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Site Investigation SFR

Drilling of the cored borehole KFR105

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Abstract

One of the cored boreholes included in the investigation programme for the SFR Extension project, KFR105, is designed and drilled from underground inside the SFR-facility, in order to assure high-class hydrogeochemical samples below repository depth. Performance of and results from drilling and measurements during drilling of borehole KFR105 are presented in this report.

KFR105, which is designed as a so called traditional borehole of SKB chemistry type, is 306.81 m long and is at its starting point inclined –10.40° from the horizon. The borehole reaches about 302 m in horizontal distance and approximately 50 m in vertical depth from the collar, the elevation of which is –106.82 m RHB70. The elevation of the borehole end is –156.63 m RHB70.

The inflow of groundwater from the entire borehole (0–306.81 m) amounted at c. 15 L/min, which was measured immediately after completion of drilling.

A relatively complicated flushing water/return water system is applied by SKB for drilling of cored boreholes. The flushing water is prepared in several steps before use, and the return water is taken care of, as to permit drill cuttings to settle before the water is discharged to an approved recipient. During drilling, a number of technical and flushing water/return water parameters are registered in order to obtain a good control of the drilling process and to permit an estimation of the impact on the rock aquifer penetrated by the borehole of flushing water and drilling debris.

A sampling- and measurement programme for core drilling 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. For example, the drill cores together with later produced video images of the borehole wall (so called BIPS-images), were used for so called Boremap mapping of the borehole. A diagram of the Boremap mapping results is included in this report.

After completion of 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 kärnborrhål, KFR105, som ingår i undersökningsprogrammet för Projekt SFR-utbyggnad borrades i SFR-anläggningen, dvs från en borrplats under jord. Borrhålet utfördes med det specifika syftet att säkerställa så ostörda grundvattenkemiska förhållanden som möjligt vid grundvattenprovtagning under förvarsdjup. Utförandet och resultaten från borrningen och de mätningar som utfördes under borrningen presenteras i denna rapport. Borrhål KFR105, som är utfört som ett traditionellt kärnborrhål av s k SKB kemityp, är ansatt med en lutning av –10,40° från horisontalplanet och är 306,81 m långt. Det når cirka 302 m i horisontell riktning och når 49,81 m djup från påslagspunkten, där vertikaldjupet är –106,82 m RHB70. Vid borrhålets slutpunkt uppgår vertikaldjupet till –156,63 m RHB70.

Grundvatteninflödet i det färdigborrade hålet (0–306,81 m) uppgick till ca 15 L/min.

Vid borrning av kärnborrhål använder SKB ett relativt komplicerat spol- och returvattensystem, där spolvattnet prepareras i olika moment före användning. Returvattnet leds till ett system av containrar, där borrkaxet sedimenterar i två steg innan returvattnet leds vidare till godkänd recipient. Under borrningen registreras ett antal borr- och spolvattenparametrar, så att god kontroll uppnås dels avseende borrningens tekniska genomförande, dels beträffande den påverkan av spolvatten och borrkax på grundvattenakvifären i anslutning till borrhålet som kärnborrningen medför.

Ett mät- och provtagningsprogram för kärnborrningen gav preliminär information om borrhålets geologiska och hydrauliska karaktär direkt under borrning samt underlag för fördjupade analyser efter borrning. Exempelvis utgör de upptagna borrkärnorna, tillsammans med videofilm av borrhålsväggen (s k BIPS-bilder), underlaget för geologisk kartering av hela borrhålet med en teknik som benämns Boremap-kartering. Ett resultatdiagram från Boremapkarteringen av borrhål KFR105 finns redovisad i denna 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 bedrock 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 of those, “Projekt SFR-utbyggnad – Undersökningar” (Project SFR Extension – Investigations).

The geoscientific investigations for the planned extension of SFR are performed in compliance with the 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 completed 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 overlapping, the SFR-area. Data and experiences also from these investigations have strongly influenced the elaboration of investigation strategies for the current SFR-investigation programme.

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

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-drilled and five core-drilled boreholes from the ground surface and one core-drilled borehole drilled underground 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 (see definition in Method Description 620.003, Table 1-1) KFR105 which is part of the initial investigation phase of project SFR Extension (SFR Utbyggnad) programme. The core drilling efforts were carried out in accordance with Activity Plan AP SFR-09-004. Controlling documents for performing this activity are listed in Table 1-1. Both the Activity Plan, the method documents and the report ID 1203500, which briefly describes the underground drilling performance within the SFR-facility, 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 in 1985, KFR27, was rediscovered, although the borehole casing was covered with gravel of one metre thickness below ground surface. As the borehole was restored, prolonged and used for measurements within the scope of project SFR Extension, a minor drill site was prepared also around this borehole.

The preparation for drilling of KFR105, located underground in the SFR-facility, has involved an extensive work which was initiated already early 2008. During this period the SFR-facility was classified as a nuclear facility, meaning that the corresponding safety regulations applied for a nuclear power plant was enjoin. Based on preceding inquiries and analyses of different safety aspects, the results of which were presented in two reports (see Section 5.1), a permission was granted to establish a drill site in one of the tunnels, the "Nedre Byggtunneln", in the SFR-facility, in November 2008. However, the permission was linked to conditions regarding safety, especially fire protection and personal skill. For example, every staff member needed an approved medical examination including a drug test, as well as a certificate of a passed through and approved security regulation check (a so called paragraph 6 check), cf. Section 5.1.

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

Activity Plan	**Number**	**Version**
Kärnborrning av borrhål KFR105 (under jord)	AP SFR-09-004	1.0
Report		
Kärnborrning under jord – projekt SFR-utbyggnad.	ID 1203500	
Method documents	**Number**	**Version**
Metodbeskrivning för kärnborrning.	SKB MD 620.003	3.0
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 undersök-ningar	SKB MD 600.006	1.0
Metodbeskrivning för genomförande av hydrauliska enhålspumptester	SKB MD 321.003	1.0
Metodbeskrivning för krökningsmätning av hammar- och kärnborrhål	SKB MD 224.001	2.0

