P-09-55

Forsmark site investigation

Drilling of the cored borehole KFR106

Göran Nilsson, GNC AB

November 2009

Svensk Kärnbränslehantering AB
Swedish Nuclear Fuel
and Waste Management Co

Box 250, SE-101 24 Stockholm
Phone +46 8 459 84 00

ISSN 1651-4416
SKB P-09-55

Forsmark site investigation

Drilling of the cored borehole KFR106

Göran Nilsson, GNC AB

November 2009

Keywords: P-report SKBDoc id1231270, Review statement SKBDoc id 1231271, AP SFR-09-055, AP SFR-09-016, Percussion drilling, Core drilling, Project SFR extension.

Abstract

A borehole drilled in solid rock, KFR106, was drilled from “Kobben”, a small islet located 225 m SE the pier at the Forsmark harbour, using traditional core drilling technique, in order to receive drill cores from the shallow and semi-deep parts of the bedrock. To simplify for the core drilling and to shorten the time schedule, the upper bedrock was drilled and cased with a percussion drilling method prior to commencement of core drilling.

KFR106 is 300.13 m long, inclined 69.89° from the horizon, has a bearing of 195.11° from N, and reaches about 290 m in vertical distance from the ground surface.

During core drilling, return water ceased at 108 m drilling length. Consequently, all flushing water and drilling debris remained in the borehole and in the penetrated fractures during continued core drilling.

A sampling- and measurement programme for core drilling of KFR106 provided preliminary but current information about the geological and hydraulic character of the borehole directly on-site. It also served as a basis for extended post-drilling analyses. E.g., the drill cores together with later produced video images of the borehole wall (so called BIPS-images), were used as working material for the borehole mapping (so called Boremap mapping) performed after drilling. Results of the Boremap mapping of KFR106 are included in this report.

After completed drilling, grooves were milled into the borehole wall at certain intervals as an aid for length calibration when performing different kinds of borehole measurements after drilling.

Sammanfattning

Ett traditionellt kärnborrhål har borrats på ”Kobben” som ligger 225 m SE om piren från Asphällskulten vid Forsmarks hamn. För att effektivisera borrning av foderrör och förkorta tidplanen utnyttjades en hammarborrmaskin som drev ner ett foderrör till fast berg.

Borrhålet som benämns KFR106, är 300,13 m långt och är ansatt med 69,89° lutning från horisontalplanet samt når cirka 290 m i vertikal riktning från markytan. Ett 9,13 m långt foderrör drevs ner med hammarborrmaskinen. Under den efterföljande kärnborrningen upphörde returvatten helt vid 108 m, vilket innebär att huvuddelen av allt borrkax och spolvatten blev kvar i borrhålet.

Ett mät- och provtagningsprogram under kärnborrningsfasen gav preliminär information om borrhålets geologiska och hydrauliska karaktär direkt under pågående borrning samt underlag för fördjupade analyser efter borrning. Bland de insamlade proverna utgör borrkärnorna tillsammans med videofilm av borrhålsväggen (s k BIPS-bilder) underlaget för borrhålskartering (s k Boremapkartering) som utförs efter borrning. Även resultaten från Boremapkarteringen av KFR106 finns redovisade i föreliggande rapport.

Efter avslutad borrning frästes referensspår in i borrhålsväggen med syftet att användas för längdkalibrering i samband med olika typer av borrhålsmätningar som senare utförs i det färdiga borrhålet.

Contents

1 Introduction

The Swedish Nuclear Fuel and Waste Management Co (SKB) is since the mid 80-ies running the underground final repository for low- and medium level radioactive operational waste (SFR) at Forsmark within the Östhammar municipality, see Figure 1-1. Since April 2008, SKB conducts bed-rock investigations for a future extension of the repository. The extension project, in Swedish termed "Projekt SFR-utbyggnad" (Project SFR Extension), is organized into a number of sub-projects, of which geoscientific investigations are included in one sub-project, "Projekt SFR-utbyggnad – Undersökningar" (Project SFR Extension – Investigations).

The geoscientific investigations for the planned extension of SFR are performed in compliance with an investigation programme /1/. Experience and data from the construction of the existing SFR facility in the 1980-ies served as important input for the programme. Further, the recently com-pleted comprehensive site investigations for a final repository for spent nuclear high-level waste at Forsmark (controlled by a general investigation programme /2/), provided a vast amount of data about the sub-surface realm down to about 1,000 m in the immediate vicinity of, and even over-lapping, the SFR-area. Data and experiences also from these investigations have strongly influenced the elaboration of investigation strategies for the current SFR-investigation programme.

For direct sub-surface investigations, drilling is an inevitable activity. Providing investigation boreholes is especially vital in the SFR-project, because the major part of the rock volume to be investigated is covered by the Baltic Sea, thereby rendering ground geophysical measurements and other surface-based investigations more difficult than at land. Two main types of boreholes will be produced within the scope of the site investigations, core drilled- and percussion drilled boreholes, respectively. For the initial phase of the investigations five percussion boreholes and five cored

Figure 1-1. *General overview over Forsmark and the SFR site investigation area.*

boreholes drilled from the ground surface and one underground cored borehole drilled from the SFR facility have been suggested /1/. However, recent assessments of the investigation results obtained so far indicate that two of the percussion boreholes, HFR103 and HFR104, may not need to be drilled in order to obtain the objectives of the site investigation.

This document reports the data and results gained by drilling the cored borehole of traditional type, KFR106, from the small islet "Kobben" located c. 225 m SE the pier at Forsmark harbour, an activity which is included in the final investigation phase of Project SFR Extension (SFR Utbyggnad) programme. The percussion- and core drilling operations were carried out in accordance with activity plans AP SFR-09-015 and AP SFR-09-016. Controlling documents for performing this activity are listed in Table 1-1. Both activity plans and method descriptions are SKB's internal controlling documents.

New drill sites for five cored boreholes were built on the pier at Asphällskulten during the spring 2008, see Figure 1-2. In addition, an old borehole drilled 1981, KFR27, was rediscovered, although the borehole casing was covered with gravel of one metre thickness. A minor drill site was prepared also around this borehole, and the borehole was restored, prolonged and used for measurements within the scope of Project SFR Extension.

Züblin (Sven Andersson in Uppsala AB) was contracted for the pre-drilling through the upper bedrock, whereas Drillcon Core AB was employed for the core drilling commission. Support was provided from SKB-personnel regarding measurements and tests during drilling.

Pre-drilling and casing installation to c. 9 m was carried out between June 22nd and June 25th 2009. Core drilling and measurements were conducted during the period August 19th to September 3rd, 2009.

Original data from the reported activity are stored in the primary database Sicada. Data are traceable in Sicada by the Activity Plan numbers (AP SFR-09-015 and AP SFR-09-016). Only data in databases are accepted for further interpretation and modelling. The data presented in this report are regarded as copies of the original data. Data in the databases may be revised, if needed. Such revisions will not necessarily result in up-dating of the P-report, although the normal procedure is that major revisions also entail a revision of the P-report. Minor revisions are normally presented as supplements, available at www.skb.se.

Table 1-1. Controlling documents for performance of the activity.

Activity plan	Number	Version
Kärnborrning av borrhål KFR106	AP SFR -09-016	1.0
Hammarborrning av HFR106 samt förborrning och montering av foderrör i KFR106	AP SFR -09-015	1.0
Method documents	**Number**	**Version**
Metodbeskrivning för kärnborrning	SKB MD 620.003	3.0
Metodbeskrivning för hammarborrning	SKB MD 610.003	4.0
Metodinstruktion för rengöring av borrhålsutrustning och viss markbaserad utrustning	SKB MD 600.004	1.0
Metodinstruktion för användning av kemiska produkter och material vid borrning och undersökningar	SKB MD 600.006	1.0
Metodbeskrivning för genomförande av hydrauliska	SKB MD 321.003	1.0
enhålspumptester	SKB MD 640.001	2.0
Metodbeskrivning för registrering och provtagning	SKB MD 321 002	1.0
av spolvattenparametrar samt vägning av borrkax under kärnborrning		
Metodbeskrivning för vattenprovtagning, pumptest och tryckmätning i samband med wirelineborrning.		
Metodbeskrivning för krökningsmätning av hammar- och kärnborrhål.	SKB MD 224.001	2.0

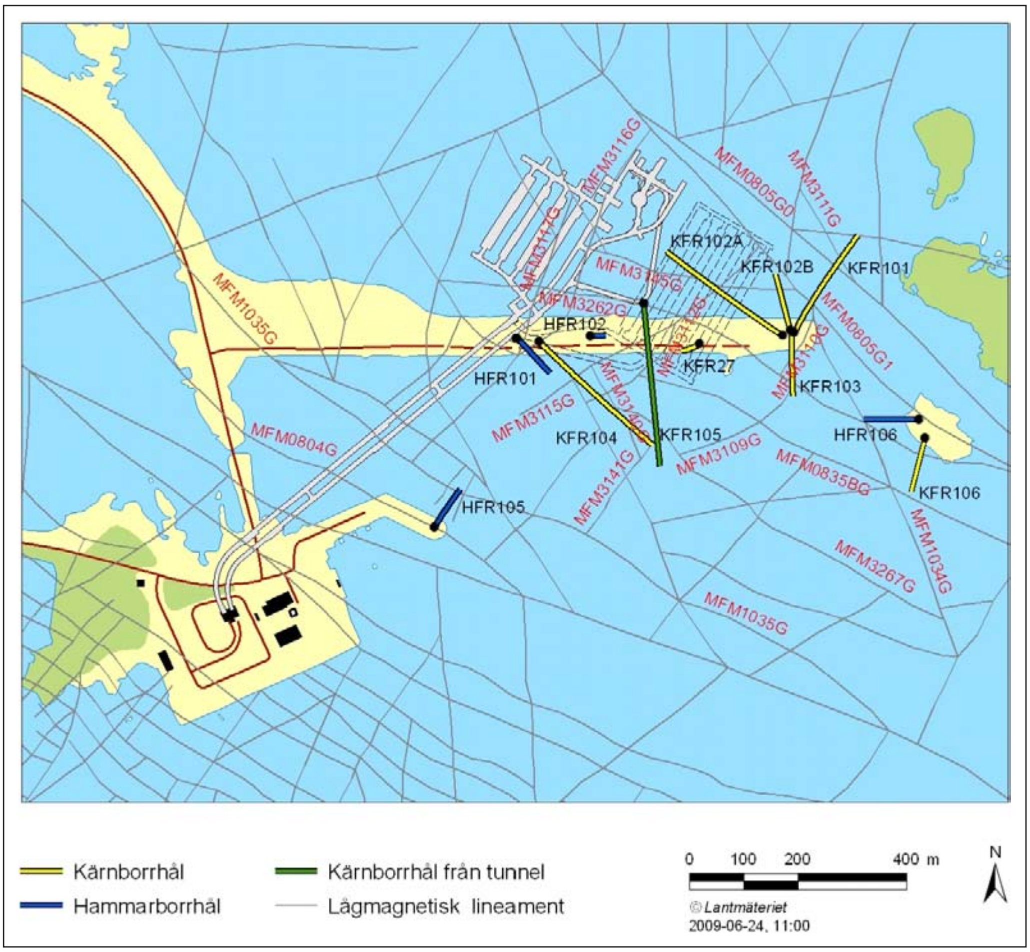


Figure 1-2. *Overview over the SFR site investigation area, with boreholes drilled during Project SFR Extension – investigations and the candidate area for the SFR extension marked with lines.*

2 Objective and scope

The overall objective of drilling borehole KFR106 was to investigate the rock volume selected for a future extension of SKB´s final repository for radioactive operational waste (SFR). The borehole was specifically drilled to:

- Provide drill cores all the way from the rock surface to the borehole bottom. The rock samples collected during drilling are used for lithological, structural and rock mechanical characterization.
- Render geophysical borehole investigations possible, e.g. TV logging, borehole radar logging and conventional geophysical logging as an aid for the geological/rock mechanical characterization.
- Allow hydraulic borehole tests (single hole tests as well as interference tests by employing also nearby boreholes,) for characterization of the hydrogeological conditions of the bedrock.
- Enable long-term hydraulic and hydrogeochemical monitoring at different levels of the bedrock.

A specific objective for borehole KFR106 was to intend to explore a possible (but not verified) near-horizontal fracture zone in the upper bedrock as well as some minor fracture zones striking north-east.

