Borehole Plugging Experiment in OL-KR24 at Olkiluoto, Finland

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April 2006
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The conclusions and viewpoints presented in the report
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coincide with those of Posiva.
Sealing of investigation boreholes has been studied by Svensk Kärnbränslehantering AB (SKB) and Posiva Oy (Posiva) as a part of final disposal research. The proposed principle is that investigation boreholes drilled at a site must not act as a continuous flow path for groundwater but be sealed to become as tight as the surrounding rock.

As a part of the investigations SKB and Posiva started the third phase of the joint project “Cleaning and sealing of investigation boreholes” in 2005. One of the sub-projects was the plugging experiment in borehole OL-KR24 at Olkiluoto. The aim of the experiment was to test all main procedures of borehole sealing concept in practise in a deep borehole. Borehole KR24 was drilled to the depth of 551.11 metres in 2003 and it was located inside the shaft profile in Onkalo. From the surface to the depth of about 120 m the borehole diameter is 98 mm. The rest of the borehole is 75.7 mm in diameter. The borehole is vertical and the inclination is quite accurately 90 degrees.

The plugging experiment in borehole OL-KR24 consisted of four main activities: 1) cleaning of the borehole, 2) characterization of the borehole 3) selective stabilisation of the borehole, and 4) emplacement of plugs.

The comprehensive cleaning of the borehole was to be done in the first stage to provide the basis for other activities.

The aim of characterization was to study the borehole in order to determine the sections for selective stabilisation and the locations for plugs. The characterization phase consisted of caliper measurements, dummy probing and optical borehole imaging (OBI).

The aim of selective stabilisation was to show that selected borehole sections can be stabilised using new techniques and methods. One borehole section was reamed from Ø 76 mm to Ø 98 mm. The reamed borehole section should have been filled with sufficient amount of cement-based material to achieve a stable “concrete tube” after redrilling, but due to encountered problems and tight timetable testing was interrupted.

The purpose of the installation of concrete and clay plugs was to test the practicality in constructing plugs in deep borehole with an acceptable quality. The sampling for determination of the physical and chemical properties of the plugs will be done when excavation has reached the test area. It is expected that the plugs will have sufficient physical strength, and that those consisting of clay are sufficiently tight.

Keywords: sealing, deep borehole, plugging experiment, cleaning of borehole, selective stabilisation, characterization, bentonite plug
KAIRANREIÄN OL-KR24 SULKEMINEN EURAJOEN OLKILUODOSSA

TIIVISTELMÄ


Reiän OL-KR24 sulkeminen sisälsi neljä eri vaihetta; 1) reiän puhdistaminen, 2) reiän karakterisointi, 3) reiän selektiivinen stabilointi ja 4) reiän sulkeminen.

Reiän perinpohjainen puhdistaminen tehtiin ensimmäisessä vaiheessa. Puhdistamisella luotiin edellytykset seuraavien vaiheiden toteuttamiselle.


Selektiivisellä stabiloinnilla pyrittiin osoittamaan, että jokin vyöhyke voidaan tukea uudella teknikalla ja metodeilla. Kokeessa pyrittiin avartamaan rikkonainen reikäosuus, joka sen jälkeen täytettiin se auki massalla ja kairattaisiin auki massan kovettumisen jälkeen. Tällä menetelmällä saadaan aikaan ehkä ”betoniputki” valitulle vyöhykkelle. Yksi valittu vyöhyke avarrettiin auki sekä halkaisijakoosta 76 mm 98 mm:iin. Sementtipohjaisen massan lasku avarrettuun kohtaan on jalanepävää, mutta menetelmiä on oikeastaan kyseistä aikataulullisista syistä johtuen.

Betoni- ja savirakenteisten tulppien asentamisen (reiän sulkeminen) tarkoituksena oli kokeilla käytännössä riittävän laadukkaiden tulppien rakentamista syviin kairanreikiin. ONKALOn vinotien louhinnan edettyä syvyydelle (n. -520 tasoo), jolle tulpat on asennettu, tulppien fysikaaliset ja kemialliset ominaisuudet tullaan tutkimamaan näytteenoton avulla. Nyt asennetuilla tulppilla oletetaan olevan riittävä fysikaalinen kesto ja tiiveys.

Avainsanat: reiän sulkeminen, syvä kairanreikä, selektiivinen stabilointi, karakterisointi, bentoniittitulppa
BOREHOLE PLUGGING EXPERIMENT IN OL-KR24 AT OLKILUOTO, FINLAND

ABSTRACT

TIIVISTELMÄ

CONTENTS

1. INTRODUCTION 3
   1.1 Background 3
   1.2 Objective of the experiment 4
   1.3 Parties involved in the experiment 5
   1.4 Description of borehole KR24 and the drilling site 5

2. CLEANING OF THE BOREHOLE 9
   2.1 Description of the task 9
   2.2 Removal of the packer and the grouting material from upper part of the borehole 9
   2.3 Setting of the casing tube 11
   2.4 Removal of the grouting material and the wooden packer from the lower part of the borehole 11
   2.5 Problems encountered 12

3. CHARACTERISATION 13
   3.1 General 13
   3.2 Borehole imaging (OBI) 13
   3.3 Caliper 16
   3.4 Dummy-probing 17

4. SELECTIVE STABILISATION 19
   4.1 Description of the method 19
   4.2 Selection of stabilised sections 20
   4.3 Equipment and materials 20
   4.4 The principles of stabilisation 23
   4.5 Description of the stabilisation work 24
   4.6 Problems encountered 33

5. PLUGGING OF THE BOREHOLE 35
5.1 Types and dimensions of plugs 35
5.2 Plug material 36
5.3 Installation phases and techniques 37
5.3.1 Cement/quartz concrete plug 37
5.3.2 Copper/clay plug 38
5.3.3 Upper cement/quartz concrete plug 40
5.3.4 Concrete plug 40
5.4 Demobilization 41
5.5 Outcome of the work vs. plans 41

6. SUMMARY 43

7. REFERENCES 45
1. INTRODUCTION

1.1 Background

In 1999, Posiva Oy filed an application for the Decision in Principle from the Government of Finland for selecting Olkiluoto in the Eurajoki municipality as the site of the final disposal facility of spent fuel. In December 2000, the Government made a positive policy decision and in May 2001, the Parliament ratified the decision.

The policy decision makes it possible to concentrate the research activities at Olkiluoto in Eurajoki. One part of the research is to build an underground rock characterisation facility (called “ONKALO”). Construction of the access tunnel was started in autumn 2004. The complementary investigations to be made from both the ground surface and underground will include drilling of boreholes. This far some forty deep surface-based boreholes have been drilled at the Olkiluoto study site.

Sealing of investigation boreholes will be an essential part of the final closure of the repository system. Svensk Kärnbränslehantering AB (SKB) and Posiva are developing a proper sealing concept as a part of their research programme for final disposal. The basic requirement is that the investigation boreholes drilled at a site must not act as a continuous flow path for groundwater but be sealed to become as tight as the surrounding rock.

SKB and Posiva started Stage 3 of the joint project “Cleaning and sealing of investigation boreholes” in 2005. The Stage 3 is divided into 4 sub-projects:

1. Preparation of a design for the main concept with highly compacted bentonite in perforated copper tube.
2. Plugging and testing in short holes – eight 5 metre deep holes – in the Äspö HRL with different methods.
3. Field studies of plugging of deep core drilled boreholes - borehole OL-KR24 in ONKALO.
4. Plugging of upper part of deep investigation holes, which are represented by three short holes with a diameter of Ø 200 mm.

