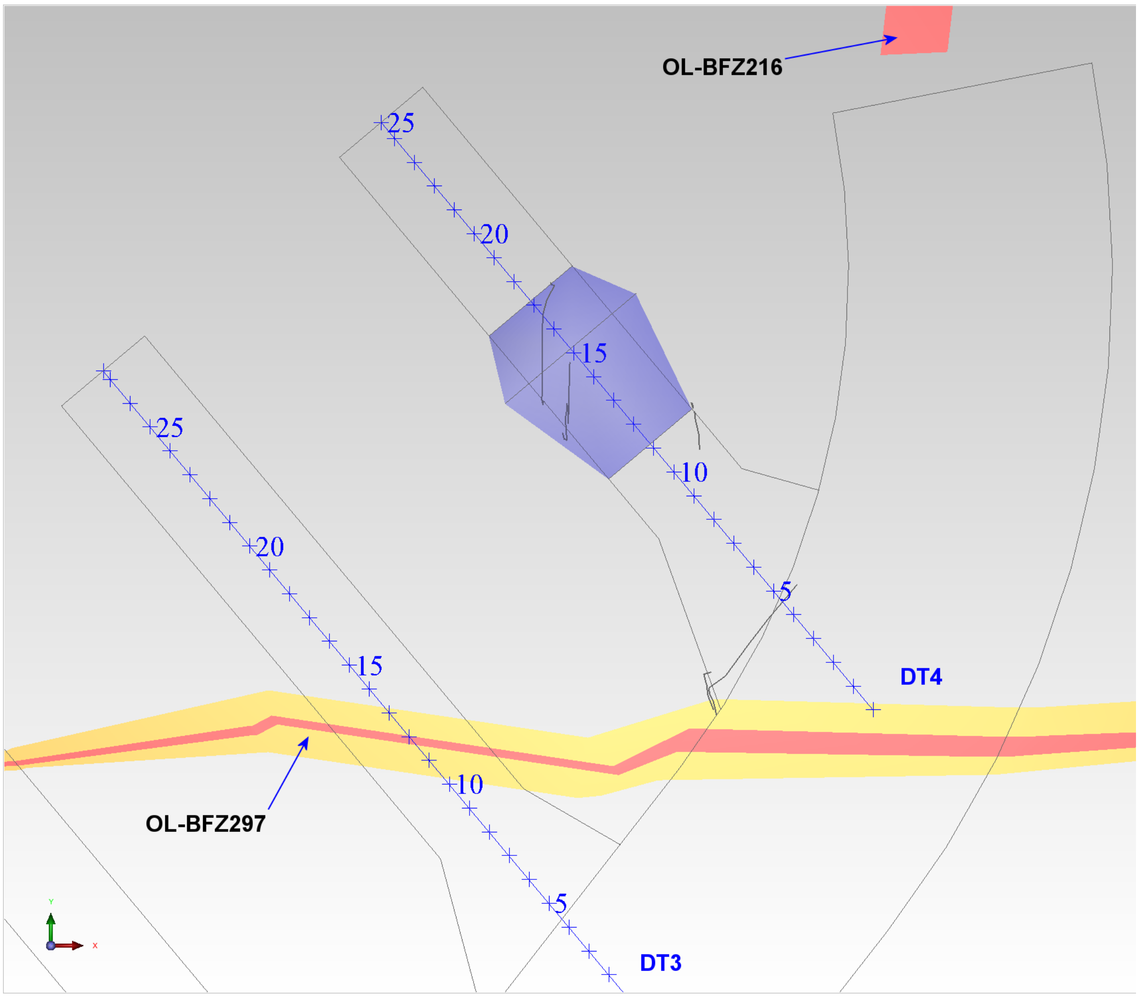

Figure 12. *Significant bedrock structures in the vicinity of the demonstration tunnel 4 (DT4) and the suggested plug location. Solid red = a brittle fault zone based on the geological model of the Olkiluoto site v. 2.0 (Aaltonen et al., 2010); yellow and red = a brittle fault zone based on the detailed-scale model (red - core, yellow - influence zone), horizontal cross-section at tunnel floor level. Tachymeter-measured traces of the largest fractures observed in the tunnel are shown as dark grey lines. The centre lines and chainages of the tunnels are shown in blue, the suggested plug location in translucent blue.*