Another objective was to provide perspicuous geological information of the bedrock conditions at depth beneath the SFR facility.

During drilling, a number of drilling related parameters were monitored by a drilling monitoring system. Part of this data set, in this report called DMS (Drilling Monitoring System) data, which after drilling are transferred to Sicada, may be used as supplementary data for geological and hydraulic characterization as well as for assessment of technical aspects of the drilling operations. The DMS-data from KFR106 are described in this report.

Furthermore, a number of hydraulic tests and water samplings are normally performed during the drilling process, whereby a specifically designed test system, a so called wireline probe, is utilized. However, as water from the Baltic Sea was used as flushing water, which renders the possibilities of obtaining high-class samples for hydrochemical analysis more difficult compared to if flushing water from a drilled water well or from clean tap water is used, and because flow logging was carried out shortly after drilling, no tests with the wireline probe were performed.

3 Equipment

In this chapter a short presentation is given of the drilling systems and the technique applied, as well as of the equipment used for measurements and sampling during drilling. Besides, the instrumentation used for deviation measurements performed after completion of drilling is briefly described.

3.1 Equipment used for the pre-drilling

For pre-drilling of the cored borehole of traditional type KFR106 a Nemek 407 RE percussion drilling rig was employed applying the NO-X 115 system $Ø_o/Ø_i$ 139.7/129.7 mm.

The Nemek 407 RE drilling machine is equipped with separate engines for transportation and power supplies. Water and drill cuttings were discharged from the borehole by means of an Atlas-Copco XRVS 455 Md 27 bars diesel compressor. The air-operated DTH (Down The Hole) drilling hammer was of type Secoroc 5”, descended in the borehole by a Driconeq 76 mm pipe string.

All DTH-components were, prior to be used in the borehole, cleaned with a Kärcher HDS 1195 high-capacity steam cleaner.

3.2 Core drilling system

For drilling of the cored borehole KFR106 a drilling machine from Sandvik, type DE130, was employed. This machine was supplied with an electrically-driven hydraulic system, see Figure 3-1. The drilling capacity of a Sandvik DE130 with WL76 is maximum c. 700 metres. The capacity estimate is presupposing the use of AC Corac N3/50 NT drill pipes.

The drill pipes and stainless steel core barrel used constitute a wireline system applied to fit SKB’s need for a “triple tube wireline system” with a core dimension slightly exceeding 50 mm. Technical specifications of the drilling machine with fittings are given in Table 3-1.

Core drilling with a wireline system involves recovery of the core barrel via the drill pipe string, inside which it is hoisted up with the wireline winch. During drilling of boreholes KFR106, a 3 m triple tube core barrel was used. The nominal core diameter for the Ø 75.8 mm part of the borehole is 50.8 mm. Minor deviations from this diameter may however occur.

Figure 3-1. *The Sandvik DE130 drilled boreholes KFR106.*

Table 3-1. Technical specifications of the Sandvik DE130 with appurtenances.

Unit	Manufacturer/type	Specifications
DE130	Sandvik	Capacity for 76–77 mm holes of max approx. 700 m borehole length
Flush water pump	Bean	Max flow rate: 170 L/min
		Max pressure: 103 bars
Submersible pump	Grundfoss SQ	Max flow rate: 200 L/min

3.2.1 Flushing/return water treatment – equipment and methods

Core drilling involves pumping of flushing water down the drill string, through the drill bit and into the borehole in order 1) to conduct frictional heat away from the drill bit, and 2) to enhance the recovery of drill cuttings to the ground surface. The cuttings, suspended in the flushing water (in general mixed with groundwater), are forced from the borehole bottom to the ground surface via the gap between the borehole wall and the drill pipes.

A schematic illustration of the flushing/return water system when drilling KFR106 is displayed in Figure 3-2. Below, the following equipment systems and their functions are briefly described:

- equipment for preparing the flushing water,
- equipment for measuring flushing water parameters (flow rate and electrical conductivity),
- equipment for storage and discharge of return water.

Preparation of flushing water

The water source for supply of flushing water when drilling KFR106 was the Baltic Sea, (Figure 1-2). The flushing water was prepared before use in accordance with SKB MD 620.003 (Method description for core drilling), with an organic dye tracer, Uranine, which was added to the flushing water at a concentration of 0.2 mg/L before the water was pumped into the borehole, see Figure 3-2. The tracer was thoroughly mixed with the flushing water in the tank. Labelling the flushing water with the tracer aims at enabling detection of flushing water contents in groundwater samples collected in the borehole during or after drilling.

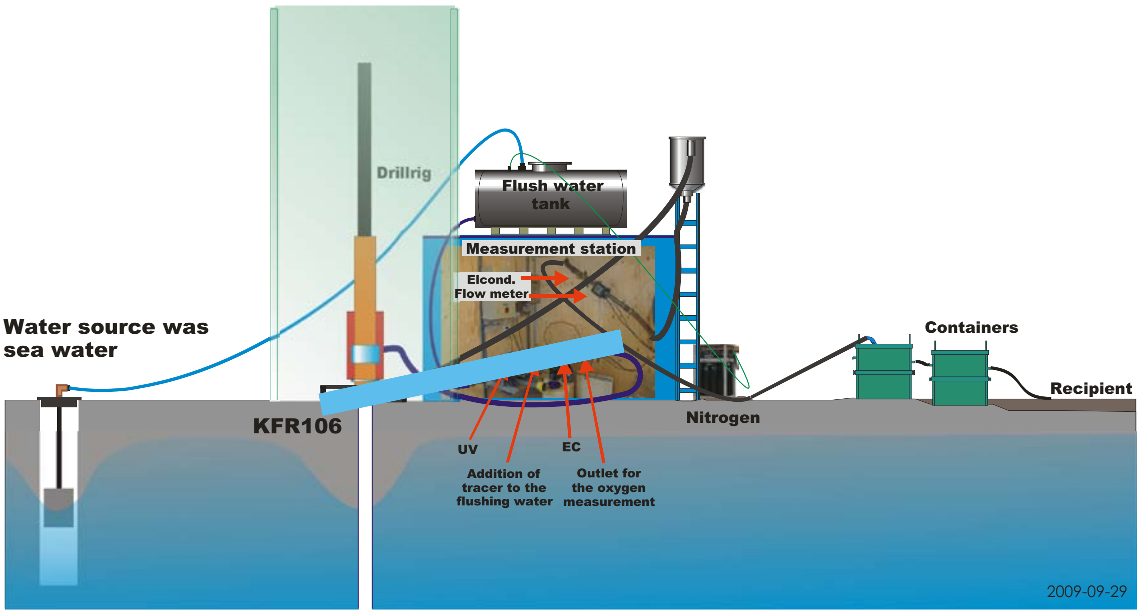


Figure 3-2. Schematic illustration of the flushing/return water system when drilling KFR106. The measurement station included logger units and an UV-radiation unit, and an additional manual flow meter measured the total incoming water. The Baltic Sea, surrounding the islet from which KFR106 was drilled, served as flushing water source as well as recipient for the return water.

In order to reduce the contents of dissolved oxygen in the flushing water, nitrogen gas was continuously flushed through the flushing water tank, see Figure 3-2. The oxygen contents of the flushing water was measured before use in the borehole, see Section 5.3.1.

Measurement of flushing water parameters

The following two flushing water parameters were measured on-line when pumping the flushing water into the borehole:

- flow rate,
- electrical conductivity.

Data were stored in a drilling monitoring system. Technical specifications of the measurement instruments are presented in Table 3-2.

The total quantity of water supplied to the borehole, used as a double-check of the flow measurements, was acquired by manual reading of a flow meter. Besides, the electric conductivity of the flushing water was measured by manual readings of a conductivity meter. The readings were stored and afterwards compared to the automatic readings, a measure taken which served as a data quality check.

Storage and discharge of return water

The return water was discharged from the borehole via the expansion vessel, a discharge hose, a flow meter and a discharge pipe to two containers (see Figure 3-2), in which the drill cuttings separated out in two sedimentation steps. The cuttings were preserved in the containers for later weighing. Due to strict environmental restrictions, the return water was pumped through an oil separator and thereafter through an exit pipe string directly to the Baltic sea.

3.3 Groove milling equipment

After completion of drilling, the borehole is to be used for a variety of borehole measurements, employing many types of borehole instruments with different stretching characteristics (pipe strings, wires, cables etc). In order to provide a system for length calibration in the borehole, reference grooves were milled into the borehole wall with a specially designed tool at regular levels. This was carried out after drilling, but with use of the drilling machine and pipe string.

At each level, two 20 mm wide grooves were milled with a distance of 10 cm between them, see Figure 3-3. After milling, the reference grooves were detected with the SKB level indicator (a calliper instrument). A BIPS-survey provided the final confirmation that the groove milling had been successful.

Table 3-2. Technical specifications of instruments used for measurement of flushing water parameters.

Instrument	Manufacturer/type	Range of measurement	Remarks
Flow meter	Krohne IFC 010-D	1–350 L/min	Inductive
Electrical Conductivity	Kemotron 2911	1 mS/cm–200 mS/cm 0.1 mS/m–20 S/m	
Electrical Conductivity	YOKOGAWA SC72	0.1 μ/cm–20 S/m	Hand-held instrument

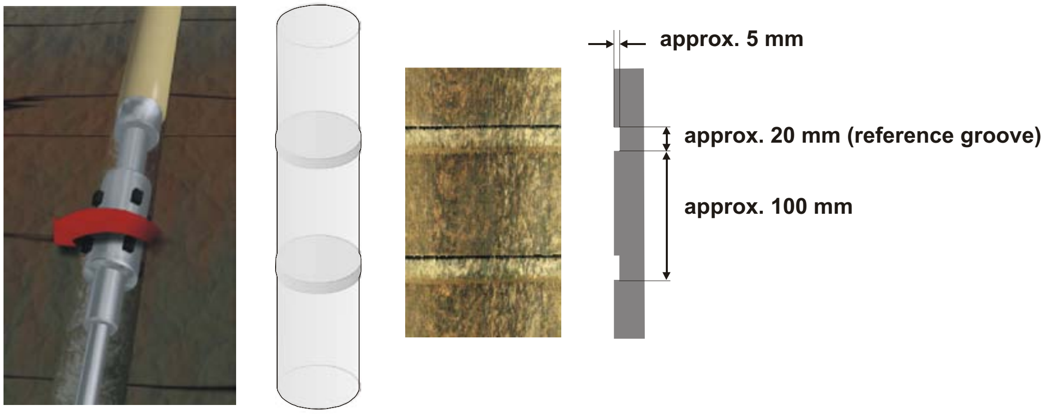


***Figure 3-3.** Layout and design of reference grooves.*

3.4 Equipment for deviation measurements

After completed drilling, deviation measurements were made in order to check the straightness of the borehole. The measurements were performed with a Reflex Maxibor II™-system, which is an optical, i.e. non-magnetic, measurement system. Azimuth and dip are measured at every third metre. The borehole collar coordinates and the measured values are used for calculating the coordinates of the position of the borehole at every measurement point.

Also another method, based on magnetometer-/accelerometer technique, was applied for deviation measurements in the borehole. The surveying instrument used was the Flexit Smart Tool System. All available deviation measurements, Flexit- as well as Maxibor-data, have been used for estimation of the uncertainty of deviation data.

Results from the deviation measurements and data handling are presented in Sections 5.3.3.

3.4.1 Calibration of borehole deviation data due to local variations in the magnetic field

Deviation equipment based on magnetometer/accelerometer is sensible to disturbances in the magnetic field. A known possible disturbing factor in the Forsmark area is the Fenno-Skan HVDC cable between Sweden and Finland. Therefore, a special procedure was introduced in order to ensure that no serious changes in the magnetic field, caused by Fenno-Skan, appeared during borehole deviation logging. The procedure implies that a number of readings with the Flexit probe are made in a fixed reference stand before and after each borehole deviation logging with this probe. If the two sets of readings agree within certain limits, the borehole deviation logging can be accepted. If the readings disagree, the Flexit-logging should be error-marked and a new logging performed. The reference stand (see Figure 3-4) was established at Asphällskulten in May 2008.

The reference stand is non-magnetic, inclined approximately 45 degrees and bolted to the bedrock in a fixed position. So far 15 reference measurements have been executed and stored in the SKB database Sicada at Id code PFR000120, Activity Type Code EG157. They show very small variations of the magnetic field and have a marginal affect on the borehole deviation loggings in the Forsmark area.