This report presents the field operations of the sub-project 3 related to the plugging experiment in borehole OL-KR24 at Olkiluoto. The experiment consisted of four main activities: 1) cleaning of the borehole, 2) characterisation of the borehole 3) selective stabilisation of the borehole, and 4) emplacement of the plugs.
Sampling and laboratory testing of the plug components set to -520 level will be made from the -520 level in a later stage, after the excavation of the access tunnel has reached this level.

The excavation of the shaft access tunnel (connection tunnel) at the -87 level was planned to take place at the end of the year 2005, and it would penetrate the borehole KR24. In order to prevent water inflow from the borehole into the ONKALO tunnel the hole was to be plugged before the start of the excavation activities.

### 1.2 Objective of the experiment

The aim of the experiment was to test all main procedures of the borehole sealing concept in practise in a deep borehole. The comprehensive cleaning of the borehole was to be done in the very first stage to provide the basis for other planned activities. This stage consisted of removal of all extraneous materials from the borehole, setting the casings in the borehole and flushing the borehole.

The aim of characterisation was to study the borehole in order to determine the sections for selective stabilisation and the locations for the plugs. The characterisation phase consisted of caliper measurements, dummy probing and optical borehole imaging (OBI).

The aim of the next activity was to show that stabilisation of selected borehole sections can be made using new techniques and methods. As a part of selective stabilisation of one section was reamed from Ø 76 mm to Ø 98 mm. The reamed section should have been filled with sufficient amount of concrete to achieve a stable “concrete tube” after redrilling. These techniques and methods are being developed within the site investigation programme by SKB.

The purpose of the installation of concrete and clay plugs was to test the practicality in constructing plugs in a deep borehole with an acceptable quality. Later in the future the final sampling for determination of the physical and chemical properties will be done. It is expected that the plug components will mature nearly completely in less than a month, that the plugs will have sufficient physical strength and that those consisting of clay are sufficiently tight.
1.3 Parties involved in the experiment

The sealing experiment of borehole OL-KR24 was included as a sub-project in the joint SKB/Posiva project “Sealing of investigation boreholes”.

Before starting the experiment a working platform on the shaft was constructed by Posiva. As the first activity Suomen Malmi Oy (Smoy) contracted by Posiva carried out the cleaning work. The work was done with a drill rig and in-hole equipment. The second activity, the characterisation work, was also carried out by Smoy by using a wireline winch and measuring equipment.

The selective stabilisation was performed in co-operation between Posiva and SKB. Smoy was assigned to the work as the responsible contractor by Posiva. The selective stabilisation was carried out with techniques and methods developed within SKB's investigation programme. Therefore the fieldwork was coordinated by SKB’s consultants from Sylog Consulting AB, Drillcon Core AB and CBI (Cement och Betong Institut). For the milling (reaming) work Smoy provided a computer controlled hydraulic Diamec U8 APC drill rig and in-hole equipment (core barrels, core bits, drill string etc.) with two drillers. Drillcon Core AB provided the milling tool, accumulators, cement tube with bottom and top packers and one driller as a consultant. The representative of CBI was responsible for the materials needed for the concrete and making the mixture. The representative of Sylog Consulting AB worked as the technical adviser in stabilisation phase.

The construction and emplacement of the plug was carried out by using Smoy’s drill rig (Diamec U8 APC) and in-hole equipment. The representative of CBI was responsible for all concrete mixtures and the representative of LiwInStone AB (SKB’s consultant) was in charge of the plug installation.

1.4 Description of borehole OL-KR24 and the drilling site

The borehole was drilled to the depth of 551.11 metres in 2003 and it is located inside the planned ventilation shaft profile of the ONKALO at Olkiluoto in Eurajoki. The location of the borehole is shown in Figure 1. At the depth interval from 20.13 to 119.87 m the borehole diameter is 98 mm. At the depth interval from 119.87 to 119.91 m the diameter is 86 mm and from 119.91 to 551.11 m (the bottom of the borehole) 75.7 mm. The borehole is vertical and the inclination is quite accurately 90 degrees. In connection with
the construction of the ventilation shaft the bedrock has been excavated between the levels + 9.74 (ground level) and about – 11 metres, which equals the borehole's depth interval from 0 to 20.74 m. The realization of borehole OL-KR24 is presented in the reports by Niinimäki (2003) and (2004), including e.g. a preliminary geological description and other appropriate borehole data.

Figure 1. Location of deep boreholes OL-KR1 – OL-KR39 in the Olkiluoto area.
The collaring point was marked and the reference level (0-level) for the depth of the borehole was stated and clearly marked near the borehole. The level of the platform is +10.34 m. The depth measurements are made from the platform level unless otherwise stated.

Figure 2. Drill site OL-KR24 in the Olkiluoto area.
2. CLEANING OF THE BOREHOLE

2.1 Description of the task

Borehole OL-KR24 is located in the area, where the ventilation shaft with a diameter of 6.2 metres is planned to be located. The upper part of the shaft has been excavated to the level of -11. When excavating the shaft drift at the level -11, one injection hole drilled for pre-injection penetrated borehole OL-KR24 causing a large water flow into the tunnel. Because of the leakage, the borehole was closed with a rubber packer. The length of the rubber packer was 1.05 m and its diameter was 66 mm. The rubber packer was connected to a wire line with a steel adapter that was 0.17 m long. During pre-injection, the borehole OL-KR24 became partly filled with the grout. In addition, during the cleaning operation in the year 2004 one wooden packer, 0.70 m in length, was left at the very bottom of the borehole.

The aim of the cleaning activity was to open the borehole and to remove the rubber packer, pre-injection grout and the wooden packer out of the hole. The volume of the grout was not known.

2.2 Removal of the packer and the grouting material from the upper part of the borehole

The drilling operation was started on August 24th at 2 p.m. using 98/89 mm casing and a 98.4 mm diamond bit. Drilling was started with the drill rig Onram 1000 on the platform. The drilling was carried out with a low rotation speed and with just the rod weight only without any feed. The 0-level of this drilling was the bedrock surface of the shaft drift at the level of about – 11 m. The drilling was continued to the depth of about 3.70 m below the shaft floor (at the depth of 25.04 m from the platform) and stopped at this depth due to bumping and faltering of the rods.

As the rods were lifted it was noticed from the core sample that the drilling had started to deviate from the original hole at about 0.60 m below the shaft floor. The borehole was full of grouting material from the very beginning. The drilling was stopped because the drill bit was stuck due to the steel adapter of the rubber packer.

When it was noticed that the borehole had deviated from the original borehole and that removal of the rubber packer with the 98/89 mm casings failed, it was decided to remove the packer by overcoring the original borehole with a T-116 equipment from the tunnel level. The drill rig Diamec 260 was moved to the shaft access tunnel and the
casing 114/104 between the platform and the shaft floor was removed. After removal of the casing the water flow rate from the borehole into the tunnel was measured to be four litres per minute.