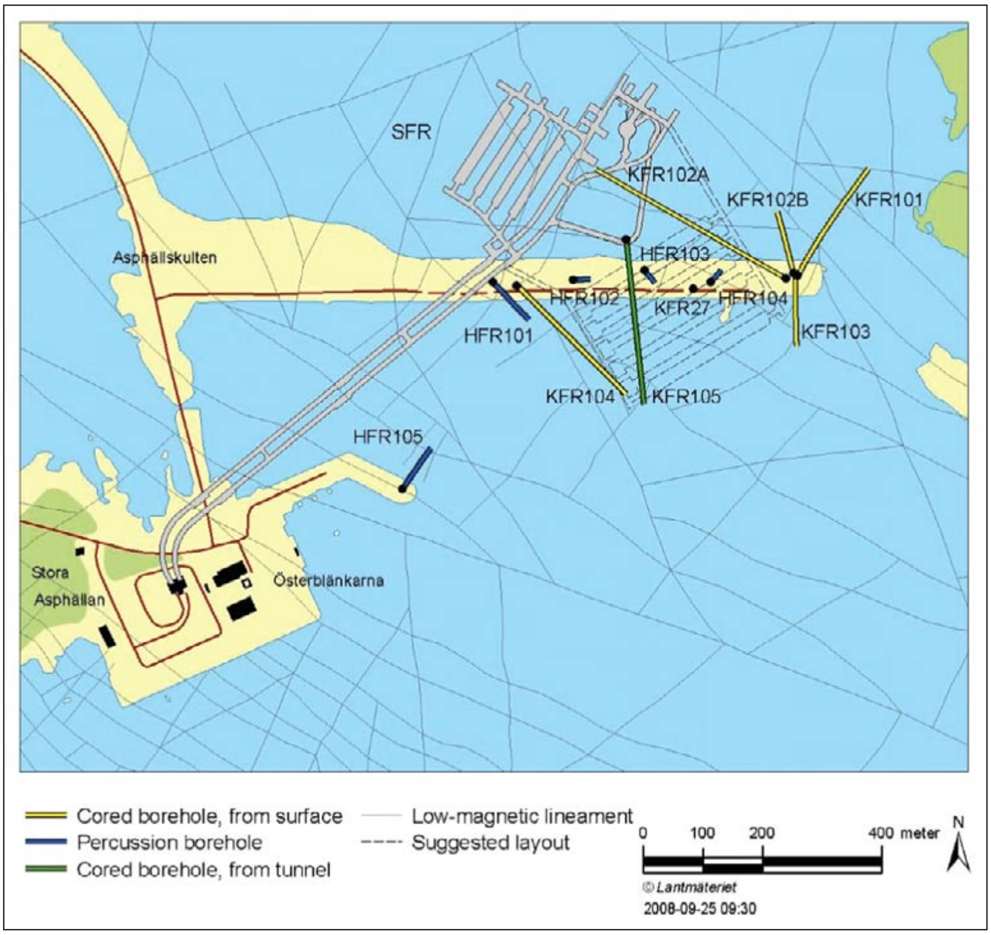


Figure 1-2. *Overview of the SFR site investigation area with planned investigation boreholes. Also the suggested layout of the extended SFR facilities as well as low-magnetic lineaments in the area are displayed.*

The drill site for KFR105 was designed according to the demands stipulated, and during the spring 2009 the preparations were completed and approved. Drillcon Core AB was employed for the core drilling commission. Support was provided from SKB-personnel regarding measurements and tests during drilling.

Pre drilling, installation and grouting of casing were performed on April 21st–23rd, and core drilling and measurements were carried out during the period April 28th to June 2nd 2009 in accordance with Activity Plan AP SFR-09-004, Version 1.0.

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-09-004). 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 a revision 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.

2 Objective and scope

The overall objective of drilling borehole KFR105 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, which 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 borehole tests as well as interference tests) for characterization of the hydrogeological conditions of the bedrock,
- enable long-term hydraulic and hydrogeochemical monitoring at different levels of the bedrock.

KFR105 was aimed to confirm the current structural model of the site as well as to intersect several, previously not modelled potential deformation zones related to magnetic lineaments with a surface exposure, see Table 2-1.

As KFR105 was slightly negatively inclined, and directed to the south, the borehole was mainly intended to traverse near-vertical fracture zones/lineaments, see Table 2-1.

Table 2-1. Zone/lineament identity with predicted borehole length at intersection of KFR105.

Borehole ID	Zone/Lineament	Predicted intersect [mbhl]
KFR105	ZFM3262	8–12
	ZFM3115	63–68
	ZFM3112	111–117
	ZFM0835	123
	ZFM3267	228–236
	ZFM3141	242–252
	ZFMNE3112	249–250
	ZFMNE3141	452–454

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 Core drilling system

A core drilling machine from Sandvik, type DE130, was employed for drilling of the cored borehole KFR105. The drilling machine was powered with an electrically-driven hydraulic system (see Figure 3-1). The drilling capacity of a Sandvik DE130 with WL76 is maximum c. 700 metres (considered a steep and straight borehole), which was sufficient for the expected drill length and inclination of borehole KFR105 using drill pipes AC Corac N3/50 NT.

The AC Corac N3/50 core barrel with split inner tube of stainless steel constitutes 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 accessories are given in Table 3-1.

Core drilling with a wireline system involves a wire winch for recovery of the core filled inner-tube through the drill pipes. During the drilling of borehole KFR105, a 3 m triple tube core barrel was used. The nominal core diameter for the AC Corac N3/50 is 50.8 mm. Minor deviations from this diameter may however occur.

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

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

Figure 3-1. *The Sandvik DE130 machine used for drillingborehole KFR105.*

3.1.1 Flushing/return water treatment – equipment and methods

Core drilling involves pumping of flushing water into 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 flush the drill cuttings off the borehole. The cuttings, suspended in the flushing water (in general mixed with groundwater), are flushed 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 KFR105 is displayed in Figure 3-3. 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 handling of the return water.

Preparing the flushing water

The flushing water for drilling of KFR105 was supplied from an underground basin, "Nedre bassängen" in "Nedre byggtunneln", (see Figure 1-2). The flushing water was prepared in accordance with SKB MD 620.003 (Method description for core drilling), with an organic dye tracer, Uranine, added to and thoroughly mixed at a concentration of 0.2 mg/L, see Figure 3-2. Labelling the flushing water with the tracer enables detection of flushing water contents in groundwater samples collected from the borehole during or after drilling.

In order to reduce the contents of dissolved oxygen in the flushing water, nitrogene gas was continuously flushed through the flushing water tank, see Figure 3-3. The oxygen contents of the flushing water was measured before use in the borehole, see Section 5.5.1.

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.