As an example, Figure 3-5 shows the readings before and after the deviation logging in another borehole, KFR103. As seen, the difference in magnetic bearing in the reference stand is less than 0.1 degree between the readings made before and after logging in the borehole for almost all data points. Also for borehole KFR106 the reference logging indicated a very good agreement. Hence, the borehole deviation logging was accepted and delivered to Sicada.

Figure 3-4. The Flexit Smart Tool is prepared for readings in the Forsmark reference stand.

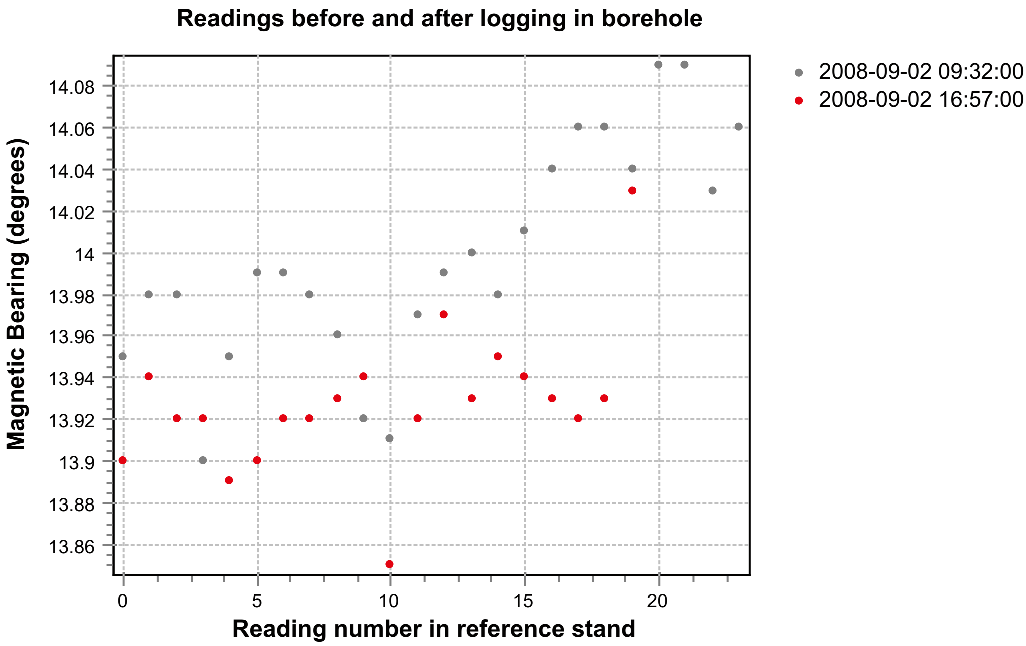


Figure 3-5. The magnetic bearing (azimuth) from readings made in the reference stand before and after logging in borehole KFR103 on 2 September, 2008. The difference is less than 0.1 degree.

4 Execution

4.1 General

The activities were conducted in compliance with Activity Plans AP SFR-09-015 and AP SFR-09-016, which refer to SKB MD 610.003 (Method description for percussion drilling) and SKB MD 620.003 (Method description for core drilling), respectively. The drilling operations for percussion drilling as well as for core drilling included the following parts:

- preparations,
- mobilisation, including lining up the machine and measuring the position,
- drilling, measurements and sampling during drilling (measurements and sampling during drilling performed only during core drilling),
- finishing off work,
- data handling.

Furthermore, the drilling activities were subject to an environmental control programme with the purpose of minimizing the risk of environmental disturbance, for example pollution of the ground layer or groundwater by oil or other contaminants.

These five items are presented more in detail in Sections 4.2 to Section 4.6.

4.2 Preparations

The preparations included the Contractor's service and function control of his equipment. The machinery was supplied with fuel, oil and grease entirely of the types stated in SKB MD 600.006. Finally, the equipment was cleaned at level one in accordance with SKB MD 600.004.

4.3 Mobilization

Mobilization onto and at the site included preparation of the drill site, transport of drilling equipment, flushing water equipment, sample boxes for drill cores as well as hand tools etc. Furthermore, the mobilization consisted of cleaning of all in-the-hole equipment at level one in accordance with SKB MD 600.004, lining up the machine and final function control of all equipment.

4.4 Drilling, measurements and sampling during drilling

4.4.1 Pre-drilling (percussion drilling)

The drill site was, prior to commencement of drilling and in a separately managed activity, prepared according to SKB MD 600.005 (Method instruction for constructing drill sites), aiming at facilitating the drilling operations as much as possible. For example, a steel platform was cast around the planned borehole collar to serve as a convenient working space and to enable firm anchorage of the core drilling machine during drilling. The drill site was also connected to the local data communication net by using radio technique from the islet to the on-land net.

As no overburden covers the islet, the N-OX 115 percussion drilling with the Nemek 407 RE drilling machine was performed directly on a the rock surface. A c. 9 m long stainless steel casing was driven through the upper bedrock during drilling. Technical data of the installed casing are presented in Chapter 5.

Due to the limited extent of percussion drilling in the borehole, the programme for measurements and sampling during drilling was omitted.

4.4.2 Core Drilling

Core drilling started from the bottom of the pre-drilled borehole inside the stainless steel casing.

During and immediately after core drilling a programme for sampling, measurements and some other activities was performed, cf. SKB MD 620.003. Results from these measurements are presented in Chapter 5.

4.5 Finishing off work

The concluding work included the following items:

1) The borehole was flushed for a few minutes ensuing percussion drilling and for about one hour after completion of core drilling in order to rinse the borehole from drilling debris adhered to the borehole walls, settled at the bottom of the hole or suspended in the water.
2) The drill string was pulled.
3) The borehole was, after completed core drilling, secured with a lockable stainless steel flange.
4) The drilling equipment was removed, and after core drilling the site was cleaned and a joint inspection made by SKB and the Contractor to ensure that all agreed work had been executed and that the drill site was left in the same good condition as before drilling.

4.6 Data handling/post processing

Minutes with the following headlines: Activities, Cleaning of equipment, Drilling, Borehole, Percussion drilling penetration rate, Deliverance of field material and Discrepancy report were collected by the Activity Leader, who made a control of the information, and had it stored in the SKB database Sicada. The minutes are traceable by the respective Activity Plan number.

4.7 Environmental programme

A programme according to SKB´s routine for environmental control was followed throughout the activity. A checklist was filled in and signed by the Activity Leader, who also filed it in the SKB archives.

4.8 Nonconformities

The core drilling operation in KFR106 resulted in a number of nonconformities with the Method Descriptions and Activity Plans for core drilling. Table 4-1 below presents a comparison of the suggested performance of KFR106 according to SKB MD 620.003 and the Activity Plan AP SFR-09-016 with the real performance.

Table 4-1. Programme for performance and frequency of sampling, measurements, registrations and other activities during and immediately after core drilling of KFR106 according to SKB MD 620.003 and AP SFR-09-016 compared to the virtual perfomance.

Activity	Performance and frequency according to SKB MD 620.003	Performance and frequency during drilling of KFR106
Registration of drilling- and flushing water parameters.	Registration during the entire drilling.	According to programme. (Methods described in Section 3.2.1.)
Core sampling.	Continuous sampling of the entire drilled section.	According to programme.
Deviation measurements.	Normally performed every 100 m and after completion of drilling.	Two Maxibor measurements after completion of drilling as well as two measurements with Flexit.
Hydraulic tests.	Normally performed every 100 m, and also when penetrating larger conductive fractures/deformation zones. The tightness of the drill pipe string should be controlled before each test.	No measurements performed.
Water sampling.	Normally performed every 100 m, and also when penetrating larger conductive fractures/deformation zones. The tightness of the drill pipe string should be controlled before each test.	No measurement performed.
Absolute pressure measurements.	Normally during natural pauses in drilling.	No measurements performed.
Groove milling in the borehole wall, normally at each 50 m drilling length.	Normally performed after completion of drilling.	Six grooves milled.

5 Results

Prior to drilling of KFR106, the basic drilling programme within Project SFR-Extension had successfully been executed with six cored and three percussion drilled boreholes from the ground surface as well as one cored borehole drilled from the SFR underground facilities.

When the preliminary results were summarized, the geological model indicated a possible, however not verified, near-horizontal fracture zone striking NW-SE that, if existing, could penetrate the preliminary SFR extension layout, see Figure 1-2. At least one cored borehole would be preferable to verify or dismiss this potential zone. As most of the area suitable for drilling boreholes with a potential to penetrate this zone (i.e. the Forsmark harbour area) is covered by the sea, off-shore drilling initially seemed to be inevitable. However, a pre-study was initiated aiming at assessing all available possibilities regarding drilling technique (primarily off-shore technique) as well as costs and time consumption for different alternatives regarding drilling in the Forsmark harbour area. Primarily, one inclined cored borehole of 300–400 m length and one inclined percussion borehole of about 200 m length were considered in the pre-study. The result from the study focused on three different alternatives;

- Extension of the existing pier.
- Drilling from an offshore platform.
- Drilling from the islet “Kobben”.

The first alternative includes construction of a 300 m long pier perpendicular to the existing pier. That would provide a drill site placed on ground surface, meaning that drilling and measuring activities could follow the standard investigation programme. By using material from the existing pier, the new pier could be constructed in six weeks. On the other hand, a facility like this would have to undergo an environmental impact assessment, that probably could demand several years to be approved, and therefore this alternative was excluded.

The second alternative, drilling from an off-shore located platform, was judged practicable but cost expensive. Available floating off-shore platforms are tightly anchored in four directions, but still surging sea may cause swelling of the platform, necessitating drilling and measurement stops of unpredictable lengths. Furthermore, the borehole will have to be plugged before liquidation of the platform, entailing that a long-time monitoring programme must be left out, with less data input to the geoscientific models as a consequence.

Finally, the third alternative, drilling from the small islet, “Kobben”, 225 m SE of the pier at Asphällskulten,(see Figure 5-1) involves a flat-bottomed barge for transportation of drilling and measuring equipments. Transportation and establishment of equipment cause increased costs, but on the other hand drilling, measurements and monitoring activities can be performed according to the standard programme for on-land boreholes. Also the environmental demands can be fulfilled by following the standard routines with an announcement to the local government and a building licence from the local community that could be received in not more than about two months.

When the modelling group confirmed that drilling of two boreholes from the islet could cover the lack of data in the Forsmark harbour area and provide sufficient information to be used for different model purposes, the project management decided to choose the third alternative and to conclude the drilling program with these boreholes. Below a summary is presented of the site preparation, data acquired during drilling and drilling related measurements in the traditional core drilled borehole KFR106 on the islet “Kobben”.

5.1 Preparation of the drill site

In early May 2009, when the location and orientation of the cored borehole KFR106 and the percussion borehole HFR106 were settled, the practical preparations continued with building of a temporary slope for barge loading/unloading, at the end of the pier at Asphällskulten, see Figure 5-2.

Figure 5-1. Overview of the surroundings at the Forsmark harbour area and SFR. The new drill sites for percussion borehole HFR106 and the cored borehole KFR106 are located on the islet "Kobben".

Figure 5-2. At the end of the pier at Asphällskulten a temporary slope was built in order to easily load or un-load the barge.

The end of the pier offers a lot of space and could be used as a temporary storage for the equipments before they were shipped to the islet "Kobben".

In mid June 2009, a self-propelled flat-bottomed barge was contracted for three weeks, and started to carry gravel and a bucket loader from the pier to the islet for building a temporary slope on the northern part of the islet, to load/unload the barge. Gravel was also used to level the rock surface on vital parts for smoother transportation on the rocky islet, see Figure 5-3.

Figure 5-3. *Also at the islet "Kobben" a temporary slope was built of gravel carried from the pier with the barge. A bucket loader was stationed on the islet in order to load and un-load the barge.*

Some of the core drilling equipment was not transported to the islet at this stage, for two reasons. Firstly, the diesel powered electric generator was too heavy to unload on the islet. Secondly, the diesel fuel tanks could possibly be emptied by theft during the summer. These equipments were therefore loaded on two sliding barges after the summer vacation, tugged to the islet and anchored beside the drill site, see Figure 5-4.

When drilling a traditional SKB cored borehole, is it stated that a platform with surrounding sideboards, must be established around the borehole with the main task to collect accidental oil spillage from the drill rig. Usually, a reinforced concrete slab is cast around the borehole collar but during drilling of KFR105 from underground, a mobile steel platform was used, see Figure 5-5.