When the rubber packer was overcored with the T-116 equipment, the rods were stuck again at the depth of 4.78 m (measured from the shaft floor). The drilling was carried out with short runs and low rotation speed. The core barrel was lowered to the borehole without the core lifter case and the core lifter ring to avoid sticking. The reason for the sticking was believed to be the pieces of the rubber packer, which wedged the core barrel in the borehole. A jack lifter with a lift force of 300 kN was set up at the drilling site (in the tunnel) and the drill string was loosened. The outer parts of the packer (part of rubber and part of steel body) were loosened from the borehole and lifted up inside the core barrel. The packer was broken during the overcoring. The rest of the packer was loosened and it started to sink in the borehole while rescuing it later with fishing tools. The drilling had started to deviate from the original borehole and it was not possible to lower the 98/89 mm casing into the original borehole. However, the original borehole was “found” using a slimmer NK3-equipment (76mm).

To remove all the hardened grouting material from the borehole (116 mm), it was decided to ream the upper part of the borehole with a reamer, 103 mm in diameter. The reaming was estimated to be necessary only in the borehole section that was 116 mm wide. In order to steer the reamer to the right direction, one NT-drill rod was installed under the reamer. The grouting material was removed in this way and it was possible to take the 98/89 -casing into the borehole.

The inner parts of the packer sank downwards in the borehole when the drilling was continued with the 98/89 –casing. However, the casing did not go down freely, because there were thin layers of grout in the borehole wall. The work continued by drilling with the 98/89 –casing and the NK3 -equipment. Grout existed only occasionally in the borehole walls and there was no continuous concrete layer and the concrete was flushed out with the drilling water. When the drilling was at the depth of 72 m, the packer stopped. The NK3 –equipment was lowered to the borehole and most of the packer was removed from the borehole.

After removing the packer, the water flow rate from the borehole into the tunnel was measured again. The measured water flow rate from the borehole was the same as earlier, four litres per minute.
The 98/89–casing was drilled to the depth of 97.30 m from the shaft floor. The casing was drilled 0.27 m deeper than the previous casing depth, i.e. 119.87 m. The occurrence of grout was not intact, but there were some grout layers occasionally in the borehole wall. No grout samples were recovered due to grinding and flushing out with the drilling water.

2.3 Setting of the casing tube

When the upper part of the borehole was cleaned, the work was continued from the platform structure. The drill rig Diamec 260 was removed from the borehole and the 114/104 mm casing was installed back to its place in the shaft between the platform and the floor of the shaft at -11 level.

After the 114/104–casing was mounted the 84/77–casing was installed into the borehole using Onram 1000 drill rig. To prevent any notches in the borehole the casing was centralized with a tight centralizing ring. The casing was installed at the depth of 120.74 m measured from the platform, i.e. the borehole depth of 120.14 m.

2.4 Removal of the grouting material and the wooden packer from the lower part of the borehole

After the casings were installed, the NK3–equipment with corborit core bits was used to clean the borehole section that was 76 mm wide. There were some intact layers of hardened grout only occasionally, but the layers were short and between them there were long intervals, where the grout existed only in the borehole walls or was absent. At the borehole depth of about 296 m intact grout layers were met extending down to the depth of 329.40 m. About 50 % of the grout was recovered as core samples. At this depth the drill rods were suddenly stuck. The jack lifter was set up again at the drilling site and the drill string was loosened.

Below the depth of 330 m only a small amount of grout was met. Most of grout was in the borehole wall and was flushed out as drill cuttings. The drilling was continued to the depth of 425.40 m. Due to the difficulties (lack of capacity) the drill rig Onram 1000 was moved from the borehole and Diamec U8 APC was set up at the drilling site.
When reaching the depth of about 544 m, hardened cuttings and rock material was met at the bottom of the borehole. The drilling operation was continued with a low rotation speed and with just the rod weight and heavy flushing. The drilling was continued to the bedrock to be sure that all the hard material met was removed from the borehole. The borehole was extended 2.83 m deeper than the original hole and the new depth being 554.54 metres measured from the platform. After drilling the borehole was thoroughly flushed.

2.5 Problems encountered

As a whole the task to clean of the hole was difficult and troublesome. During the task several problems were encountered. Some of these problems were technical, caused by the excavated shaft, some were due to the borehole conditions. Due to the open shaft the situation of the packer was inexact. Especially this was a problem when the rubber packer and the hardened concrete around it were removed from the borehole.

When the drilling started, the deviation in the beginning of the borehole caused severe problems. The borehole was filled with pre-injection grout and the hole deviated twice from the original trace along a new branch. When drilling the borehole in 2003 the borehole was reamed to the diameter of 98 mm and the 98/89 -casing was set to the depth of about 120 m. For cleaning work concerning the 76 mm wide diameter borehole section there was a possibility to use corborit core bits to remove the hardened grout. But in the case of the 98 mm wide borehole section similar bits were not available on the market. When drilling with the corborit bit the risk of deviation out of the hole to a new branch is smaller, because the corborit core bit cuts the bedrock weaker than a common diamond core bit.

The risk of getting equipment stuck in the borehole is always present in this kind of works. There are many ways to remove rods that are stucked in a borehole. Rods may be removed by lifting them with a drill rig. If the pulling force of the rig is insufficient a separate hydraulic jack lifter can be used. The rods can be taken apart by using special break-up rods with left handed couplings and they can be lifted one by one from the hole. In addition the rods may be removed by overcoring them with a larger diameter bit and rods. During the current work the drill rods were stuck three times. In every occasion the rods were loosened with jack lifting.
3. CHARACTERISATION

3.1 General

The characterisation of the borehole OL-KR24 was carried out in order to select the sections for the stabilisation. The fractures and fractured zones were assessed for the stabilisation experiment using re-measurements with the OBI 40 optical imaging and the Mount Sopris caliper probes. Also the dummy probing was done to check that the borehole was completely open and that there were no tight bends that could cause problems when lowering plugs.

The characterisation carried out in OL-KR24 included optical imaging, caliper – measurements and dummy probing. The optical imaging and caliper –measurements were done with a cable, which was operated by a motorised winch. The depth measurement is triggered by pulses of sensitive depth encoder, installed on a pulley wheel. The cable was marked with 10 m intervals for controlling the depth measurement to adjust any cable slip and stretch. The dummy probing was done with the wire line cable of the drill rig. This report describes the technical operation of the characterisation. The results of these surveys are reported separately (Majapuro & Tyyskä 2006).

3.2 Borehole imaging (OBI)

The borehole imaging was carried out using the OBI 40 optical televiwer manufactured by Advanced Logic Technology (ALT). The tool diameter is 42 mm. The maximum azimuthal resolution is 720 pixels and the vertical resolution is 0.5 mm. Smoy has prepared special centralisers for the 76 mm boreholes. The tool configuration is shown in Figure 3 and the optical assembly in Figure 4.

The optical imaging was carried out on the 2nd and 3rd of October. The imaging was done from the hole depth of 190 m to the hole depth of 552 m. The tool images the illuminated borehole wall through conical mirror to a camera objective and digital CCD element, and records the 24-bit RGB image step by step while the probe slowly proceeds in the borehole, triggered by a cable depth encoder. The resulting bitmap is scalable and it can be oriented according to the coordinate system. The measurement direction was from the top to the bottom. The borehole was imaged in 40…160 m long sections with a slight overlap.
Figure 3. The configuration of the OBI 40-mk3, length 1.7 m (ALT, Optical Borehole Televiewer Operator Manual).