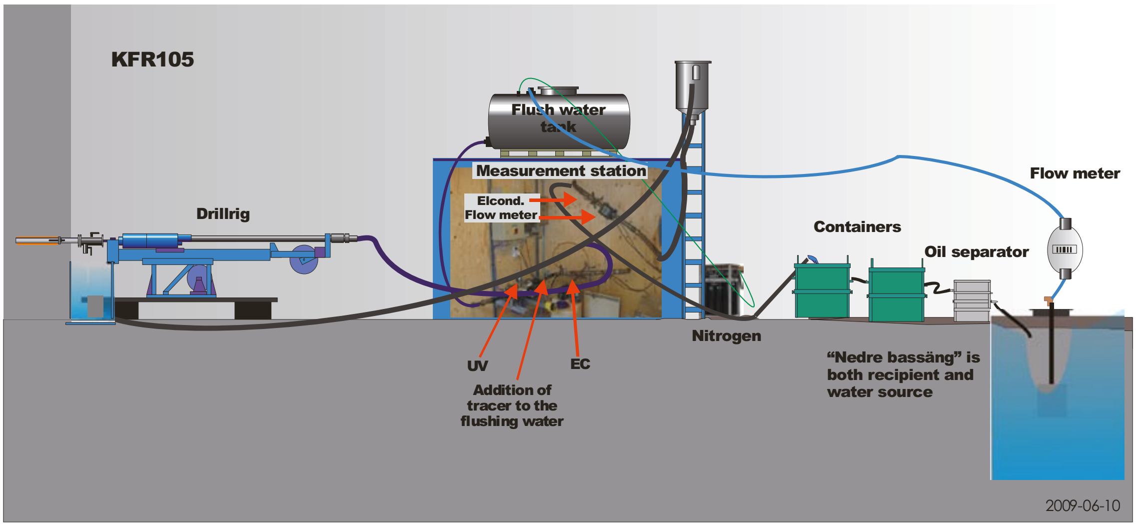
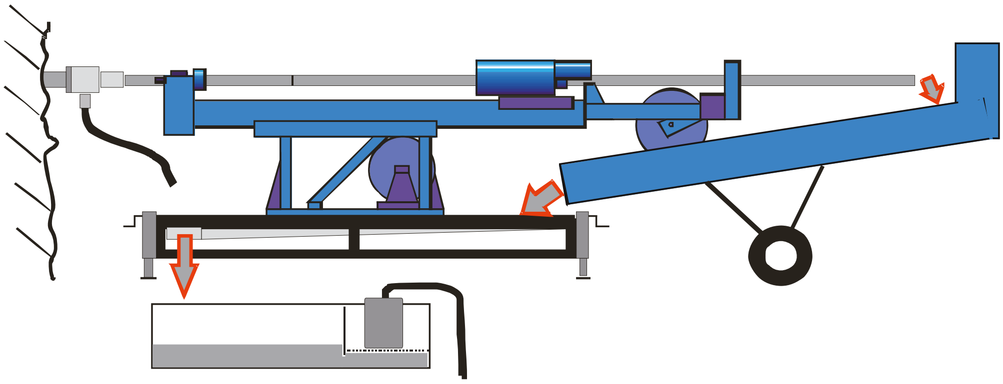


Figure 3-2. Schematic illustration of the flushing/return water system when drilling KFR105. The measurement station included logger units and an UV-radiation unit, and an additional flow meter measured the total incoming water. "Nedre bassängen" is located at the lowest elevation in the SFR-facility and served as the flushing water source and also as the recipient for the return water during core drilling of KFR105.



Figur 3-3. *As an underground drilled borehole is in a state of constant hydrostatic overpressure, most of the return water discharges at TOC. Return water can also flow through the open drill rods, but was when drilling KFR105 funnelled to the drill platform which had an outlet to a collecting box for further pumping.*

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

The total quantity of water supplied to the borehole, used as a double-check of the flow measurements, was acquired by manual readings of flow meters. The readings were stored and afterwards compared to the automatic registrations, which served as a data quality check. An additional manual flow meter, mounted close to the water pump measured the accumulated volume of water pumped from the underground basin "Nedre bassängen".

Storage and discharge of return water

When drilling underground and below the groundwater table, the borehole is in a state of constant hydrostatic overpressure, bringing all return water to flush out from the borehole at TOC (top of casing) where it has to be collected. The return water at KFR105 was discharged from the borehole via an over-sized casing, which decreased the water flow speed, allowing the water to be discharged via a T-piece connector without waste. From the T-piece connector a hose led the water via a flow meter and electric conductivity meter to two containers (see Figure 3-2 and 3-3), in which the drill cuttings could sediment in two 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 before it was let out into the drainage ditch that leads back to underground basin "Nedre bassängen".

3.2 Groove milling equipment

After completion of drilling, the borehole is to be used for a variety of borehole measurements, employing many types of logging strings (pipes, wires, cables etc.) with different stretching characteristics. In order to provide a system for length calibration in the borehole, reference grooves were milled into the borehole wall of KFR105 with a specially designed tool at predetermined levels. The determination of the levels was executed by checking the drill core quality, which is practically representative of the borehole wall quality, at approximately every 50 m borehole lengths. This checking is done to avoid a milling in a cavity or a fractured zone which could harm the milling tool or complicate the later coming detection of the grooves. The milling was carried out after completion of drilling by using the drilling machine and pipe string.

At each level, two 20 mm wide grooves were milled simultaneously with a distance of 10 cm between them, see Figure 3-4. Normally after milling, the reference grooves are detected with the SKB level indicator (a calliper instrument), but this could not be done in KFR105 due to the almost horizontal borehole, precluding cable measurement. Instead, the BIPS-survey provided the final confirmation that the grooves exist.

3.3 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-, Maxibor-data and the measured data of the borehole collar, have been used for estimation of the uncertainty of deviation data.

Results from the deviation measurements and data handling are presented in Sections 5.5.4.

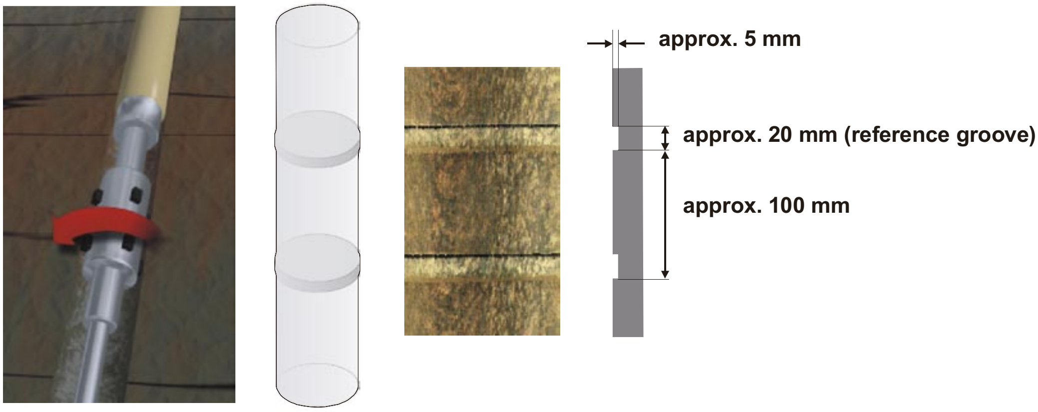


Figure 3-4. Layout and design of reference grooves.