Figure 5-4. *The diesel powered electric generator and the fuel tanks were loaded on two sliding barges and anchored beside the KFR106 drill site.*

Figure 5-5. The platform, originally constructed for underground use, was modified to be used for core drilling on the islet.

Both constructions fulfil these environmental demands. For KFR106, the steel platform was modified for on-land use and established on the islet, see Figure 5-6. The platform is constructed to collect all liquids that are led to a side pocket where oil spillage can be observed and decontaminated. When all drilling activities had been completed, the steel platform was easy to demobilize.

Figure 5-6. Usually, the drilling rig is placed on a concrete plate, but instead, when drilling KFR106, a steel platform was used to fulfil the environmental demands (same platform was used for borehole KFR105 that was drilled from underground).

Simultaneously as percussion drilling of HFR106 and pre-drilling of KFR106 was performed, most of the core drilling equipment as well as measurement equipment for investigation of the two boreholes was carried to the islet. As the SFR-Extension project at this occasion was the only currently on-going SKB field project, most of the SKB owned measurement instruments were available, e.g. the BIPS-/radar- and HTHB-instruments (the latter used for flow measurement in percussion boreholes). Also these instruments were stationed at the islet, giving more flexibility in time to execute the measurements, see Figure 5-7.

For the daily transports of SKB staff and the drill crew, an all-around boat supplied with an outboard engine was used, that easily could find lee on either side of the island, depending on current weather conditions, see Figure 5-8.

A flat-bottomed barge is sensitive for strong wind, but despite a couple of days standstill, the work followed the time schedule. Therefore, in early July the main part of the field crew could leave for a well-deserved summer vacation.

Figure 5-7. *Two drilling rigs including all measurement equipment were successfully transported to the islet. To minimize the number of establishments for the flat-bottomed barge, also measurement instruments as BIPS-/radar-, flow logging- and air-flushing equipment were shipped to the islet during the first three weeks.*

Figure 5-8. *All-around boat used for staff transport between the harbour and the islet.*

5.1.1 Borehole geometrical definitions

After the drilling activity is executed, an intensive measurement programme is normally carried out in the borehole. In order to perform these measurement in a rational way and to enable quality assurance of measurement data, crucial borehole geometrical data, like borehole collar coordinates, borehole orientation and inclination, borehole and casing lengths and diameters etc are needed as input data.

To facilitate collection and further treatment of logging data, and in order to minimise the risk of misunderstandings of e.g. which level in the borehole the measured data are associated to, clear and indisputable definitions of borehole geometrical data must be available shortly after the drilling is completed. In Figure 5-9 some important borehole geometrical definitions are given.

The coordinate system used for all geographical objects in this report is:

RT90 2.5 gon V 0:-15 (x- and y-coordinates).

RHB 70 (z-coordinates).

It is important that the SKB field-crew, who is managing the drilling operations, and all logging crews, are fully aware of these definitions to ensure correct data filing.

5.2 Overview of the drilling of KFR106

Figure 5-10 illustrates the logistics during drilling of KFR106 and the separate sub-activities versus time, such as drilling, casing driving, grouting, and measurements while drilling. The horizontal axis represents real time and the vertical is the length of the borehole during the activity.

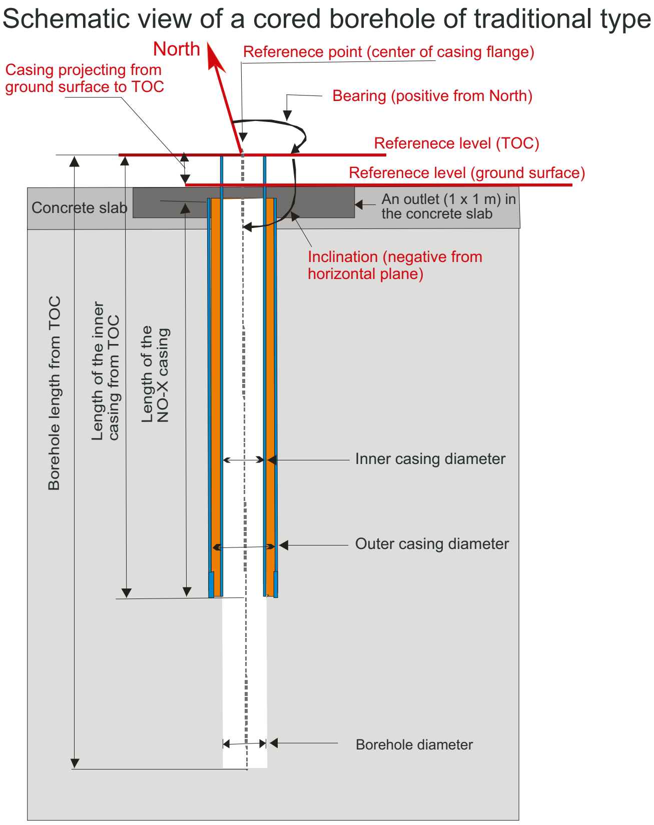


Figure 5-9. Schematic drawing of the upper part of a cored borehole of traditional type. The figure shows definitions of the most important data, as reference points, lengths and dimensions used for the technical description of the borehole in this report.

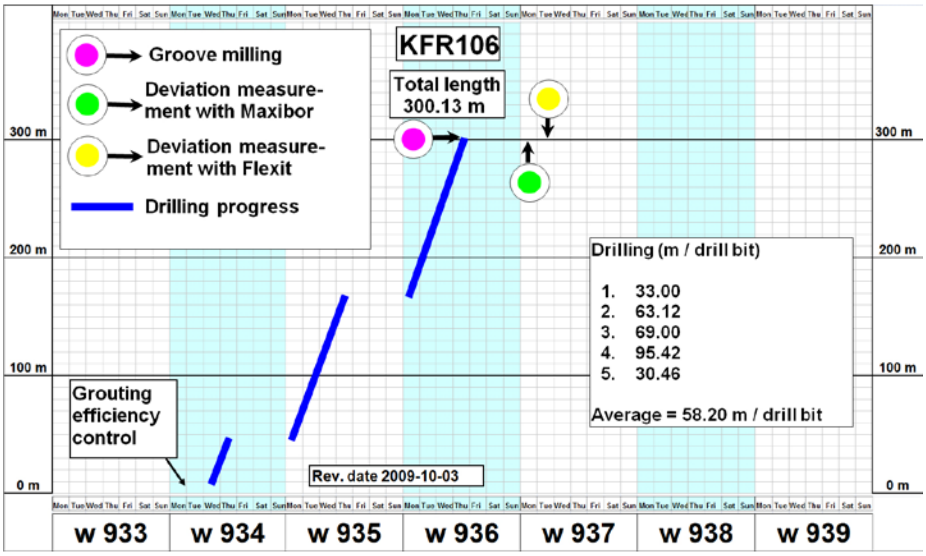


Figure 5-10. Overview of the drilling progress for percussion borehole KFR106.

5.3 Geometrical design of the percussion drilled borehole

Administrative, geometric, and technical data for KFR106 are presented in Table 5-1. The technical design of the borehole is illustrated in Figure 5-11.

Table 5-1. Administrative, geometric and technical data for borehole KFR106.

Parameter	Data
Borehole name	KFR106
Location	Forsmark, Östhammar municipality, Sweden
Drill start date	June 23, 2009
Completion date	September 03, 2009
Percussion drilling period	2009-06-23 to 2009-06-26 (including cement injection)
Core drilling period	2009-08-19 to 2009-09-03
Contractor core drilling	Drillcon Core AB
Subcontractor percussion drilling	Züblin Svenska AB; Sven Andersson i Uppsala AB
Percussion drill rig	Nemek 407 RE
Core drill rig	Sandvik DE130 (Onram 1000/3)
Position at top of casing	N 6701541.18 (m)
(system RT90 2.5 gon V 0:-15 / RHB 70)	E 1633592.14 (m)
	Z 1.06 m RBH70
	Azimuth (0–360°): 195.11°
	Dip (0–90°): –69.89°
Position at bottom of hole	N 6701440.43
(system RT90 2.5 gon V 0:–15 / RHB 70)	E 1633560.07
	Z –279.81 m RBH70
	Azimuth (0–360°): 199.73°
	Dip (0–90°): –68.95°
Borehole length	300.13 m
Borehole length and diameter	From 0.31 m to 9.13 m: 0.152 m
	From 9.13 m to 300.13 m: 0.0757 m
Outer casing, diameter and borehole length	Casing $Ø_o/Ø_i$ = 139.7/129.7 mm, from 0.30 to 9.01 m
	Casing shoe $Ø_o/Ø_i$ = 139.7/122 mm, from 9.01 to 9.05 m
	Casing shoe bit $Ø_o/Ø_i$ = 152/116 mm, from 9.05 to 9.13 m
Inner casing, diameter and borehole length	Casing $Ø_o/Ø_i$ = 80/77 mm, from 0 to 9.13 m
Drill core dimension and borehole length	Ø 50,2 mm, from 9.13 m to 300.13 m
Average length of core recovery	2.80 m
Number of coring runs	104
Diamond bits used	5
Average bit life	58.2 m

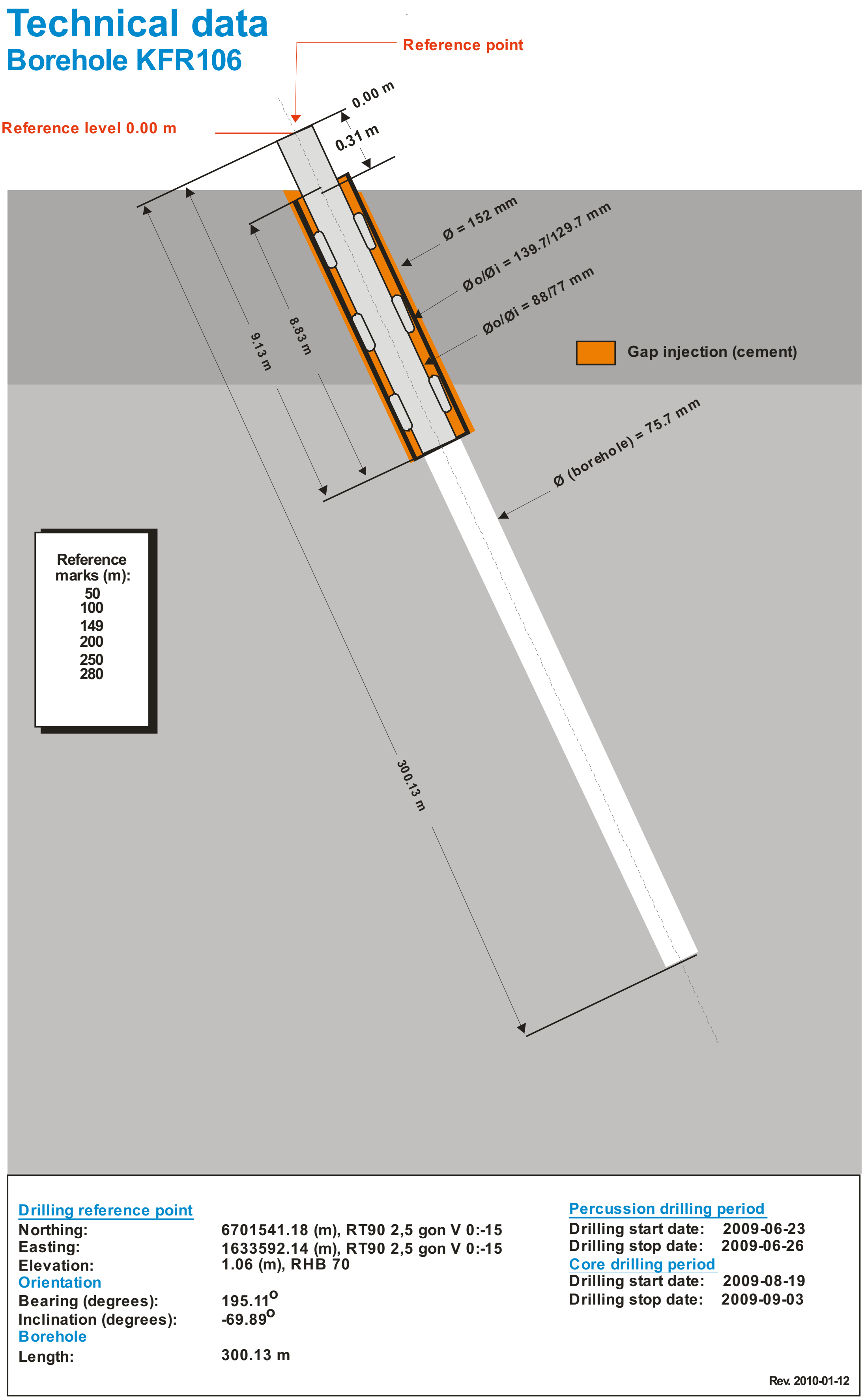


Figure 5-11. Technical data of borehole KFR106.