Figure 4. Optical assembly of the OBI 40. The high sensitivity CCD digital camera with Pentax optics is located above a conical mirror. The light source is a ring of light bulbs located in the optical head (ALT, Optical Borehole Televiewer Operator Manual).
The images were oriented to the north using simultaneous borehole deviation tool and orientation survey (3-component accelerometers and magnetometers). The depth encoder calibration shift (1 % of the borehole length) was matched using the cable depth marks and the geological depth references, e.g. the previous gamma-gamma density log. The current depth accuracy of image is 0.02-0.05 m from the core sample and the radial accuracy is better than one degree.

The image quality is very good compared to the original imaging data, which has been run immediately after completion of the drilling in October 2003 (Lahti 2004). The some narrow fractures have been partially filled with concrete during the construction of the upper part of the shaft. These can be clearly seen as reddish white bright patches and stripes on the image (Figure 5).

Figure 5. Concrete fillings in fracture at the depth of about 271 m in the borehole OL-KR24.
3.3 Caliper

The borehole caliper survey was carried out with a Mount Sopris 2PCA100 3-arm caliper tool. The tool diameter was 39 mm. The device applies three connected hard metal arms, of which the angle of opening produces the primary signal. The data was calibrated using measurements of four rings with different diameters in the measurement range from 70 to 140 mm, performed before and after the logging run. The resolution of the aperture was 0.08 mm. The tool configuration is shown in Figure 6.

The caliper survey was run on the 3rd of October from the bottom of the borehole to the top at about 120 m, with a recording spacing of 0.01 m. The caliper data were depth matched to the core sample and the previous caliper record, with an accuracy of better than 0.02-0.05 m. The data quality suffers below 521 m from the noise, which is possibly of electrical origin. Elsewhere the data were of very high quality.

![Image of Mount Sopris 2PCA100 3-arm caliper tool](image)

**Figure 6.** The configuration of the Mount Sopris 2PCA100 3-arm caliper tool, length 1.59 m.
3.4 Dummy probing

The dummy probing was done with the wire line cable of the drill rig. The dummy probing was done to check that the borehole was completely open and that it was straight enough. In addition, the purpose of the probing was to check the openness of the borehole. The dummy probing tools with different lengths were used to give an idea of the possible lengths of perforated copper tubes, which would be installed in the borehole at a later stage. The diameter of the tool was 72 mm, which is the same as the planned diameter of the perforated copper tubes in copper-bentonite plugs. The used tool lengths were 3, 6, 9 and 12 m.

The dummy-probing was done in two occasions. The first occasion was just before the stabilisation and the other during plugging. During the first occasion all the dummy tool lengths were used. The 3 m long tool proceeded in the borehole to the depth of 223 m and the 6 m long tool to the depth of 359 m. The heavier 9 m and 12 m long tools proceeded to the bottom of the borehole.

In the second testing only the 12 m long dummy tool was used. The tool proceeded to the bottom of the borehole. There were severe problems to lift the tool from the borehole, because there was some very fine grained residue of the sand that was used in the plugging process in the borehole.
4. SELECTIVE STABILISATION

4.1 Description of the method

To provide stable conditions in the borehole during the installation of the plugs preparations were made in the borehole OL-KR24. Cleaning of the borehole was followed by the selective stabilisation of the chosen sections. The techniques and methods to stabilise the borehole are developed within the SKB programme for site investigations.

The aim of this activity was to show that the selective stabilisation of boreholes can be made by reaming from Ø 76 m to Ø 98 mm, section by section. The borehole should be filled with a sufficient amount of concrete to achieve a stable “concrete tube” after redrilling. The reaming tool was adapted to the Atlas Copco Corac N3 coring system. The principle of the selective stabilisation of borehole is shown in Figure 7.

*Figure 7. The principle of the selective stabilisation of borehole.*
4.2 Selection of stabilised sections

The sections to be stabilised were selected at the meeting with Posiva and SKB. After the meeting the representatives of Sylog and Posiva checked together the core boxes to decide the exact locations of the three borehole sections. The following sections were chosen for stabilisation (all depths are measured from the platform, + 10.34):

1. 346.00 – 348.50 m
2. 380.36 – 383.36 m
3. 397.30 – 399.80 m

The first section was selected with the highest priority. The section included about 0.1 m of fractured zone with three fracture orientations and loose rock particles. The stabilised section was defined to cover a 2.5 metres long borehole section starting 1.50 metres above the fractured zone and extending 0.90 metres below the fractured zone. This was based on the fracture orientation.

The second section included a fractured zone that is 0.82 metres thick with one fracture orientation and loose rock particles. The section to be stabilised was decided to be 3.0 metres long, starting about one metre above the fractured zone and extending about one metre below it.

The third stabilised section included a fractured zone that is 0.86 metres thick with one clear fracture orientation and some fractures with fillings. The section to be stabilised was decided to be 2.5 metres long starting about 0.30 metres above the zone and extending 1.30 metres below it.

4.3 Equipment and materials

Before the work started the requirements of the drill rig and the equipment that were needed for the stabilisation of the borehole were specified. The milling (reaming) was done from the lower end of the stabilised section upwards. The penetration rate of the drill rig had to be controlled. The minimum requirement for the rig was to have a lifting capacity of 560 m of NT drill rods and to ream upwards with a force of 10 000 N. Another requirement was to record the exact penetration rate while reaming upwards. The requirement for the flush pump was to be able to regulate the pressure up to 70
bars. The flow capacity for the pump should be 50 l/min with a possibility to regulate flow down to 5 l/min. Because of the previously mentioned requirements Smoy provided a computer controlled hydraulic Diamec U8 APC drill rig for the work. Before starting a number of preparatory measures were taken. These preparations included among other things service, functional inspections and calibration of the drill rig. The drill rig was thoroughly cleaned.

The drill rods (NT) were checked to be in good condition, i.e. the threads were not leaking or bulged, because the pistons pushing down the concrete should pass through the rods. Both impregnated and corborit bits were reserved for drilling through the concrete.

The milling tool, which was used to ream the borehole diameter from 76 to 98 mm, needed a constant water flow rate and pressure. For this reason the flush pump had to be equipped with two accumulators of different sizes. For the constant pressure during reaming one or two accumulators were required for the milling tool.

The accumulators, milling tool with stabilisers and spare parts, bottom packers and hold-down-plugs, top packers with adapters, plastic tubes and pistons for concrete transport or concrete tubes with the Corac N3 head and transport-safety tool and the kit of plastic pistons were provided by Drillcon.

CBI provided all required materials and mixing equipment for the production of the fibreglass reinforced concrete. The materials used and the volumes are presented in Table 1. The basic components of the materials used in the plugging experiment are presented in Table 2.
Table 1. Suggested materials and the volumes as planned for the stabilisation experiment at Olkiluoto.