4 Execution

4.1 General

The activities were conducted in compliance with Activity Plan AP SFR-09-004, which refer to SKB MD 620.003 (Method description for core drilling) and the internal report ID 120 3500 (Kärnborrning under jord – SFR Utbyggnad). The drilling operations included the following items:

- preparations of drilling equipment,
- mobilisation,
- drill site preparations, core drilling, measurements and sampling during drilling,
- finishing off work,
- data handling.

These items are presented more in detail in Sections 4.2–4.6.

The commission was performed in compliance with an environmental control programme, see Section 4.7.

Nonconformities with the Method Documents and Activity Plan are presented in Section 4.8.

4.2 Preparations of drilling equipment

The preparations included the Contractor's service and function control of his equipment. The machinery was supplied with oil and grease entirely of the types stated in SKB MD 600.006. Finally, the equipment was cleaned in accordance with SKB MD 600.004. Regarding installation of the borehole casing, preparations, performance and results are described in Section 5.4 in one and the same context.

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 Drill site preparations, core drilling, measurements and sampling during drilling

4.4.1 Drill site preparations

The drill site was, prior to commencement of drilling operations and performed as a separate 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 drilling platform made of steel was constructed to collect the return water as well as to prevent discharge of oil to the tunnel drainage (see Figures 4-1 and 4-2).

However, drilling in the SFR-facility demands enhanced fire prevention. E.g. a water sprinkler in the tunnel roof covered most of the equipment on the drill site, and a large fire-extinguisher (50 kg) supplemented the ordinary above ground fire prevention.

As a consequence also the alarm system was extended with a smoke detector (sniffer) connected to the SFR-alarm system, while a local gas detector would alarm the drillers if lack of oxygen would occur. Finally, the guard at the SFR-control room on ground could control the drill site day and night

Figure 4-1. *The figure shows the empty steel platform on ground, with levelling jacks on each corner.*

Figure 4-2. *The figure shows the steel platform in use underground.*

via a video camera. The site was also connected to the local electrical- and data communication nets. The results of the drill site preparations, i.e the drill site in its finished state, is described in detail in Section 5.1.1.

4.4.2 Core drilling, measurements and sampling during drilling

Core drilling of SKB investigation boreholes is normally associated with a programme for sampling, measurements and other activities during and immediately after drilling, cf. SKB MD 620.003. However, for different reasons, during drilling of KFR105, deviations from this programme could not be avoided. These deviations are presented in Section 4.8 below. Results from the measurements and registrations during core drilling are presented in Chapter 5.

4.5 Finishing off work

The concluding work included the following items:

1) The borehole was flushed for about one hour in order to clean it 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 out.
3) The borehole was, after completed core drilling, sealed with a stainless steel flange.
4) The core drilling equipment was removed, the site 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, 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 Activity Plan number.

4.7 Environmental program

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 KFR105 resulted in a number of nonconformities with the Method Descriptions and Activity Plan. Table 4-1 below presents a comparison of the suggested performance of KF105 according to SKB MD 620.003 and the Activity Plan AP SFR-09-004 with the real performance.

Table 4-1. Suggested programme for performance and frequency of sampling, measurements, registrations and other activities during and immediately after core drilling of KFR105 according to SKB MD 620.003 and AP SFR-09-004 compared to the real performance.

Activity	Performance and frequency according to SKB MD 620.003	Performance and frequency during drilling of KFR105
Registration of drilling- and flushing water parameters.	Registration during the entire drilling.	According to programme. (Methods described in Section 3.1.1.)
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 measurement and four measurements with Flexit after completion of drilling.
Hydraulic tests.	Normally performed every 100 m, and also when penetrating larger conductive fractures/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/zones. The tightness of the drill pipe string should be controlled before each test.	One 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.	Five grooves milled.

5 Results

This chapter is structured as follows:

- Section 5.1 – General.
- Section 5.2 – Drilling progress.
- Section 5.3 – Geometrical and technical design of borehole KFR105.
- Section 5.4 – Pre-drilling and mounting of casing.
- Section 5.5 – Core drilling KFR105, 2.77–306.81 m.

Well Cad plots are composite diagrams presenting the most important technical and geoscientific results from drilling and investigations made during and immediately after drilling. Well Cad presentations of borehole KFR105 are shown in Appendix A.

5.1 General

Experiences and data from the construction of the existing SFR-facility in the 1980s served as important input for the programme governing the current investigations. During this period a large number of cored boreholes were drilled from underground in the SFR-facility. However, 1988, the SFR-facility was made operational for storing medium- and low-level radioactive waste, and has recently been classified as a nuclear facility with safety regulations that have drastically reduced the accessibility to the SFR-facility.

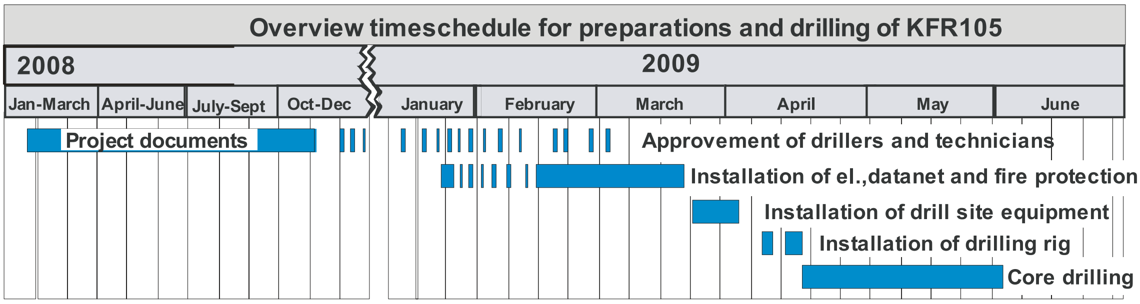
However, the investigation programme stipulates that at least one borehole had to be drilled from an underground position, and therefore the work to receive permission for drilling of KFR105 from an underground drill site was initiated more than a year prior to the planned drill start. Several meetings with the SFR organisation in the beginning of 2008 resulted in guidelines for the continued work. A detailed description of the project was needed so that the SFR management could make a general assessment of the project. For this purpose two reports were produced: “Undersökningar i berg” and “Kontrollprogram för spol- och returvatten”. The first report provides a detailed description of drilling and measuring activities including human and technical resources needed to perform the work. The second report describes the planned groundwater sampling program during and after drilling, in order to demonstrate to the controlling authorities these activities would not cause disturbances for the SFR hydrochemical-sampling program, which has been ongoing for many years.