5.3.1 Measurement while drilling KFR106

During, and immediately after drilling, a programme for sampling and measurements was applied, cf. Section 4.4.2. Some of the results are displayed in the Well Cad presentation in Appendix A whereas other results (flow data and electrical conductivity) are only used as supporting data for on-site decisions.

Flushing water and return water flow rate – water balance

Figure 5-12 displays the accumulated volumes of flushing water respectively return water from the entire drilling period. The accumulated volumes of flushing water and return water are also illustrated in the histogram in Figure 5-13, from which the return water/flushing water quotient at the end of the drilling period may be calculated, in this case resulting in a quotient of 0.16, due to complete flushing water loss at 108 m drilling length.

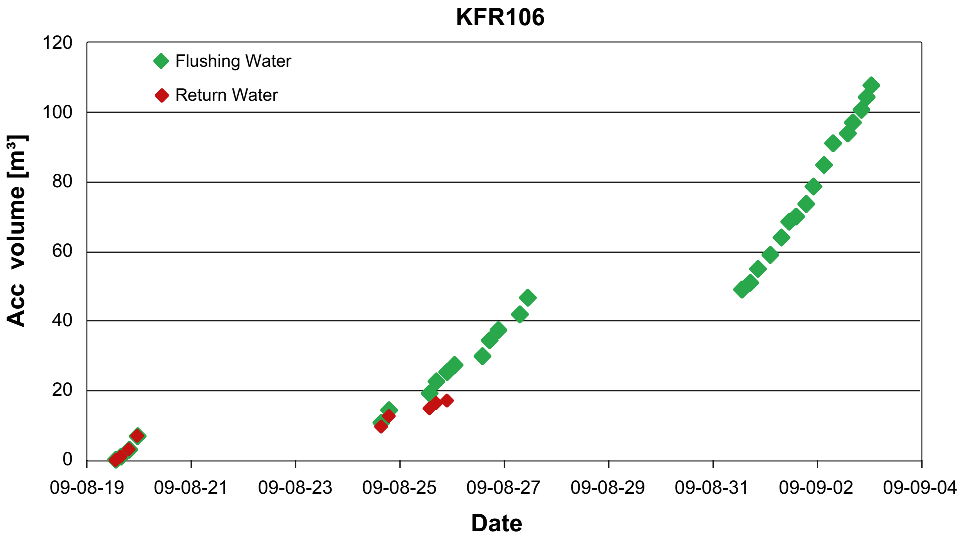


Figure 5-12. *Accumulated volumes of flushing water (green) and return water (red) versus time during core drilling of borehole KFR106. The return water disappeared after a short time of drilling.*

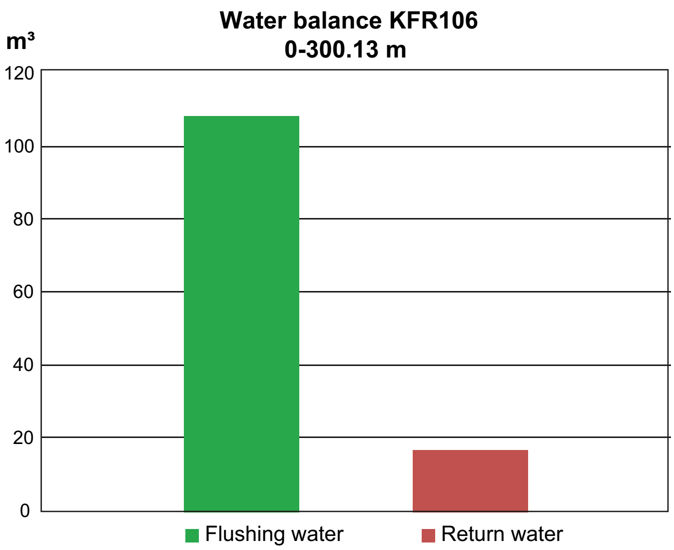


Figure 5-13. *Total amounts of flushing water and return water during drilling of borehole KFR106. The total volume of flushing water used during core drilling amounted to 108 m^3. During the same period, the total volume of return water was only 17 m^3. The return water/flushing water balance is then as low as 0.16 due to loss of return water at 108 m length.*

Uranine content of flushing water and return water – mass balance

During the drilling period, sampling and analysis of flushing water and return water for analysis of the contents of Uranine was performed systematically with a frequency of approximately one sample per every fourth hour, see Figure 5-14. A dosing feeder controlled by a flow meter was used for labelling the flushing water with Uranine to a concentration of 0.2 mg/L.

In drilling situations with a continuous yield of return water, which consists of a mixture of (unlabelled) groundwater and labelled flushing water, a mass balance calculation of the tracer contents in the water samples from the flushing water and return water is a method for demonstrating the amount of flushing water lost in the aquifer during drilling. When return water yield ceases, like in KFR106, all flushing water is lost to the formation.

According to notations in the logbook, the amount of Uranine added to the borehole was 25 g. If the averages of the Uranine concentration values in the flushing water and return water samples (to 192 m borehole length) are used to calculate the amount of Uranine added and recovered from the borehole, the result is 22 g and 3 g, respectively. After finished drilling, water samples collected in connection with nitrogen flushing in KFR106 confirmed that flushing water still remains in the borehole.

Electric conductivity of flushing water and return water

Flushing water during drilling of KFR106 was supplied from the Baltic Sea. A sensor in the measurement station registered the electric conductivity (EC) of the flushing water on-line before the water entered the borehole, see Figure 3-2. Another sensor for registration of the electric conductivity of the return water was positioned between the surge diverter (discharge head) and the sedimentation containers (Figure 3-2). The results of the EC-measurements are displayed in Figure 5-15. The electrical conductivity of flushing water (sea water) is almost constant at 900 mS/m through the drilling period.

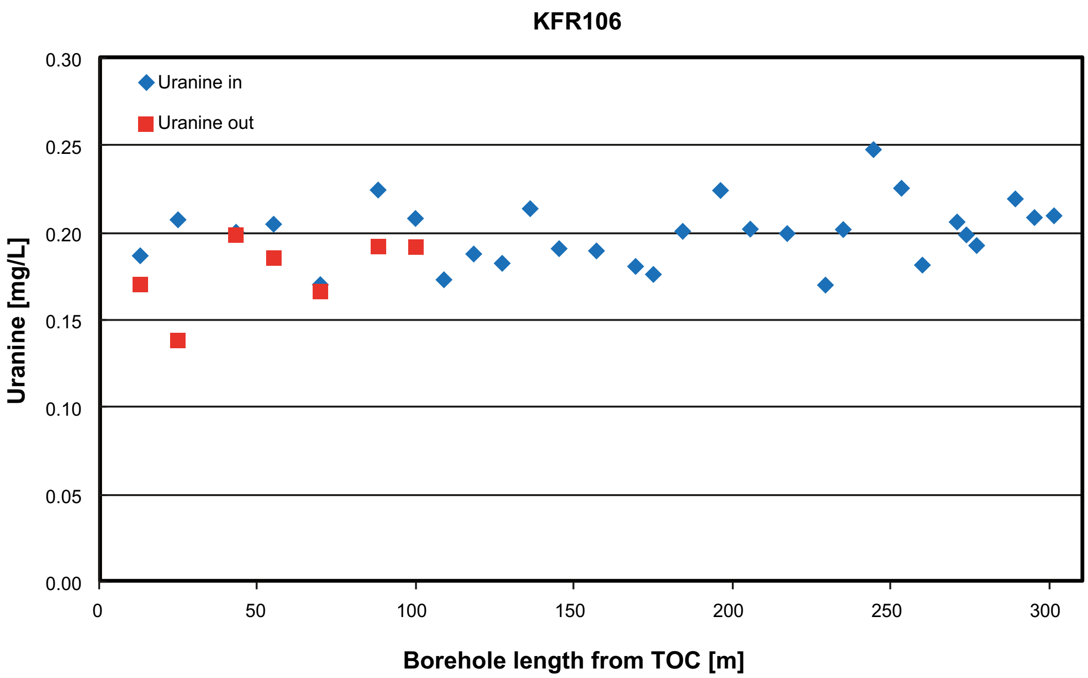
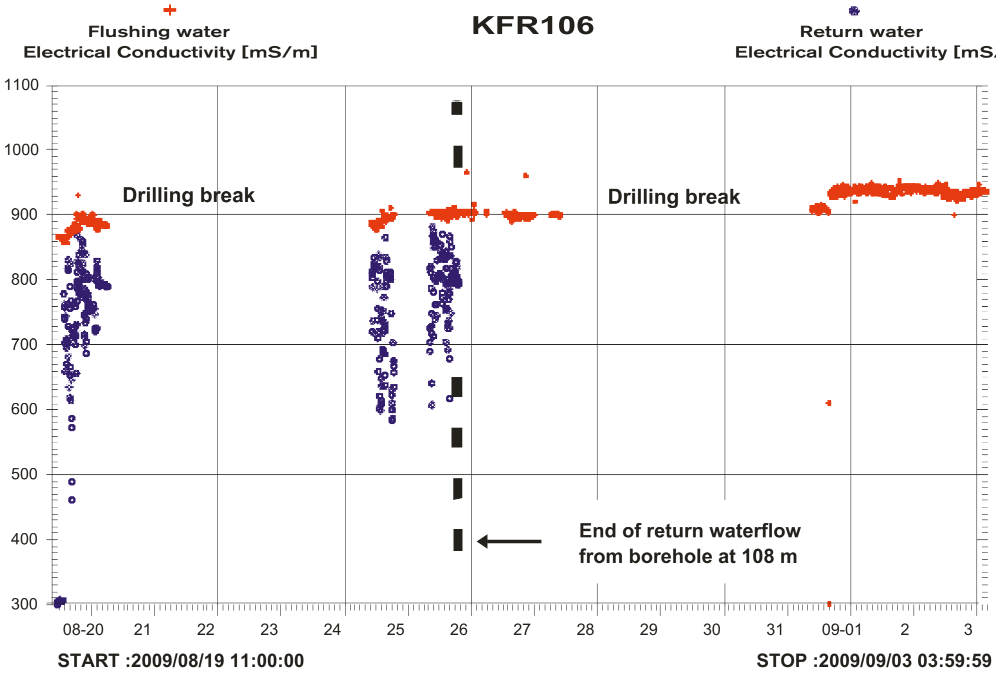


Figure 5-14. Uranine contents in the flushing water consumed and the return water recovered versus drilling length during drilling of borehole KFR106. Automatic dosing equipment, controlled by a flow meter, accomplished the labelling with Uranine.



Figur 5-15. *Electrical conductivity of flushing water (water from the Baltic sea) and return water from KFR106.*

The average electrical conductivity of the return water from KFR106 (Figure 5-15) was generally lower than that of the flushing water, indicating inflows in the upper part of the borehole of less saline shallow groundwater, which was mixed with the flushing water, giving the return water lower EC-values. As mentioned, total water loss occurred at 108 m borehole length.

Contents of dissolved oxygen in flushing water

The amount of dissolved oxygen in the flushing water was measured and plotted versus time. The concentration of dissolved oxygen has generally been kept between 2–4 mg/L. In order to ensure a continuous inflow of nitrogen to the flushing water tank (cf. Section 3.1), the pressure in the nitrogen bottles was observed and documented once a day, see Figure 5-16.