<table>
<thead>
<tr>
<th>Material</th>
<th>Amount (kg/m³ concrete)</th>
<th>Manufacturer</th>
</tr>
</thead>
<tbody>
<tr>
<td>White cement (SR cement)</td>
<td>514.26</td>
<td>Aalborg Portland</td>
</tr>
<tr>
<td>Microsilica Grade 940</td>
<td>342.84</td>
<td>Elkem</td>
</tr>
<tr>
<td>Fine ground α-quartz M300</td>
<td>133.2</td>
<td>Sibelco</td>
</tr>
<tr>
<td>Fine ground α-quartz M500</td>
<td>107.5</td>
<td>Sibelco</td>
</tr>
<tr>
<td>Glenium 51</td>
<td>8 (dry content)</td>
<td>Degussa</td>
</tr>
<tr>
<td>Fine quartz sand &lt; 250 µm</td>
<td>325.4</td>
<td>Askania</td>
</tr>
<tr>
<td>Coarse quartz sand &lt; 500 µm</td>
<td>488.1</td>
<td>Askania</td>
</tr>
<tr>
<td>Cem-FIL glass fiber 6 mm</td>
<td>53.6</td>
<td>Saint Gobain</td>
</tr>
</tbody>
</table>

Table 2. The basic components of the materials to be used in the stabilisation and plugging experiment.

<table>
<thead>
<tr>
<th>Material</th>
<th>Components</th>
</tr>
</thead>
<tbody>
<tr>
<td>White cement</td>
<td>CaO, SiO₂, Al₂O₃, Fe₂O₃</td>
</tr>
<tr>
<td>Microsilica Grade 940</td>
<td>SiO₂</td>
</tr>
<tr>
<td>Fine ground α-quartz</td>
<td>SiO₂</td>
</tr>
<tr>
<td>Fine ground cristobalite quartz</td>
<td>SiO₂</td>
</tr>
<tr>
<td>Glenium 51</td>
<td>Polycarboxylate solution, 35 % dry content</td>
</tr>
<tr>
<td>Fine quartz sand &lt; 250 µm</td>
<td>SiO₂</td>
</tr>
<tr>
<td>Coarse quartz sand &lt; 500 µm</td>
<td>SiO₂</td>
</tr>
<tr>
<td>Granitic aggregates 0-4 mm</td>
<td>Granitic rock composition</td>
</tr>
<tr>
<td>Cem-FIL glass fiber 6 mm</td>
<td>SiO₂, ZrO₂, Na₂O, K₂O</td>
</tr>
<tr>
<td>Copper tubes</td>
<td>Cu</td>
</tr>
<tr>
<td>Na-bentonite clay</td>
<td></td>
</tr>
<tr>
<td>Grout aid</td>
<td>SiO₂, CaO, Al₂O₃</td>
</tr>
<tr>
<td>SR cement</td>
<td>CaO, SiO₂, Fe₂S</td>
</tr>
<tr>
<td>Retardant</td>
<td>Na₂O, P₂O₅, C₆H₁₁Na O₇</td>
</tr>
</tbody>
</table>
4.4 The principles of stabilisation

The milling tool was connected to the drill rods. Before lowering it into the borehole it was tested on the surface to make sure that the cutting segments were moving out by raising the pressure and moving in when the pressure was dropped. The milling tool was lowered to the lower end of the section to be stabilised.

The bottom packer was mounted to the drill rods and lowered below the milled section and it was inflated with water pressure. To avoid the risk that the pressure from below would move the bottom packer upwards a hold-down-plug could be set above the bottom packer.

For transport of concrete mixture to the milled section without contamination of the borehole two different methods were available:

1. “Grouting method”. A top packer was mounted on the bottom drill rod and lowered into the borehole 10 – 12 m above the milled section. Concrete was mixed and the lower piston was prepared and set in the drill rod. The drill rods above lower piston were filled with the concrete mixture while lowering the top packer into its final position just above the milled section. When calculated volume of concrete mixture was filled upper piston was set and water swivel was connected. Column of cement-mix was pumped to the bottom of the rod string (top packer) and a valve in lower piston opened by raising pressure and cement-mixture was pumped out into the milled section. When section was filled the top packer was locked by pulling the rod string, thus closing the grouted section of the borehole. Rod string was unscrewed from the top packer and a non-return valve in bottom rod closed to ensure that remaining cement mix stayed in the rod string. The rods were pulled up to the surface and cleaned from remaining concrete.

2. “Inner tube method”. An outer core barrel with diamond bit was mounted and lowered into the position ~3 m above bottom packer. A special cement inner tube was screwed together to suitable length (12 – 24 m) depending on volume of milled section. Concrete was mixed and inner barrel was loaded with concrete mixture between two expandable pistons. A special core barrelhead was connected and inner tube was pumped down into position, where inner tube extruded through the bit ~2.5 m. Core barrelhead was opened by overshot and lower piston was pumped out above bottom packer. Rod string lifted slowly while pumping out cement mix. Upper piston was pumped out above milled section to close it. Rod string was lifted 20 – 30 m and inner tube was pulled out by overshot.
When the concrete was being mixed two samples were taken into plastic cups. One was stored in a dry place and the other was stored in water at the same temperature as was estimated to be prevailing in the stabilised section of the borehole. When the sample had hardened sufficiently, the drilling could to be started.

The drilling through stabilised section to reopen the borehole could be done either with the Corac N3 core barrel or with a thin wall core barrel of type TNW, which would cut easier through the packers. A Corborit tungsten carbide bit is normally the best choice. It will cut easier through aluminium and plastic parts in the packers and have lower tendency to deviate.

### 4.5 Description of the stabilisation work

The stabilisation work was started on the 5th of October 2005. The milling tool (Figure 8) was lowered to the borehole depth of 348.50 metres (the platform as the reference level) and the milling was started. The drill rig was calibrated before starting. The milling was done with somewhat lower speed than planned. The probable reason for having lower penetration was the hard rock and difficulties to control the force applied on the milling tool. The penetration rate was about 0.2 m/min. The milling was done to the depth of 346.00 metres.

![Figure 8. Milling tool mounted on the Corac N3 core barrel.](image)
After milling the bottom packer (Figure 9) was installed to the drill string and lowered to a position below the milled section. The depth of the packer was 349.30 metres. The shear pins were broken and the packer was set. The rods were pulled out of the borehole and the top packer was connected to the end of the drill string. The drill rods with the top packer were lowered 12 metres above the milled section and were filled with water. The lower cement piston was placed into the drill rods and drill rods were lowered to the setting position. The drill rods above the lower piston were filled with concrete mixture (Figure 10). While placing to put the upper cement piston into the tube, blasting in the tunnel interrupted the work.

After the blasting, when the work continued, the water swivel was connected and the pumping was started. While waiting for blasting for about half an hour, the weight of the concrete had pushed the lower piston down, and created a section with air between the concrete and the upper piston. The upper piston was placed tightly in the rods and the piston was pumped down with 30 l/min and 15 bars, (in some rod joints pressure increased to 20 – 25 bars). The calculated pumping time was 30 minutes. After 29 minutes the pressure was raised to 80 bars and the lower piston should have been down at the packer. Normally the shear pins in the valve brake at 50 bars, but supposedly friction in the upper piston has caused the pressure to increase. By increasing the pressure to 85 bars the pressure dropped and it was assumed that the shear pins had broken and the valve had opened. After the pressure decrease pumping was continued.
for about 2.5 minutes for filling milled intersection with concrete. Then the top packer was locked by pulling the rod string, which closed the milled section.