The permission to establish a drill site in “Nedre byggtunneln” was granted in late 2008 after which the preparations continued to licence the drillers and all the measuring technicians. The activity leaders of the different geoscientific disciplines listed the staff needed to perform their respective activities. The drilling activity included 12 individuals, 7 drillers and 5 technicians.

According to the safety regulations, before access to the SFR-facility is approved, an employee needs 1) a certified education in fire protection, 2) approved medical examination including a drug test, 3) not to be found in the Swedish criminal register and 4) participate in an introductory course regarding working in nuclear facilities. Usually, when all forms are strictly filled in and delivered to FKA (Forsmarks Kraftgrupp), it takes between 6–8 weeks before all information is examined. Finally, a couple of weeks before the drilling started, all permissions were approved. An overview of the preparations and drilling performance of KFR105 is given in Figure 5-1.

5.1.1 Drill site KFR105 in its final state after special preparations

As soon as the permission to drill underground was approved, the technical preparations of the drill site for KFR105 commenced, see Section 4.4.1. In the present section the results of the preparations are described more exhaustively.



Figur 5-1. *Overview time schedule of the preparations and drilling performance of borehole KFR105. More than a year before commencement of drilling, the initial work started in order to get approvement för drilling performance during mid April to early June 2009.*

Fibre cable for the data net and electricity (200 A) to supply the drilling rig were installed. To optimize the budget, the electrical cable used for supporting drilling of boreholes KFR101-104 on the pier at Asphällskulten could now be transferred to the SFR-facility for underground installation.

Always when drilling, both underground and from ground surface, several fire-extinguishers shall be available, but drilling in the SFR-facility demands further fire prevention. Close to the tunnel roof a water sprinkler was mounted, covering most of the equipment, especially the drill rig and the hydraulic unit, whereas a large fire-extinguisher (50 kg) was placed closed to the hydraulic unit, see Figure 5-2. The fire alarm system was extended with a fire detector (sniffer) installed in the data vehicle and connected to SFR alarm system, see Figure 5-3. If activated, the system will alarm at the drill site with a flashlight and a ringing bell, simultaneously as the guard upstairs calls back to the working staff underground.

Also a local system for gas detection was installed, see Figure 5-3. If an oxygen deficiency would occur in the tunnel air, a flashlight and a ringing bell would alarm the drillers. This system was not connected to the SFR alarm system.

A number of motor cars were needed for transport purposes. The major part of "Nedre byggtunneln" is inclined, and a moving vehicle creates high kinetic energy that could cause serious damage already after a couple of metres of uncontrolled rolling. To avoid serious accidents and to protect the working staff and their equipment, the drill site was fenced with heavy cement blocks, see Figure 5-4.

Finally, the SFR-guard could, via a video camera, observe the drill site from the office on the ground surface all around the clock, see Figure 5-5.

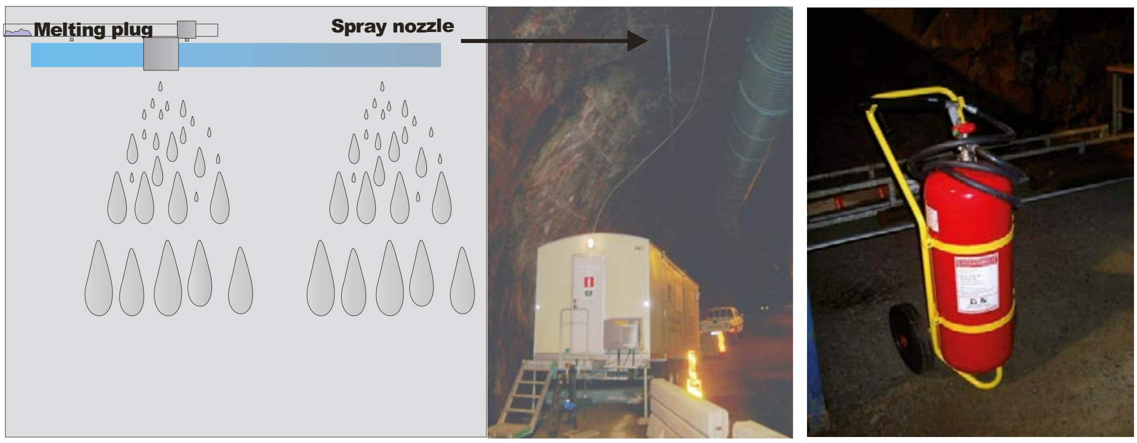


Figure 5-2. *The extended fire prevention included a sprinkler mounted in the tunnel roof, covering most of the drill site. In addition, an extra fire-extinguisher (50 kg) was placed close to the drilling machine and the hydraulic unit.*