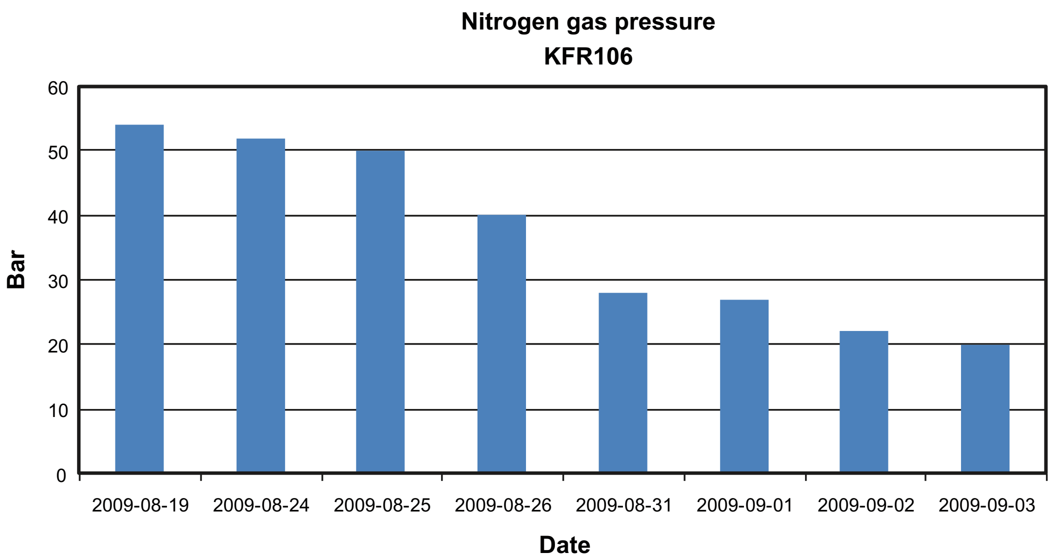


Figure 5-16. *Nitrogen contents (measured as pressure) in the bottles used for nitrogen bubbling of flushing water in KFR106.*

5.3.2 Core sampling

As mentioned in Section 3.2. the Sandvik DE130 core drilling system was supplied with a triple tube core sampling unit. The average drill core length per run was 2.80 m (section 9.13–300.13 m). One unbroken 3 m core was recovered. Fracture minerals were relatively well preserved. Preliminary core logging was performed continuously in connection with the drilling, see Figure 5-17.

5.3.3 Core sampling from borehole KFR106 for investigation of increased uranium content in groundwater

During the site investigation 2002–2007 for storage of spent nuclear fuel in Forsmark, a number of groundwater samples with increased uranium contents have been identified at borehole lengths equal to the storage level. Analyses made show that the uranium from depths exceeding 200 m origins from dissolved uranium from fractures within certain deformation zones. To improve the comprehension of this phenomenon, there was need for additional samples of 1) groundwater and of 2) fracture minerals from water-bearing sections within this type of deformation zones. The last cored borehole planned to be drilled within Project SFR Extension, KFR106, is situated close enough to the Forsmark candidate area for a spent nuclear fuel storage to fulfil the needs for additional sampling for continued analysis of the uranium problem.

Only mineral fillings from permeable fractures were of interest. Totally 37 core samples were during drilling estimated to be water-bearing, and sampling of mineral fillings was performed in all of these. The samples were accurately wrapped up and stored in a freezer at the Llentab facility, see Figure 5-18. The borehole logging program in KFR106 was completed and by consulting the results an improved judgement of which fractures that are water yielding and non-water yielding could be done. Samples that coincide with water yielding fractures were selected for further analysis. All other samples were returned to the respective core box.

Groundwater samples from the corresponding borehole sections will be collected when straddle-packer installation have been executed in the borehole.

Figure 5-17. The core boxes were transported every morning during the drilling period to the core storeroom, the so called Llentab facility. A simplified geological core mapping was performed, and afterwards all core boxes were photographed. A detailed core mapping together with analysis of BIPS-images, so called Boremap mapping, will be carried out after completion of drilling.

Figure 5-18. *Every potential water-bearing fracture in KFR106 was sampled. The core was measured for exact borehole length and photographed. To avoid mineral oxidation, the sample was placed within three layers of plastic bags. Each layer was nitrogen filled, vacuum pumped and sealed and finally stored in a freezer at the Llentab facility.*

5.3.4 Recovery of drill cuttings

The theoretical volume of drill cuttings from section 9.13 – 300.13 m is calculated to 0.734 m^3, and c. 0.546 m^3 of that is left in the formation because complete water loss occurred at c. 108 m drilling length.

5.3.5 Deviation measurements in KFR106

The types and measurement principles of the equipment systems used for deviation measurements were explained in Section 3.3. Following the recently revised edition of SKB MD 224.001, Version 2, measurements with two different techniques have to be applied. An optic method (Maxibor II™ instrument) and a method based on magnetometer-/accelerometer technique (Flexit Smart Tool System), was chosen for the deviation measurements performed in KFR106.

The borehole collar coordinates and the borehole collar orientation has a major impact of the final borehole deviation result. Obviously, measurements in a borehole must be executed as described in method instruction SKB MD 110.001. To achieve reliable data with high accuracy, it is crucial to execute the measurement with a Total Station together with a prism reflector on a firm telescopic tube that is centralized according to the inside wall of the casing, see Figure 5-19.

Figure 5-19. *Surveying of the borehole collar coordinates and borehole orientation is crucial for calculating the borehole deviation. Lining up a borehole collar demands careful handling of the instrument as well as of the accessories. To get accurate data, the reflector must be centralized into the borehole casing. The reflector is mounted on a telescopic tube that has to be stiff when it is pulled out in order to measure the borehole orientation.*

The borehole collar data is used as an input to the Maxibor II™-logging system in order to generate deviation data. Furthermore, the borehole collar data is used when calculating final deviation result according to the specified sections in EG154.

Depending on this two-step use, imperfections of lining up the borehole collar effects especially the uncertainty calculations of the final deviation result. This happened in KFR106, and when comparing data from the Maxibor II™-loggings and Flexit loggings, large discrepancies were observed. Therefore, a new lining up of the borehole collar was conducted, where the start value for azimuth was adjusted with c. 1°, which improved the final deviation result of KFR106.

To ensure high quality measurements with the Flexit tool, the disturbances (variations) of the global magnetic field must be small during the period of measurements. Regular registrations of the global magnetic field are made at a number of stations around the world. For magnetic field values that apply for Forsmark with surroundings, a measurement station in Sodankylä, Finland, provides one-minute magnetic field values that are available on the Internet at www.intermagnet.org. The magnetic field variations during the Flexit logging on September 8th 2009 are illustrated in Figure 5-20 and display only minor disturbances when the Flexit-surveys in KFR106 were performed.

A description of the construction of deviation data for KFR106 is given below.

The deviation data used for construction of the final deviation file were two Maxibor II™-loggings to 279 m and two loggings with the Flexit Smart Tool System, to 288 m borehole length, respectively, see Table 5-2. The deviation measurements were carried out every 3 m with both instruments, downwards as well as upwards. The activities marked "CF" in Table 5-2 includes comments besides measurement data.

All deviation measurement surveys in the borehole have followed the recommended quality routines according to SKB MD 224.001, Version 2.0. This final deviation file is termed EG154 (Borehole deviation multiple measurements). See illustration of the construction principle in Figure 5-21.

The EG154-activity (see Table 5-3) specifies the sections of the deviation measurements used in the resulting calculation presented in Table 5-4. The different lengths of the upper sections between the bearing and the inclination are due to that the magnetic accelerometer measurement (bearing) is influenced by the 9 m steel casing which is not the case for the inclinometer measurements (inclination).

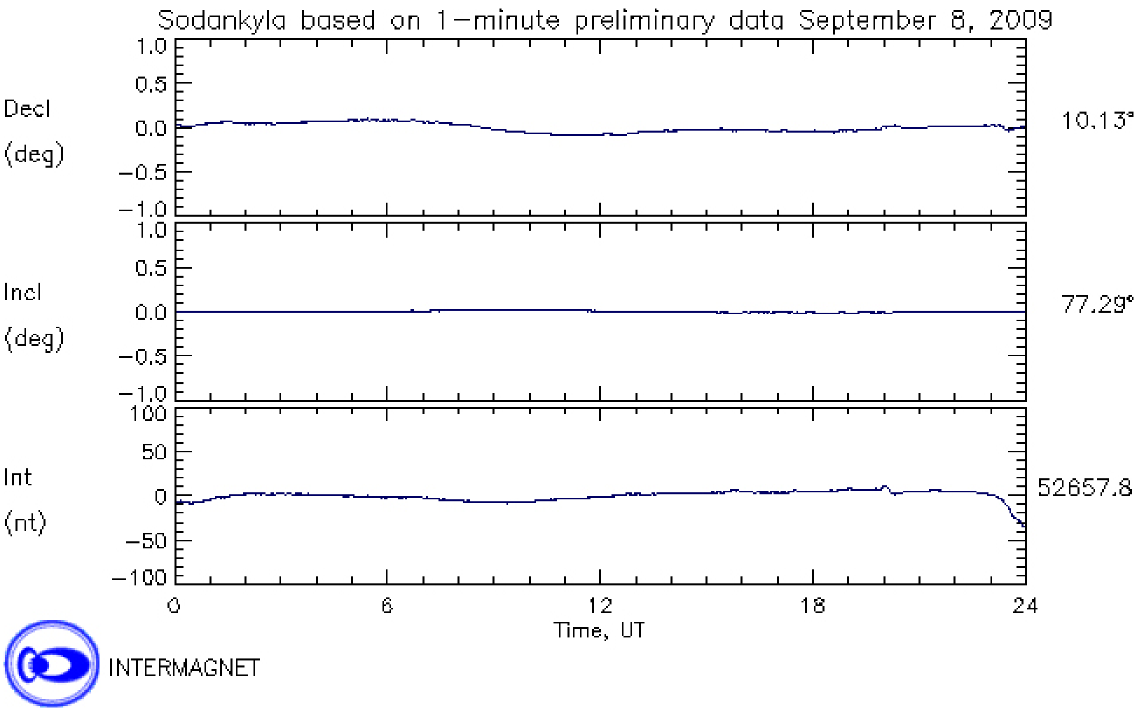


Figure 5-20. *Magnetic field variations during Flexit surveys performed on September 8th 2009 in KFR106.*

Table 5-2. Activity data for all deviation measurements approved for KFR106 (from Sicada).

Activity ID	Activity Type code	Activity	Start date	Idcode	Secup (m)	Seclow (m)	Flags
13237781	EG161	Maxibor II measurement	2009-09-07 10:00	KFR106	3.00	279.00	CF
13237782	EG161	Maxibor II measurement	2009-09-07 13:00	KFR106	3.00	279.00	CF
13238617	EG157	Magnetic – accelerometer measurement	2009-09-08 15:17	KFR106	3.00	288.00	CF
13238618	EG157	Magnetic – accelerometer measurement	2009-09-08 16:25	KFR106	3.00	288.00	CF
13238619	EG154	Borehole deviation multiple measurements	2009-10-08 09:30	KFR106	3.00	288.00	IC

Table 5-3. Contents of the EG154 file (multiple borehole deviation intervals).

Deviation Activity ID	Deviation Angle type	Approved Secup (m)	Approved Seclow (m)
13237781	Bearing	3.00	279.00
13237781	Inclination	3.00	279.00
13237782	Bearing	3.00	279.00
13237782	Inclination	3.00	279.00
13238617	Bearing	15.00	288.00
13238617	Inclination	3.00	288.00
13238618	Bearing	15.00	288.00
13238618	Inclination	3.00	288.00

Table 5-4. Deviation data from KFR106 for approximately every 30 m borehole length calculated from EG154. Coordinate system RT90 2.5 gon V 0:-15 / RHB 70.

Borehole	Length (m)	Northing (m)	Easting (m)	Elevation (m)	Inclination (degrees)	Bearing (degrees)
KFR106	0.00	6701541.18	1633592.14	1.06	–70.27*	195.11
KFR106	33.00	6701530.31	1633589.12	–29.95	–69.82	195.76
KFR106	63.00	6701520.37	1633586.21	–58.11	–69.78	196.34
KFR106	96.00	6701509.37	1633582.99	–89.05	–69.59	196.37
KFR106	129.00	6701498.3	1633579.62	–119.96	–69.29	197.27
KFR106	159.00	6701488.15	1633576.47	–148.01	–69.23	197.95
KFR106	192.00	6701477.00	1633572.76	–178.85	–69.16	198.63
KFR106	225.00	6701465.85	1633568.97	–209.68	–68.99	198.79
KFR106	255.00	6701455.69	1633565.46	–237.69	–68.96	199.66
KFR106	288.00	6701444.53	1633561.54	–268.49	–68.95	199.32
KFR106	300.13	6701440.43	1633560.07	–279.81	–68.95	199.73

* The starting values of inclination in EG154 are calculated and could therefore show a discrepancy against the values seen in Borehole direction surveying (EG151).