The rods were disconnected from the packer and were pulled out of the borehole. When the last 18 metres of the rods were lifted, concrete mixture instead of water came out of the rods. The upper piston was placed 18 m above the bottom and the lower piston was at the bottom with the unbroken shear pins. All the concrete had remained in the drill string and there was no concrete neither in the section nor in the borehole.
After the first failed attempt it was decided to clean the borehole and retry stabilisation. The top packer with the plastic tube and a part of the bottom packer were removed with a corborit bit. The remains of the bottom packer were pushed below the depth of 410 metres.

On the 8th of October a new bottom packer was set at the depth of 349.16 m. In this setting the shear pins did not break but instead were bended, and the top cover of the packer stayed in the drill rods.

A new concrete mixing was done and two reference samples in the cups were set on the site. The top packer (Figure 11) was put in the borehole with the lower piston on the top. The piston had three shear pins to open the valve. 12 metres of drill rods with the concrete mixture were set down above the packer. The upper piston was placed above the concrete in the rods.
After that the crew set down the rod string to the depth of 345.6 metres and started pumping. Water was pumped with the rate of 10 l/min and the pressure gradually rose to 80 bars, without breaking the shear pins and opening the valve. The pressure was raised a couple of times without the desired result. Further there were two attempts to give a shock on the rods by a short push and pull operation. The shocks helped and the pressure dropped from 80 to 35 bars and the valve was assumed to be open although the pressure was rather high. When the valve was assumed to be open, concrete was pumped for 2.5 minutes with a rate of 10 l/min and the top packer was locked by pulling the rod string. After that the pumping was continued and the pressure decreased from 35 to 30 bars.

The pumping was stopped after 6 minutes and the rod string was unscrewed from the packer. The rod string was pulled out of the borehole and when the last 12 metres of the
string had came up the rods were full of concrete. The concrete in the rods was still “liquid” and suitable for pumping when it came up about 4.5 hours after mixing. The same applied to the reference samples. The shear pins did not break and no concrete had ended into the borehole.

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The packers were removed by drilling with a tungsten corborit bit and the rest of the bottom packer was pushed down to the depth of about 390 metres. A new bottom packer was set at the depth of 349.30 metres on the 13th of October. On the 13th of October, before starting the third attempt in the borehole the valve was tested on the surface in a horizontal rod string filled with concrete. In this test the valve opened at 35 bars.

The mixed concrete was set down with the rod string at the depth of about 345 metres. The rods were filled with water. The pumping was started three hours after mixing the concrete. The concrete samples on the surface were still soft and pumpable. The pumping pressure was increased first to 85 bars and then to 110 bars, but the valve did not open.

The rods were pulled back and along with the rods also the top packer was brought up. When the rods came up the concrete mixture was dry and compacted above the lower piston. On the surface the rods were connected and it was tried to pump the concrete out from the rods, but the valve in the piston did not open at 88 bars. Lower piston type used was previously successfully used in Sweden with Hagby WL76 equipment. Modification made for N3 equipment was done for this work and was not used earlier.

This method was discarded and instead the second method in which the concrete is transported into the borehole in a long inner tube was implemented. This method has been used down to 345 metres in the borehole KAS 17 at Äspö with the Hagby WL equipment. The equipment was modified to fit Corac N3. The inner tube takes five litres of concrete per three metres’ length. Normally used tube lengths are between 12 and 24
metres depending on how much grouting material is required. The inner tube is pulled through the bit and it extrudes 2.5 metres below the bit when it has been placed. At both ends there is a piston and when pumping the lower piston goes out at about 30 bars and the upper piston pushes the concrete through the inner tube.

A functional test using water was carried out on the surface and the equipment was adjusted according to the test. 18 metres of inner tube was filled with 30 l concrete and pumped to the planned position on the 18\textsuperscript{th} of October (Figure 12). When the tube was in the right position, the pumping was started. The lower piston loosened at 32 bars as planned and the pumping was continued with the rate of 12 l/min and the rod string was lifted at the same time. After one minute of pumping the pressure increased suddenly and the rods were lifted 2 metres rapidly. When the pressure reached the value of 27 bars, the pressure dropped again. The phenomenon was interpreted so that the upper piston opened, the pumping was stopped and the rods were lifted 20 metres. After that the pumping was started again and the pressure increased again to 40 bars, dropped and finally increased up to 80 bars. The inner tube was pulled out and it was noticed that all the concrete had gone, but the upper piston was still at the bottom part of the inner tube i.e. some concrete was left in the milled section and some 20 metres above. The first indication (opening of the upper piston) was false; probably the upper piston was stopped in a rod joint and passed it when the pressure increased.

When the concrete was studied, it was noticed that there was no hardened concrete in the milled section. The equipment for the piston was adjusted (shears were decreased) to run smoother inside the inner tube and the inner tube to run better inside the rod string. The concrete was mixed in accordance with the CBI manual. 35 litres of concrete was filled into 21 metres of inner tube and pumped into the planned position. This time it went much faster and the inner tube was in the position in only 9 minutes. The lower end of the inner tube was just under the milled section and pumping was started. The lower piston loosened at 28 bars and while lifting the rods slowly for 3.5 metres concrete was pumped with the rate of 12 l/min. The pumping pressure increased to 80 bars indicating that the inner tube was empty. The rod string was lifted 27 metres and the inner tube was picked up with an overshot. The inner tube was empty and the upper piston had gone out. This time all the concrete had gone out within 3.5 metres above the bottom packer. Two reference samples were stored at ten degrees. After 23 hours both samples were hard.
When starting the drilling on the 22\textsuperscript{nd} of October it was noticed that the rod string was stuck in the borehole. Further there was no water circulation. It was decided to use a pneumatic rod hammer to release the rods from the borehole. The hammer arrived to Olkiluoto from Sweden on the 23\textsuperscript{rd} of October. The hammering of the rod string continued for the next two days. The only progress that was made during that time was the restoring the part of the water circulation. Most of the water that was pumped into the hole returned back through the rod string when pumping was stopped.

After it became evident that the rods stuck in the hole could not be recovered with the rig and the hammer, jack lifting was used to remove the rods. In the jack lifting the rods were pulled with a special hole jack to the point where the rods would be released or would break. It was realised that the rods are under a considerable tension and in the case of breakage the rods may be released fiercely. The jack lifting was started on the 26\textsuperscript{th} of October. The rods were kept under tension for two nights, but there were no marks of loosening.

On the 28\textsuperscript{th} of October it was decided to cut the drill rods inside the core barrel. The cutting was planned to be made with BGM drill rods and a cutter. The casing cutter was lowered inside the core barrel with the BGM drill rods. The cutting blades opened with
water pressure and the cutter was rotated with the rig and the BGM drill string. With the first trial the blades did not cut the NT drill strings. The cutting depth was probed with the BGM core barrel and the rods and it was noticed that the cutter was possibly stopped in the lift ring.

At the second trial on the 30th of October the NT drill rods were cut successfully and they were lifted from the borehole. The lifting of the drill rods was quite hard at the beginning. Around the lowest rods (about 20 m) there were noticeable signs of concrete. After the cutting operation was finished there were still a core barrel, a core bit and a reamer left in the borehole.

At the third trial, the blades cut the core barrel, but the core barrel did not become loose. The cutting place was 0.70 metres from the upper end. It was decided that the rest of the core barrel would be drilled away.