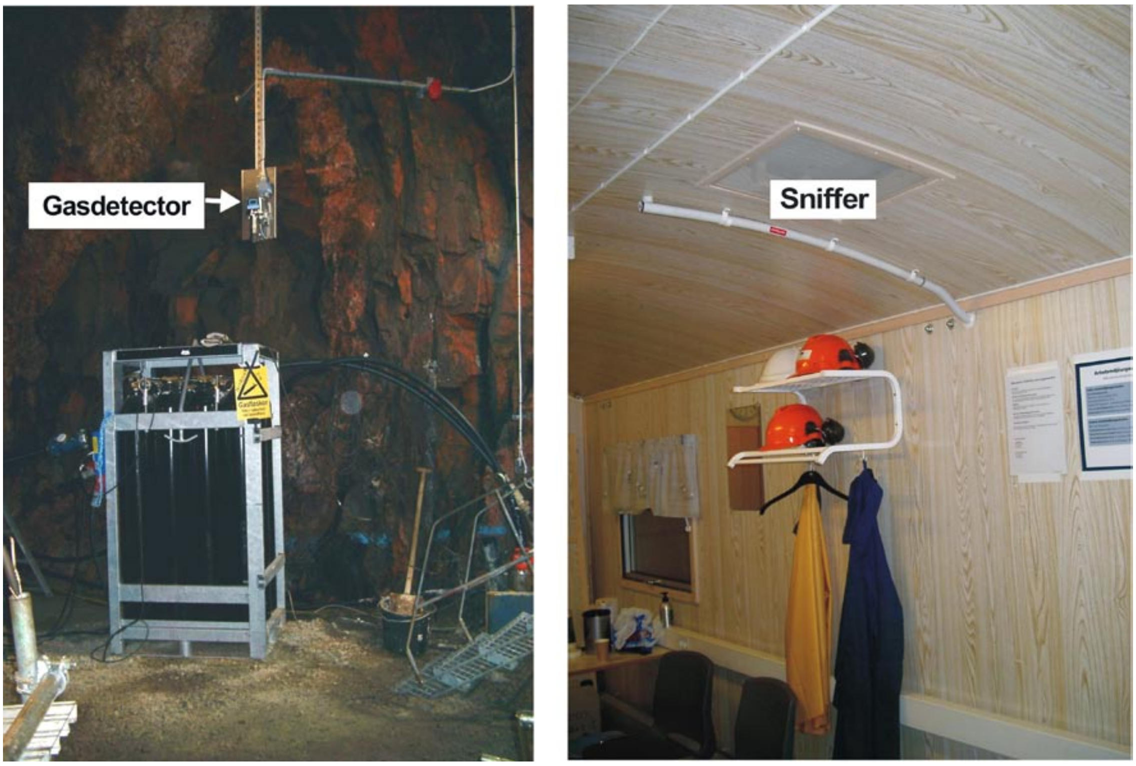


Figure 5-3. Left. Nitrogen was used for reduction of oxygen content in the flushing water tank. If nitrogen would leak out and cause a lack of oxygen in the air, the gas detector would alarm the drillers with a flashlight and a ringing bell. Right. In the personnel carriage a "sniffer" was installed in order to detect smoke from a fire. Therefore smoking is not allowed underground in the SFR-facility.

Figure 5-4. Specially designed cement blocks prohibited rolling vehicles from causing damage on personal or equipment on the drill site located in the curve at "Nedre Byggtunneln".

Figure 5-5. *A video camera provided a perspicuous picture of the drill site and was connected to the SFR alarm system where the guard crew could supervise the ongoing work at the drill site.*

5.1.2 Borehole geometric definitions

After the drilling activities of an SKB borehole have been 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. to which level in the borehole the measured data are associated, clear and indisputable definition of borehole geometrical data must be available shortly after the drilling is completed. Some important borehole geometrical definitions are given in Figure 5-6.

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.

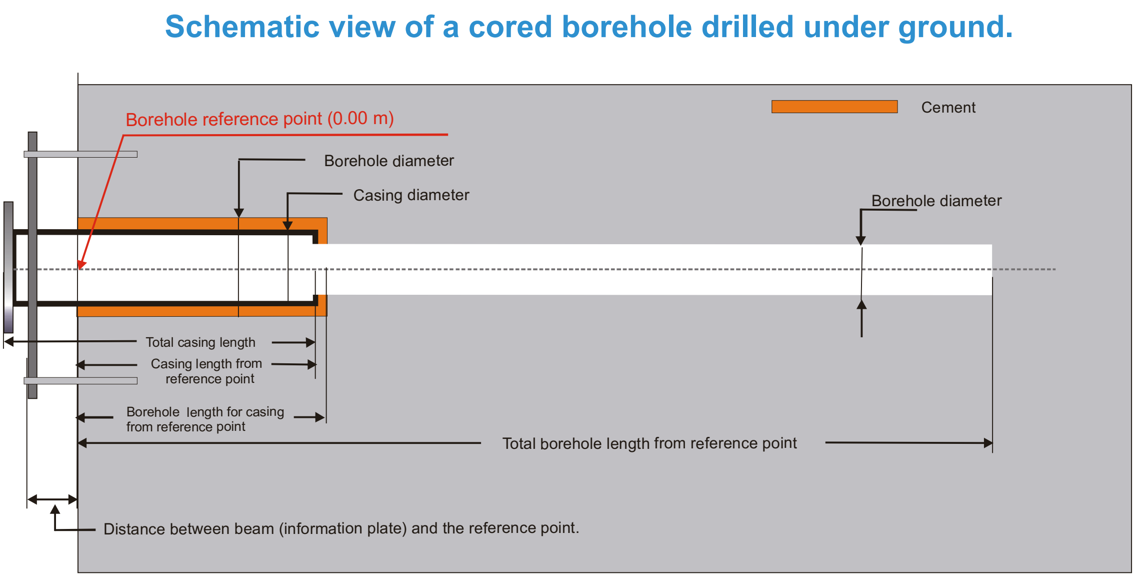


Figure 5-6. *Schematic drawing of a cored borehole of traditional type drilled from underground. The figure shows definitions of the most important data, as reference points, lengths and dimensions used for the technical description of the borehole in this report.*

5.2 Drilling progress KFR105

A WL-drilling cycle comprises four steps, namely; 1) drilling of 3 m core length, 2) pumping in the overshot inside the drill rods in order to catch the inner tube, 3) winching the inner tube back to the borehole collar and 4) pumping in and land the inner tube inside the core barrel at the bottom of the drill rods before drilling can continue (Figure 5-7). The hydrostatic overpressure in the borehole obstructs the pumping in (steps 2 and 4) and besides that, in a near-horizontal borehole the gravity force is too small to contribute more than marginally to transfer equipment into the borehole. Mostly depending on these circumstances, wireline (WL) drilling from underground is usually advancing slowly compared with WL-drilling from ground surface.

For future core drilling underground, especially at great depths, SKB should consider to apply a smaller dimension, WL56 mm or similar. This would reduce the time consumption for drilling up to 50% and the drilling cost upwards 65%. A negative aspect of smaller drilling dimensions is the smaller core size, approximately Ø 37 mm for WL 56 mm, compared to c. Ø 50 mm for WL76 mm. Drill cores of a small diameter generally provides less favourable prerequisites for geological characterisation purposes than larger cores, which has to be taken into account before a decision in this matter is made.

Pre-drilling, installation and grouting of casing were carried out on April 21st–23rd and core drilling and measurements were performed during the period April 28th to June 2nd, see Figure 5-8.