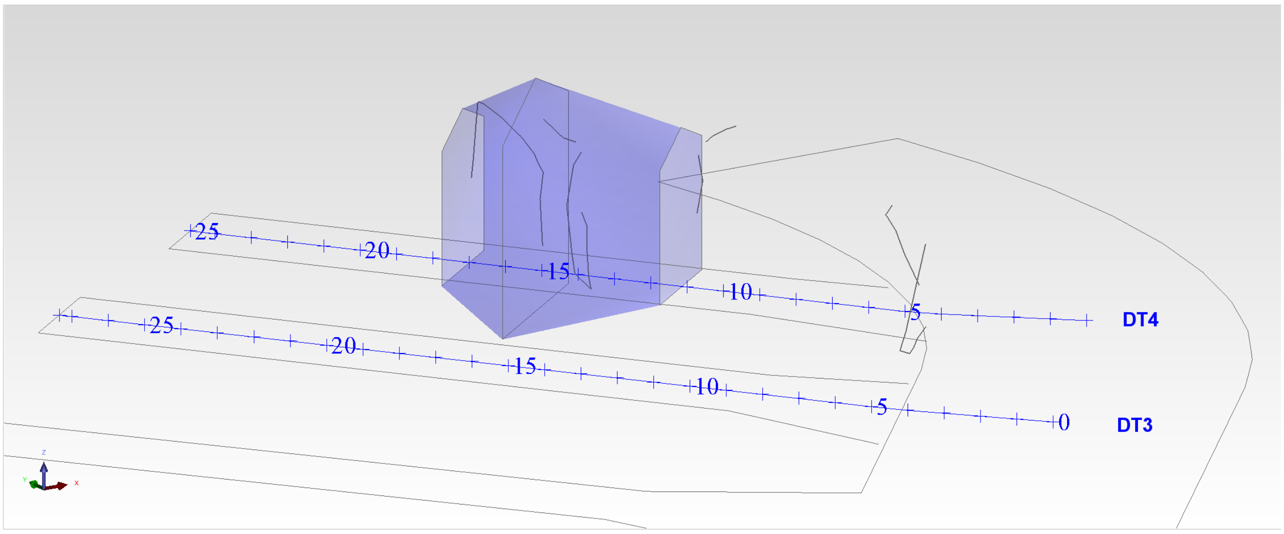

Figure 13. *Tachymeter-measured traces of the largest fractures observed in the tunnel (dark grey lines) in relation to the suggested plug location (translucent blue). The centre lines and chainages of the tunnels are shown in blue. View to Northeast.*

6 Summary

The Rock Suitability Classification (RSC) -system developed by Posiva Oy has been applied to determine the location for the POPLU plug to be constructed in the demonstration area of the ONKALO underground research facility.

The suitability of the rock volume chosen to host the demonstration tunnels 3 and 4, planned for the POPLU experiment, was assessed twice. The first classification was based on information gained from pilot holes (one drilled for each planned tunnel location) and as the result, the chainage 11 - 17 metres of the planned demonstration tunnel 4 was suggested as probably the best location for the plug. The second classification was carried out after the excavation of the demonstration tunnel 4 had proceeded past the suggested plug location, and based on the tunnel observations, the suggested location was verified to be suitable for hosting a plug.

7 References

Note: The reports published by Posiva are available for free download in PDF format from the Databank accessible through Posiva's web page: http://www.posiva.fi/en/databank

Aalto, P. (ed.), Lahti, M., Kosunen, P., Pere, T., Toropainen, V., Tarvainen, A-M., Pekkanen, J., Pöllänen, J. & Lamminmäki, T. 2011. Drilling and associated drillhole measurements of the pilot hole ONK-PH14. Posiva Working Report 2011-64. Eurajoki, Finland: Posiva Oy. 178 p.

Aaltonen, I. (ed.), Lahti, M., Engström, J., Mattila, J., Paananen, M., Paulamäki, S., Gehör, S., Kärki, A., Ahokas, T., Torvela, T. & Front, K. 2010. Geological Model of the Olkiluoto Site Version 2.0. Posiva Working Report 2010-70. Eurajoki, Finland: Posiva Oy. 580 p.

Engström, J. & Kemppainen, K. 2008. Evaluation of the geological and geotechnical mapping procedures in use in the ONKALO access tunnel. Posiva Working Report 2008-77. Eurajoki, Finland: Posiva Oy. 62 p.

Haaramo, Matti, Lehtonen, Aleksis. 2009. Principle Plug Design for Deposition Tunnels. Posiva Working Report 2009-38. Eurajoki, Finland: Posiva Oy. 60 p.

Heikkinen, E., Heinonen, S. & Ravimo, I. 2011. Semi-automated fracture classification procedure based on geophysical drillhole logging data. Posiva Working Report 2011-88. Eurajoki, Finland: Posiva Oy. 120 p.

Joutsen, A. 2012. The use of geological data from pilot holes for predicting FPI (full perimeter intersection) fractures. Posiva Working Report 2012-12. Eurajoki, Finland: Posiva Oy. 52 p.

McEwen, T. (ed.), Aro, S., Kosunen, P., Mattila, J., Pere, T., Käpyaho, A. & Hellä, P. 2012. Rock Suitability Classification - RSC 2012. Posiva Report 2012-24. ISBN 978-951-652-205-3. Eurajoki, Finland: Posiva Oy. 222 p.