The drilling was started on the 4th of November. When drilling the steel there is always a high risk that the ongoing drilling will deviate from the original hole. Therefore the core barrel was equipped with an extra centralizer ring. The drilling of the remaining parts was started on the 5th of November. When drilling was near the core bit and the reamer, the rest of the material became suddenly loose and it was lifted from the borehole with a retriever.

On the 6th of November the concrete and the packers were drilled away with the corborit tungsten bit. During the drilling it was noticed, that the level of the concrete was at the depth of 337.42 metres. Below the concrete, at the depth of 338.07 metres a top packer was encountered. Below the packer there was eight metres of hard concrete to the depth of 346.08 metres. The bottom packer was found at that level. Below the bottom packer there was hard concrete to the depth of 346.26 metres and partly hardened concrete to the depth of 346.56 metres. Below the concrete there were the bottom packer and parts of the plastic tubes. At the end of the drilling, the drill rods were lowered to the bottom of the borehole in order to check that the borehole was completely open.

When stabilising the borehole 65 litres of concrete was used. Eight metres of concrete was retrieved as core sample, which equals about 21 litres. 44 litres of concrete remained in the borehole or was flushed away with returning water.
4.6 Problems encountered

The aim of this test was to show that the selective stabilisation in boreholes can be carried out. The first phase was the reaming from Ø 76 m to Ø 98 mm, section by section. The reaming was successfully completed for the first stabilised section. Unfortunately there was time to ream only one section. In the second phase it was planned to bring concrete in the borehole in the reamed section. The method has earlier been used successfully with the WL-76 equipment.

There were severe problems with setting the concrete to the right place in the borehole. In the first trial there was a problem with the opening of the valve. The reason was that the shear pins did not brake at high pressures. One reason could be that the piston area in the valve was smaller in the piston for NT rods (ID = 60 mm) than for the Hagby Ø 76 mm WL rods (ID = 64 mm). Since the fixed centre (D=45 mm) is the same, the difference in the areas of the ring pistons is 30 %. A second reason could be that concrete above piston got dry and compacted at depth, and much more difficult to pump.

Another problem with the concrete setting was that the upper piston was stuck in the rod. The reason can be a combination of a narrow rod joint, extra waiting time during the blasting or a tight piston. Also when the rod string was pushed and pulled during setting some of the threads could have opened a little (no drilling took place to screw them together) and caused a small leakage of water and a pressure drop from 80 to 35 bars. When the rod string was once more pulled to lock the packer, the leakage increased and the pressure dropped further to 30 bars. Another reason could be that dynamic force was not developed when the lower piston hit the top packer.

Water flows in the borehole caused also some problems. It was noticed that when drilling the lower packer it was lifted some metres to the reamed part of the borehole. Further the concrete did not stay in its position but the concrete was lifted when the drill string was moved upwards in the borehole.

Because of tight timetable a decision of cancellation of the stabilisation work was done. Three selected intervals were not stabilised and furthermore uppermost intersection was reamed. In spite of these conditions, which were recognised to be possibly hazardous for the next phase i.e. plugging, the decision was made to continue to the next phase.
5. PLUGGING OF THE BOREHOLE

5.1 Types and dimensions of plugs

The purpose of the plugging experiment was to test the practicality of constructing plugs in deep boreholes and to test if their quality is acceptable. The emplacement of the plugs was the last activity in the experiment in the borehole OL-KR24. The objective of this work was also to demonstrate and test the placement of the different plug components. The plugging of the hole was performed with two types of plugs. The concrete plugs were composed of cement-based materials. In addition to cement-based plugs a 10 metres long copper/clay plug was emplaced into the hole. The copper/clay plug consisted of perforated copper tubes filled with tightly fitting clay columns.

Sampling and laboratory testing of the plug components for determination of the physical and chemical properties from the lower part of the borehole will be made from the shaft access tunnel, when excavation has reached plugging level (-520). It is expected that the plug components will mature nearly completely in less than a month, that the plugs will have sufficient physical strength and that those consisting of clay are sufficiently tight.

The figure below (Figure 13) specifies the positions and nature of the plugs.

![Figure 13. Location of the plugs in borehole OL-KR24.](image-url)
5.2 Plug materials

Before the work started the borehole was dummy probed and the borehole water was replaced with tap water. The bottom packers to drill rods and hold-down-plugs, pistons for concrete transport and copper tubes with Na-bentonite with the Corac N3 transport-safety tool and the kit of plastic pistons were provided by LiwInStone AB for the installation work of the quartz concrete plugs and the clay plugs. The bottom packer for the ordinary grouting was provided by Smoy.

The representative of CBI advised the composition of the concrete. The used materials and composition of the quartz/concrete plugs in the plugging experiment are presented in Table 3. The used materials and the composition of the ordinary concrete plugs are presented in Table 4.

**Table 3.** The basic components of the quartz concrete plugs in the plugging experiment.

<table>
<thead>
<tr>
<th>Material</th>
<th>Amount (kg/m³ concrete)</th>
<th>Manufacturer</th>
</tr>
</thead>
<tbody>
<tr>
<td>White cement</td>
<td>60.0</td>
<td>Aalborg Portland</td>
</tr>
<tr>
<td>Microsilica Grade 940</td>
<td>60.0</td>
<td>Elkem</td>
</tr>
<tr>
<td>Fine ground α-quartz M300</td>
<td>200.0</td>
<td>Sibelco</td>
</tr>
<tr>
<td>Fine ground cristobalite quartz M6000</td>
<td>150.0</td>
<td>Sibelco</td>
</tr>
<tr>
<td>Glenium 51</td>
<td>4.375 (dry content)</td>
<td>Degussa</td>
</tr>
<tr>
<td>Granitic aggregates 0-4 mm</td>
<td>1700.0</td>
<td>Jehanders grus</td>
</tr>
</tbody>
</table>

**Table 4.** The basic components of the ordinary cement-based plug.

<table>
<thead>
<tr>
<th>Material</th>
<th>Amount (kg/m³ concrete)</th>
<th>Manufacturer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sr- cement</td>
<td>500 kg/m³</td>
<td>Finnsementti Oy</td>
</tr>
<tr>
<td>Water</td>
<td>262.6 kg/m³</td>
<td>Elkem</td>
</tr>
<tr>
<td>Groutaid</td>
<td>50 kg/m³</td>
<td></td>
</tr>
<tr>
<td>Aggregates 0-8 mm</td>
<td>1381.5 kg/m³</td>
<td>Oy Sika Finland Ab</td>
</tr>
<tr>
<td>Retarding agent</td>
<td>1.5 kg/m³ (0,3 % of cement weight)</td>
<td></td>
</tr>
<tr>
<td>water/cement</td>
<td>0.5775</td>
<td></td>
</tr>
<tr>
<td>water/binder</td>
<td>0.55</td>
<td></td>
</tr>
</tbody>
</table>
5.3 Installation phases and equipment/techniques

First the drill rods were lowered to the bottom of the borehole to check the openness of the hole. The drill rods were lifted from the borehole and the bottom packer was inserted in the bottom end of the drill rods. The bottom packer is planned for grouting. The packer will open when pressure is increased to 1.8 MPa and the concrete mixture is pushed away from the drill rods to the borehole.