5.2.1 Core drilling

The progress of the core drilling from 2009-04-28 to 2009-06-02 is illustrated in Figure 5-9.

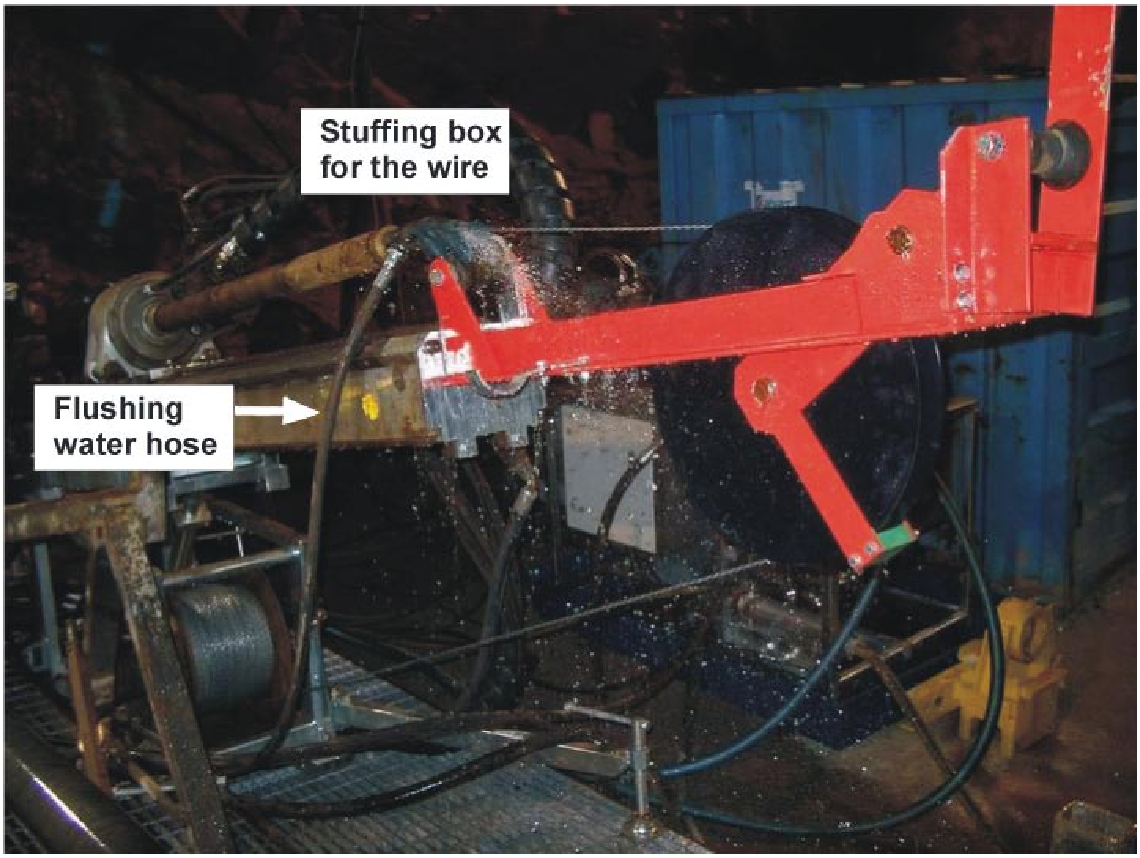
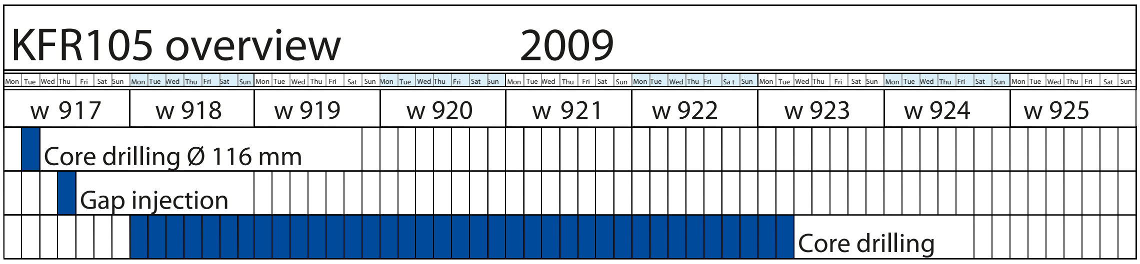


Figure 5-7. The figure shows time consuming in-pumping of the overshot and wire for retrieval the drill core filled inner tube.



Figur 5-8. Overview of the drilling performance of borehole KFR105.

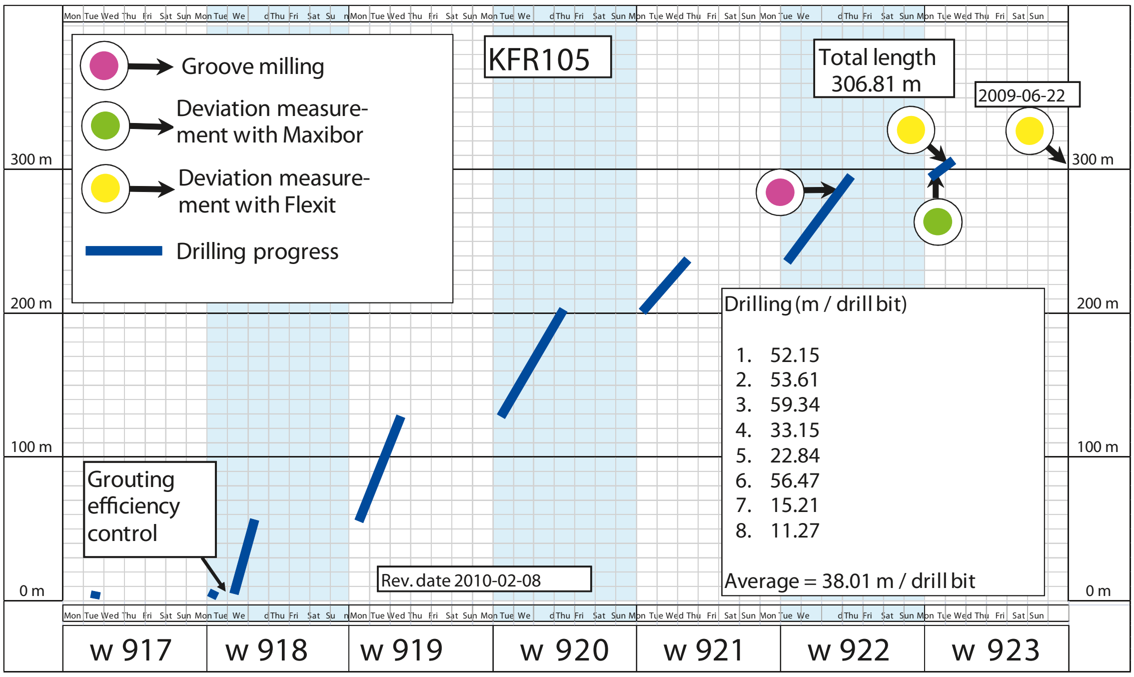


Figure 5-9. Core drilling progress (length versus calendar time). The figure includes logistics for WL-drilling, grove milling and deviation measurements with Flexit and Maxibor.