A subset of the resulting deviation files and the estimated radius uncertainty is presented in Table 5-5. Figure 5-21 illustrates the principles behind computing the borehole deviation, i.e. the borehole geometry, from several measurements, and also displays the concept of radial uncertainty.

The calculated deviation (EG154-file) in borehole KFR106 shows that the borehole deviates upwards and to the right with an absolute deviation of 5.4 m compared to an imagined straight line following the dip and strike of the borehole start point.

The "absolute deviation" is here defined as the shortest distance in space between a point in the borehole at a certain borehole length and the imaginary position of that point if the borehole had followed a straight line with the same inclination and bearing as of the borehole collar.

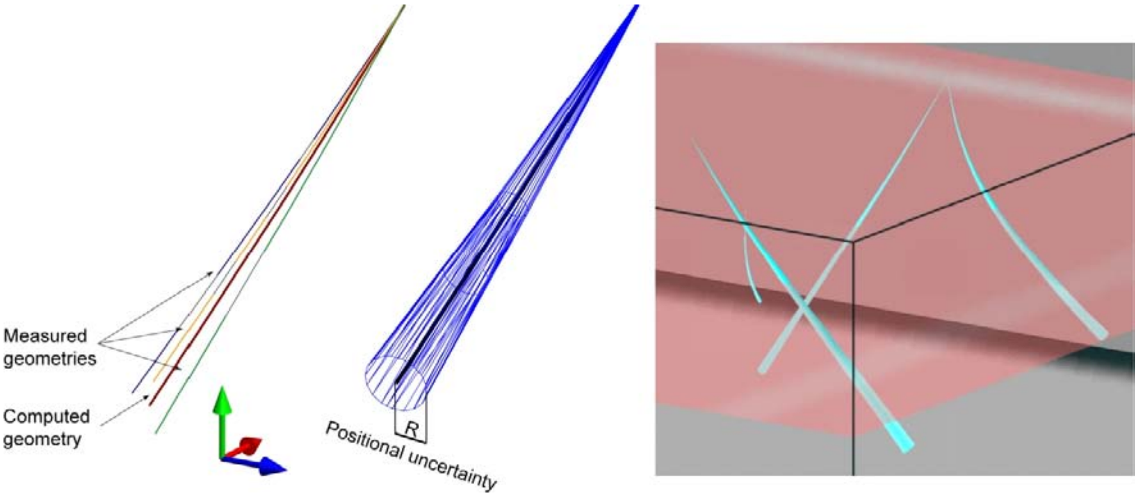


Figure 5-21. The figure to the left is an illustration of the principles for calculating the borehole geometry from several deviation measurements. The two other figures illustrate one of the uncertainty measures used for deviation measurements. In the middle figure, "R" denotes "Radial uncertainty", representing a function, which is monotonously increasing versus borehole length in relation to the borehole axis, defining the shape of a cone surrounding the borehole axis and corresponding to the parameter in the column furthest to the right in Table 5-6. The figure to the right is a block diagram imaging four fictitious boreholes deviating in different ways and with radius uncertainty illustrated as blue cones (modified after Figures 4-1, 5-1 and 5-3 in /3/, Munier and Stigsson 2007).

Table 5-5. Uncertainty data for the deviation measurements in KFR106 for approximately every 30 m borehole length calculated from EG154. Coordinate system RT90 2.5 gon V 0:-15 / RHB 70.

Borehole	Northing (m)	Easting (m)	Elevation (m)	Inclination Uncertainty	Bearing Uncertainty	Radius Uncertainty
KFR106	6701541.18	1633592.14	1.06	0.195	0.925	0,00
KFR106	6701530.31	1633589.12	–29.95	0.195	0.925	0.18
KFR106	6701520.37	1633586.21	–58.11	0.195	0.925	0.35
KFR106	6701509.37	1633582.99	–89.05	0.195	0.925	0.53
KFR106	6701498.3	1633579.62	–119.96	0.195	0.925	0.72
KFR106	6701488.15	1633576.47	–148.01	0.195	0.925	0.89
KFR106	6701477.00	1633572.76	–178.85	0.195	0.925	1.08
KFR106	6701465.85	1633568.97	–209.68	0.195	0.925	1.27
KFR106	6701455.69	1633565.46	–237.69	0.195	0.925	1.45
KFR106	6701444.53	1633561.54	–268.49	0.195	0.925	1.64
KFR106	6701440.43	1633560.07	–279.81	0.195	0.925	1.71

5.3.6 Groove milling KFR106

A compilation of length to the reference grooves and a comment on the success of detecting the grooves are given in Table 5-6. The positions of the grooves are determined from the length of the drill pipes used at the milling process. The length is measured from TOC to the upper part of the upper two grooves.

Table 5-6. Reference grooves in KFR106.

Reference groove at (m)	Detection with the SKB level indicator	Confirmed from BIPS
50	Yes	Yes *
100	Yes	Yes *
149	Yes	Yes *
200	Yes	Yes *
250	Yes	Yes *
280	Yes	Yes *

* BIPS not adjusted.

5.3.7 Nitrogen flushing

The final operation, before the drilling activity was concluded, was to rinse the borehole in order to minimize the contents of drilling debris or other unwanted material remaining in the borehole. For this purpose, nitrogen flushing was applied.

Usually, a borehole is nitrogen flushed until the recovered return-water is judged (by optical observation) to be clean or with a minimum content of drilling debris. As complete water loss occurred at c.108 m, flushing water and drill cuttings were forced into the permeable part of the rock below that level, resulting in that 0.546 m^3 (1,446 kg) of drill cuttings are left in the formation.

KFR106 had to be nitrogen flushed 22 times, on September 14th to 17th 2009, before the borehole was sufficiently clean, see Table 5-7. The estimated accumulated recovered water volume was 34.1 m^3, compared to 91 m^3 flushing water that was lost in the borehole during drilling, see Section 5.3.1.

5.3.8 Risk assessment KFR106

Ensuing completion of drilling activities, an intensive measurement programme will be carried out in the borehole. Some of the measuring tools used are developed especially for this application, and damage or loss of an instrument in a borehole will have considerable impact on costs and time-schedule. Therefore a strategy has been elaborated for risk assessment of the current status of boreholes with bearing on the activities planned in the borehole. This risk assessment will be kept topical throughout the activity period for the borehole and, furthermore, be documented in Sicada.

The risk assessment is based on a classification system consisting of four risk levels, denominated "risk classes". These classes are:

0 = no observed risk.

1 = a **potential** risk observed, but no incident has occurred (e.g. very fractured rock observed during drilling).

2 = very serious incident (e.g. probe stuck in the borehole).

3 = borehole collapse.

Table 5-7. Nitrogen flushing periods in KFR106 after drilling to 300.13 m borehole length, and estimated discharged volumes of groundwater (from EG036 in Sicada).

ID	Start date, time	Stop date, time	Volume (m^3)	Comment
KFR 106	2009-09-14 11:50	2009-09-14 12:06	1,000	Water at TOC 11:56, Blow out 11:59
KFR 106	2009-09-14 13:23	2009-09-14 13:37	1,000	Water at TOC 13:27, Blow out 13:29
KFR 106	2009-09-14 14:21	2009-09-14 14:35	1,000	Water at TOC 14:26, Blow out 14:28
KFR 106	2009-09-14 15:33	2009-09-14 15:48	1,000	Water at TOC 15:36, Blow out 15:39
KFR 106	2009-09-14 16:58	2009-09-14 17:13	1,000	Water at TOC 17:01, Blow out 17:03
KFR 106	2009-09-14 18:04	2009-09-14 18:19	1,000	Water at TOC 18:07, Blow out 18:09
KFR 106	2009-09-15 07:52	2009-09-15 08:08	1,000	Water at TOC 07:57, Blow out 08:00
KFR 106	2009-09-15 09:30	2009-09-15 09:45	1,000	Water at TOC 09:33, Blow out 09:36
KFR 106	2009-09-15 11:12	2009-09-15 11:27	1,000	Water at TOC 11:15, Blow out 11:18
KFR 106	2009-09-15 12:45	2009-09-15 12:59	1,000	Water at TOC 12:48, Blow out 12:51
KFR 106	2009-09-15 14:17	2009-09-15 14:32	1,000	Water at TOC 14:20, Blow out 14:23
KFR 106	2009-09-15 15:31	2009-09-15 15:46	1,000	Water at TOC 15:34, Blow out 15:37
KFR 106	2009-09-15 17:09	2009-09-15 17:24	1,000	Water at TOC 17:12, Blow out 17:15
KFR 106	2009-09-15 18:05	2009-09-15 18:20	1,000	Water at TOC 18:08, Blow out 18:11
KFR 106	2009-09-16 07:36	2009-09-16 07:54	1,200	Water at TOC 07:41, Blow out 07:44
KFR 106	2009-09-16 10:07	2009-09-16 10:23	1,200	Water at TOC 10:11, Blow out 10:13
KFR 106	2009-09-16 11:54	2009-09-16 12:10	1,200	Water at TOC 11:57, Blow out 12:00
KFR 106	2009-09-16 13:38	2009-09-16 13:53	1,200	Water at TOC 13:42, Blow out 13:44
KFR 106	2009-09-16 15:06	2009-09-16 15:25	1,200	Water at TOC 15:09, Blow out 15:12
KFR 106	2009-09-16 16:39	2009-09-16 16:55	1,200	Water at TOC 16:43, Blow out 16:45
KFR 106	2009-09-17 09:36	2009-09-17 11:10	9,500	Water at TOC 09:41, Blow out 09:44
KFR 106	2009-09-17 11:13	2009-09-17 12:06	3,400	Water at TOC 11:13, Blow out 11:18

Following these compulsory guidelines, the risk assessments after finishing the drilling activities of borehole KFR106 are summarized in Table 5-8. Fifty sections of borehole KFR106 have been classified as involving a potential risk (1), in this case implying that the core section is highly fractured and associated with a risk of rock fallout.

Table 5-8. Documented sections of potential risk from observations during drilling and preliminary geological core mapping of KFR106.

From (mbl)*	To (mbl)*	Risk level (code)	Description	From (mbl)*	To (mbl)*	Risk level (code)	Description
9.13	9.70	0		102.20	112.20	0	
9.70	10.40	1	Probability for rock-fallout	112.20	113.40	1	Probability for rock-fallout
10.40	12.15	0		113.40	117.60	0	
12.15	12.35	1	Probability for rock-fallout	117.60	118.00	1	Probability for rock-fallout
12.35	16.00	0		118.00	124.25	0	
16.00	19.50	1	Probability for rock-fallout	124.25	124.60	1	Probability for rock-fallout
19.50	23.00	0		124.60	140.30	0	
23.00	23.20	1	Probability for rock-fallout	140.30	141.00	1	Probability for rock-fallout
23.20	25.40	0		141.00	143.60	0	
25.40	26.00	1	Probability for rock-fallout	143.60	144.05	1	Probability for rock-fallout
26.00	26.35	0		144.05	145.20	0	
26.35	28.00	1	Probability for rock-fallout	145.20	145.50	1	Probability for rock-fallout
28.00	28.50	0		145.50	150.55	0	
28.50	29.10	1	Probability for rock-fallout	150.55	150.75	1	Probability for rock-fallout
29.10	29.90	0		150.75	154.20	0	
29.90	30.25	1	Probability for rock-fallout	154.20	155.00	1	Probability for rock-fallout
30.25	32.90	0		155.00	155.80	0	
32.90	33.70	1	Probability for rock-fallout	155.80	156.50	1	Probability for rock-fallout
33.70	39.80	0		156.50	160.70	0	
39.80	40.50	1	Probability for rock-fallout	160.70	161.05	1	Probability for rock-fallout
40.50	41.60	0		161.05	166.00	0	
41.60	43.10	1	Probability for rock-fallout	166.00	166.30	1	Probability for rock-fallout
43.10	45.90	0		166.30	169.40	0	
45.90	47.10	1	Probability for rock-fallout	169.40	170.10	1	Probability for rock-fallout
47.10	52.50	0		170.10	182.50	0	
52.50	52.90	1	Probability for rock-fallout	182.50	183.00	1	Probability for rock-fallout
52.90	54.00	0		183.00	187.70	0	
54.00	54.50	1	Probability for rock-fallout	187.70	188.90	1	Probability for rock-fallout
54.50	62.90	0		188.90	196.55	0	
62.90	63.70	1	Probability for rock-fallout	196.55	197.00	1	Probability for rock-fallout
63.70	65.50	0		197.00	202.20	0	
65.50	71.00	1	Probability for rock-fallout	202.20	202.70	1	Probability for rock-fallout
71.00	71.30	0		202.70	212.30	0	
71.30	71.60	1	Probability for rock-fallout	212.30	212.70	1	Probability for rock-fallout
71.60	72.30	0		212.70	220.30	0	
72.30	72.90	1	Probability for rock-fallout	220.30	220.60	1	Probability for rock-fallout
72.90	74.90	0		220.60	224.65	0	
74.90	75.40	1	Probability for rock-fallout	224.65	225.10	1	Probability for rock-fallout
75.40	75.90	0		225.10	229.40	0	
75.90	76.30	1	Probability for rock-fallout	229.40	230.10	1	Probability for rock-fallout
76.30	82.80	0		230.10	242.00	0	
82.80	83.20	1	Probability for rock-fallout	242.00	242.50	1	Probability for rock-fallout
83.20	85.10	0		242.50	265.45	0	
85.10	85.60	1	Probability for rock-fallout	265.45	273.80	1	Probability for rock-fallout
85.60	95.00	0		273.80	274.30	0	
95.00	95.80	1	Probability for rock-fallout	274.30	285.00	1	Probability for rock-fallout
95.80	100.50	0		285.00	291.40	0	
100.50	101.10	1	Probability for rock-fallout	291.40	292.20	1	Probability for rock-fallout
101.10	101.90	0		292.20	298.00	0	
101.90	102.20	1	Probability for rock-fallout	298.00	300.13	1	Drill cuttings

* = metres borehole length.