Mellanen, S. (ed.), Aro, S., Gerlander, J., Hollmén, K., Joutsen, A., Kosunen, P. & Mustonen, S. 2012. Underground openings line demonstrations Stage 1, 2012. Posiva Report 2012-33. Eurajoki, Finland: Posiva Oy. (in prep.)

Nordbäck, N. 2010. Outcome of the geological mapping of the ONKALO underground research facility access tunnel, chainage 1980-3116. Posiva Working Report 2010-42. Eurajoki, Finland: Posiva Oy. 113 p.

Pere, T. (ed.), Mattila, J., Aro, S., Ahokas, H., Vaittinen, T. & Wikström, L. 2012. Layout determining features, their influence zones and respect distances at the Olkiluoto site. Posiva Report 2012-21. ISBN 978-951-652-202-2. Posiva Oy, Eurajoki. 128 s.

Posiva 2012a. YJH-2012. Nuclear Waste Management at Olkiluoto and Loviisa Power Plants: Review of Current Status and Future Plans for 2013-2015. Eurajoki, Finland: Posiva Oy, 370 p.

Posiva 2012b. Underground openings production line 2012 - Design, production and initial state of the underground openings. Posiva Report 2012-22. ISBN 978-951-652-203-9. Eurajoki, Finland: Posiva Oy. 160 p.

Posiva 2012c. Safety Case for the Disposal of Spent Nuclear Fuel at Olkiluoto - Design Basis 2012. Posiva Report 2012-3. ISBN 978-951-652-184-1. . Eurajoki, Finland: Posiva Oy. 173 p.

Vaittinen, T., Ahokas, H. & Nummela, J. 2009. Hydrogeological structure model of the Olkiluoto Site – update in 2008. Posiva Working Report 2009-15. Eurajoki, Finland: Posiva Oy. 276 p.

APPENDIX 1. Locations (in metres down-hole-depth) and orientations (in degrees) of natural fractures observed from the pilot holes ONK-PH26 and ONK-PH27.

Hole id: ONK-PH26

Fracture depth	Fracture orientation: Dip dir.	Fracture orientation: Dip	Fracture depth	Fracture orientation: Dip dir.	Fracture orientation: Dip	Fracture depth	Fracture orientation: Dip dir.	Fracture orientation: Dip
3.07	336	55	6.94	190	79	9.85	316	70
3.90	186	85	6.95	322	55	10.40	349	55
3.94	328	63	6.99	179	80	11.82	311	79
3.98	336	69	7.01	156	52	12.07	321	40
4.08	329	71	7.11	190	78	12.13	313	78
4.17	323	82	7.17	196	78	12.54	131	87
4.18	347	50	7.31	190	82	13.13	311	80
4.23	321	80	7.41	180	82	13.55	141	88
4.37	347	61	7.50	161	68	14.75	311	71
4.55	321	67	7.56	328	87	14.94	141	88
5.15	13	78	7.60	2	88	15.05	306	74
5.19	340	76	7.65	187	87	15.82	317	87
5.20	127	78	7.68	183	88	16.28	323	82
5.21	358	90	**7.76**	**5**	**82**	16.94	351	89
5.28	333	59	7.83	175	72	16.95	159	85
5.31	316	83	7.89	321	83	17.27	163	72
5.35	3	76	7.97	nd.	34	17.56	189	81
5.38	185	90	7.98	23	79	17.68	186	79
6.29	9	68	**8.04**	**188**	**82**	17.97	183	79
6.37	91	88	8.32	320	86	18.11	2	82
6.48	192	78	8.49	184	90	18.13	4	80
6.50	321	70	8.61	317	86	18.88	357	70
6.54	**298**	**87**	9.01	322	90	20.66	169	65
6.60	195	77	9.08	318	86			
6.67	193	83	9.18	319	88			
6.85	155	86	9.22	343	59			

The coloured background indicates that the fracture is part of a brittle deformation zone intersection determined during the single hole interpretation: orange = influence zone, red = core. The interpreted possibly large fractures are denoted by black boxes.
Fractures interpreted to be hydraulically conductive based on the flow-log results (see Table 4) and the geological logging are shown in bold blue.

APPENDIX 1. Locations (in metres down-hole-depth) and orientations (in degrees) of natural fractures observed from the pilot holes ONK-PH26 and ONK-PH27.

Hole id:	ONK-PH27	
Fracture depth	Fracture orientation	
	Dip dir.	Dip
0.27	316	85
10.13	308	71
13.33	305	80
13.46	302	80
13.56	305	83
13.71	303	84
13.81	308	84
14.02	309	78
14.38	349	89
14.45	180	80
14.55	176	75
14.67	184	70
15.19	314	73
15.57	146	35
15.58	306	77
16.51	191	88
17.11	189	69
17.2	299	82
17.91	194	37
19.64	171	52
19.75	156	62

No brittle deformation zone intersections, possibly large fractures or hydraulically conductive fractures.