Six drill rods (about 50 litres per 30 metres) were filled with concrete (Table 4) and lowered to the depth of about 530 metres using the platform as the reference level. The pressure was increased to 90 MPa, but the valve did not open. The drill rods were lifted and it was noticed that the material was sorted. The bottom part of the drill rods contained coarse-grained sand and the upper part partly hardened concrete.

The drill rods were washed and they were lowered again to the depth of 530 m. About 0.1 m$^3$ of concrete based on ordinary cement was pumped to the bottom of the borehole. The drill rods were lifted up and washed. The level of concrete surface was checked first with a marking spike and then with the drill rods. When checking the level of the concrete surface with the drill rods, it was noticed that there was only some coarse-grained sand residue left in the bottom of the borehole and without any cement, which had been flushed away.

Due to these difficulties it was decided that the bottom of the borehole would be filled with gravel (grain size 0…8 mm) up to the depth of 530 m.

5.3.1 Cement/quartz concrete plug

The cement/quartz concrete plug (Table 3) was placed above the bottom gravel between the levels -530 m and -525 m. The material, 25 litres of quartz and cement, was lowered in two steps. The transport instrument (injector) with copper bottom plug was filled with 12.5 litres of concrete. By introducing pressure on the piston the material was pushed out from the transport instrument into the borehole above the bottom gravel. The cement/quartz concrete plug was re-drilled after hardening to the level of -525 m as the basis for the next plug.
5.3.2 Copper/clay plug

The copper/clay plug, i.e. a perforated copper tube with highly compacted smectitic (bentonite) clay inside the tube, was inserted above the quartz/cement plug. The copper/clay plug (Figure 14) was placed into the borehole in two parts (2.5 m and 7.5 m) with a transport instrument (Figure 15) planned by LiwInStone AB. Before lowering second 7.5 m section of the plug the 2.5 m long plugs were pressed together (Figure 15 and 16) to get longer plug. The diameter of the tube was 72 mm and the thickness of the copper tube was 1 mm. The weight of one 2.5 m long copper tube with bentonite infilling was 25 kg. The copper tube with bentonite was placed from the level -525 m up to the level -515 m.

Figure 14. The copper/clay plugs.
Figure 15. The tube holder and press unit used with copper/clay plugs.
Figure 16. The tube holder and press unit pressing copper/clay plugs together before transport them to the borehole.

5.3.3 Upper cement/quartz concrete plug

Another cement/quartz concrete plug (Table 3) was placed above the copper tube. The concrete was lowered in two steps as presented in Chapter 5.3.1. This cement/quartz concrete plug was inserted between the levels -515 m and -510 m.

5.3.4 Concrete plug

The upper part of the borehole was filled with ordinary cement based concrete (Table 4). The concrete was transported by truck from the mixing station by Lohja Rudus in Ulvila. Groutaid and retarding agent were added to the concrete on the site at Olkiluoto.
Pumping of concrete started when drill string was at the depth of 500 m (level –490), i.e. 20 m above the upper cement/quartz concrete plug. When 1.5 m³ of concrete was pumped into the drill string, 60 metres of rods were lifted up and another 0.3 m³ of concrete was pumped into the drill string. After this all the rods were lifted up.

When all the rods were up, the uplifting of 84/77 mm casing was started. When the casing was loose, it was filled with concrete and the casing was removed. After the casing was removed, the level of the concrete in the borehole was checked. The measured depth of the concrete surface was at the depth of 25 m and 0.1 m³ of concrete was added into the hole. Altogether about 2.6 m³ of concrete was used to fill the borehole in this step.

5.4 Demobilization

After plugging the hole the demobilization of the rig was started. When the outer casing (114 mm) was removed the level of the concrete surface was measured. The surface was 1 m below the shaft drift (-11 level) floor.

5.5 Outcome of the work vs. plans

The aim of this activity was to test the practicality in constructing plugs in deep boreholes. The plugging was performed in five steps consisting of cement-based plugs and a perforated copper tube with Na-bentonite clay filling. When placing concrete to the bottom of the borehole with the bottom packer, there were some difficulties with the sorting of the concrete. It is assumed that one reason for the sorting phenomena could be that the sand was containing small clay particles. When using sand it should be properly washed to avoid sorting problems.

The cement/quartz concrete plugs and the copper tube with bentonite were placed successfully and all the equipment worked as planned.

When filling a deeper borehole, a large volume of concrete is needed and pumping with the concrete truck is a convenient way to do it.
6. SUMMARY

Sealing of investigation boreholes will be an essential part of the final closure of a repository system. The basic requirement is that the boreholes drilled at a site must not act as a continuous flow path for groundwater but be sealed to become as tight as the surrounding rock. This far some forty deep boreholes have been drilled from the surface at the Olkiluoto site and new boreholes are planned. Boreholes will also be drilled from underground in the ONKALO facility, the construction of which started in the autumn of 2004.

SKB and Posiva are actively developing a proper sealing concept for the investigation boreholes. The companies started Stage 3 of the joint project “Cleaning and sealing of investigation boreholes" in 2005. This work presents the field operations for the sub-project related to the plugging experiment in borehole OL-KR24 at Olkiluoto. The experiment consisted of four main activities: 1) cleaning of the borehole, 2) characterisation of the borehole 3) selective stabilisation of the borehole, and 4) emplacement of the plugs.

The comprehensive clearing of the borehole consisted of removal of all the extraordinary materials from the borehole, setting the casings in the borehole and flushing the borehole. The cleaning of the borehole was done successfully, in spite of some difficulties when removing the materials from the borehole.

The aim of the characterisation was to study the borehole in order to determine the sections for the selective stabilisation and the locations for the plugs. The characterisation phase consisted of caliper measurements, dummy testing and optical borehole imaging (OBI).

The aim of the selective stabilisation was to show that the selected borehole sections can be stabilised. As the first step the borehole was reamed from Ø 76 mm to Ø 98 mm. The reaming was completed successfully for one selected section. Unfortunately there was no time to ream other sections. In the second phase the plan was to bring sufficient amount of concrete in the borehole in the reamed section. Severe problems appeared when setting the concrete to the right place in the borehole. Groundwater flow in the borehole caused also some problems. It was noticed that when drilling the lower Parker it rose some metres to the reamed part of the borehole. The concrete was set successfully in the borehole only once but even then the concrete ended to a wrong
position. When stabilising the borehole 70 litres of concrete was used and eight metres of concrete was retrieved as core sample, which equals about 21 litres. Altogether 49 litres of concrete remained in the borehole or flushed away with the returning water.

The purpose of the installation of the cement and clay plugs was to test the practicality in constructing plugs in deep boreholes with an acceptable quality. The final sampling in OL-KR24 and the determination of the physical and chemical properties of the plugs will be done after the ONKALO tunnel has reached the level -520. The plugging was performed in six steps by using cement-based plugs and a perforated copper tube filled with Na-bentonite clay. When placing the concrete to the bottom of the borehole with the bottom packer, some difficulties were met due to sorting of the concrete. The cement/quartz concrete plugs and the copper tube with bentonite were placed successfully between levels -525 and -510 and all the equipment worked as planned.

For filling the upper part of the borehole from the depth of -510 m to the tunnel level -11 m, a bigger amount of concrete was needed. The work was done by pumping the concrete with the help of the concrete truck, which proved to be a convenient way for this purpose.
7. REFERENCES