5.3.9 Consumables

The amount of grout used for gap injection of the casing for KFR106 is reported in Table 5-9. The grout was a mixture of water and Standard Cement with Calcium Chloride (CaCl) added as an accelerator. The consumption of cement is proportional to the length of the casing, meaning that the gap between casings is completely filled, and no grout was injected into the bedrock.

The special type of thread grease (silicon based) used in this particular borehole was certified according to SKB MD 600.006, Version 1. Instructions for the use of chemical products and material during drilling and surveys, see Table 1-1. Oil and grease consumptions are given in Table 5-10.

Table 5-9. Cement consumption for grouting the percussion drilled part of borehole KFR106.

Borehole ID	Borehole length from TOC (m)	Cement (kg)	CaCl [kg]	Grouting method
KFR106	8.86–9.13	5	0.2	Bottom plug
KFR106	0–8.86	79.5	0.9	Hose

Table 5-10. Diesel, oil and grease consumption during core drilling of borehole KFR106.

Borehole length from TOC (m)	Diesel (L)	Thread grease Unisilicon L50/2 (kg)	Hydraulic Oil ECO 46 (L)	Universal Grease Statoil (kg)	Gear Oil SAE 80/90 (L)
9.13–300.13	3,000*	0.5	10	0.4	1

* Diesel-powered operation as no electricity installation on the islet was performed.

6 References

/1/ **SKB, 2008.** Geovetenskapligt undersökningsprogram för utbyggnad av SFR (Investigation programme for the extension of SFR). SKB R-08-67, Svensk Kärnbränslehantering AB.

/2/ **SKB, 2001.** Program för platsundersökning vid Forsmark. SKB R-01-42, Svensk Kärnbränslehantering AB.

/3/ **Munier R, Stigsson M, 2007.** Implementation of uncertainties in borehole geometries and geological orientation data in Sicada. SKB R-07-19, Svensk Kärnbränslehantering AB.

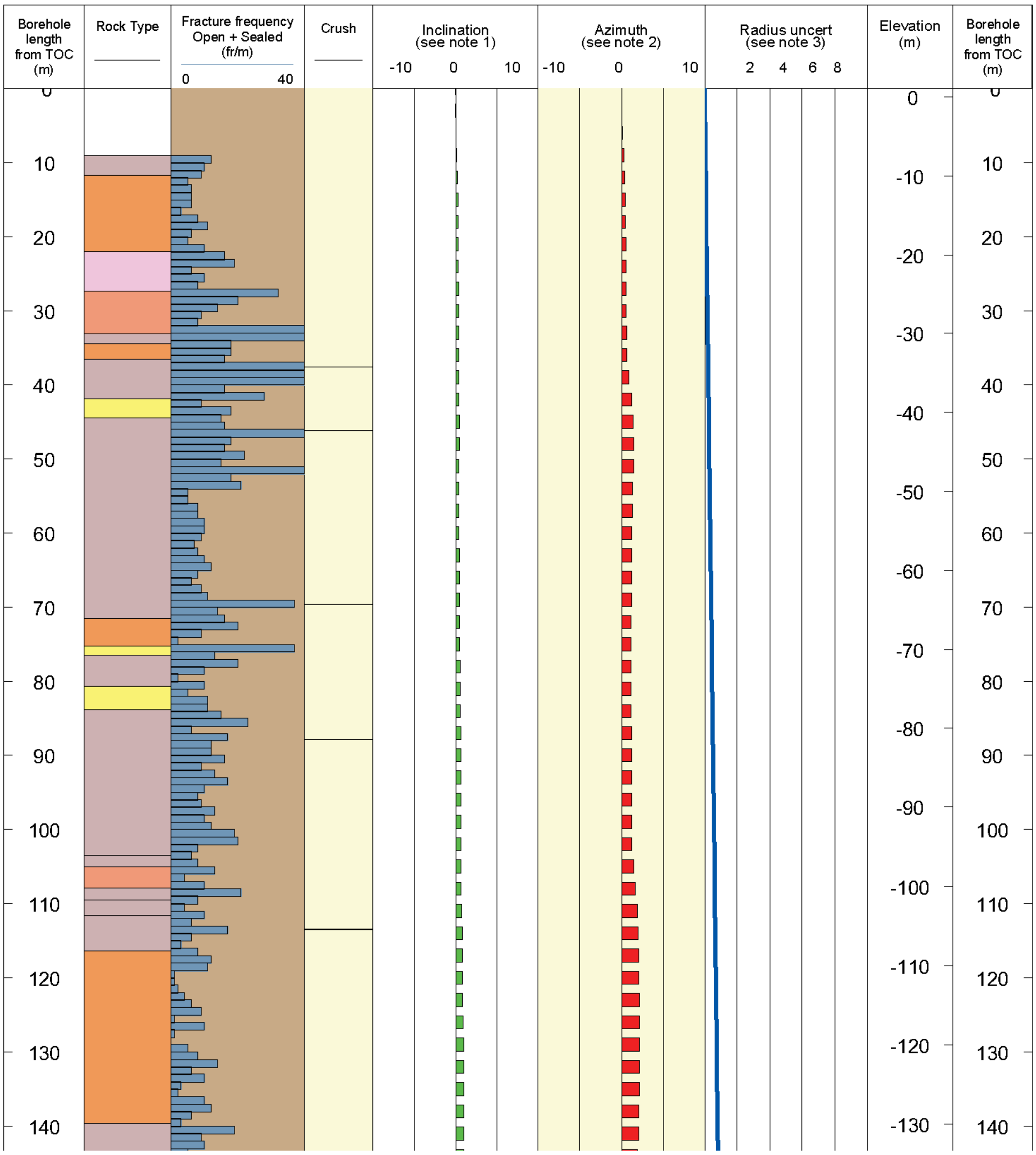
Well Cad presentation of KFR106

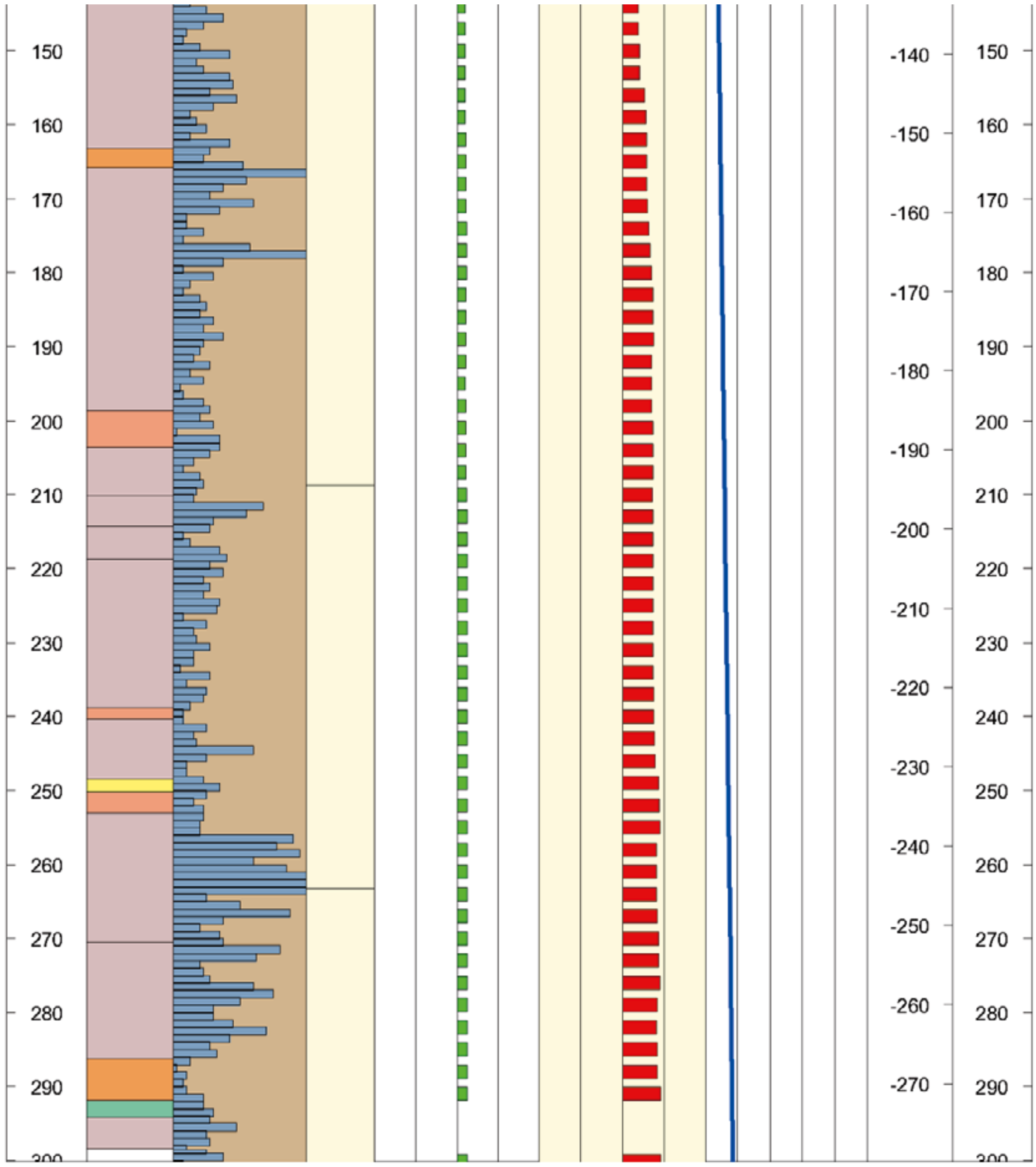
Title	CORE DRILLED BOREHOLE KFR106		
Svensk Kärnbränslehantering AB			
Site	FORSMARK - SFR	Coordinate System	RT90-RHB70
Borehole	KFR106	Northing [m]	6701541.19
Diameter [mm]	76	Easting [m]	1633592.14
Length [m]	300.13	Elevation [m]	1.06
Azimuth [°]	195.11	Drilling Start Date	2009-06-23
Inclination [°]	-69.89	Drilling Stop Date	2009-09-03
		Plot Date	2010-01-07

ROCK TYPE

- Granite, fine- to medium-grained
- Pegmatite, pegmatitic granite
- Granite, granodiorite and tonalite, metamorphic, fine- to medium-grained
- Granite to granodiorite, metamorphic, medium-grained
- Amphibolite
- Felsic to intermediate volcanic rock, metamorphic

Note 1. Difference between the azimuth value at each 3 m length and the azimuth value of the borehole collar.
Note 2. Difference between the inclination value at each 3 m length and the inclination value of the borehole collar.
Note 3. The uncertainty of the borehole location, which defines the shape of a cone surrounding the borehole.




150
160
170
180
190
200
210
220
230
240
250
260
270
280
290
300
-140
-150
-160
-170
-180
-190
-200
-210
-220
-230
-240
-250
-260
-270