5.3 Geometrical and technical design of borehole KFR105

Administrative, geometric and technical data for the telescopic borehole KFR105 are presented in Table 5-1. The technical design of the borehole is illustrated in Figure 5-10.

5.4 Pre-drilling and mounting of casing

5.4.1 Preparations of drilling equipment

When preparations of the drill site were concluded, the drilling equipment arrived at the SFR-facility on April 14th. When drilling from drill sites on ground, the final cleaning of the equipment is conducted on site, but by environmental reasons this was not allowed underground. Instead, the drilling equipment including drill pipes and casing was flushed with hot water in the SFR-garage on ground, see Figure 5-11A and Figure 5-11B, before it was transferred to the drill site underground, located in "Nedre byggtunneln".

5.4.2 Pre-drilling with Ø116 mm (metric B116)

As mentioned, a borehole drilled from underground and below the groundwater table is in a state of hydraulic overpressure. Borehole KFR105 has an elevation of c. –106 m, entailing that, when closed, it is exposed to a hydrostatic pressure of c. 10 bars above atmospheric. Working with boreholes of

Table 5-1. Administrative, geometric and technical data for borehole KFR105.

Parameter	Data
Borehole name	KFR105
Location	Forsmark, Östhammar municipality, Sweden
Drill start date	April 21st, 2008
Completion date	June 02nd, 2008
Contractor core drilling	Drillcon Core AB
Core drill rig	Sandvik DE 130
Position at reference level (rock surface (RT90 2.5 gon V 0:-15 / RHB 70)	N 6701789.85 (m)
	E 1633072.96 (m)
	Z -106.82 (m)
	Azimuth (0–360°): 174.48°
	Dip (0–90°): –10.12°
Position at bottom of hole (RT90 2.5 gon V 0:–15 / RHB 70)	N 6701489.07 [m]
	E 1633107.16 [m]
	Z –156.63 (m)
	Azimuth (0–360°): 173.23°
	Dip (0–90°): –8.23°
Borehole length	306.81 m
Borehole length and diameter	From 0.00 m to 2.77 m: 0.116 m
	From 2.77 m to 306.81 m: 0.0758 m
Casing diameter and drilling length	$\varnothing_o/\varnothing_i$ = 100.00 mm/80.00 mm: –0.33 to 2.64 m
Drill core dimension	0.00–2.77 m/ Ø = 0.0920 mm
	2.77–306.81 m/ Ø = 0.0502 mm
Average length of core recovery	2.36 m
Number of runs	129
Diamond bits used	8
Average bit life	38.01 m

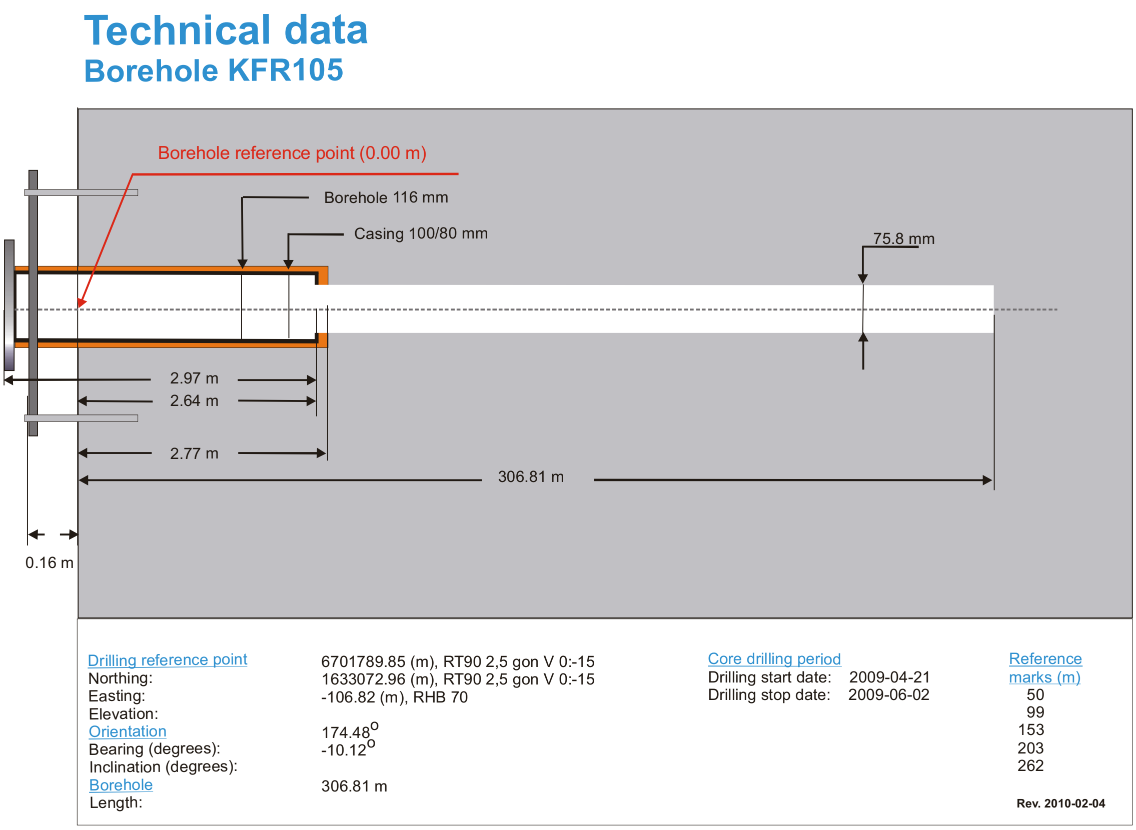


Figure 5-10. Technical data of borehole KFR105.

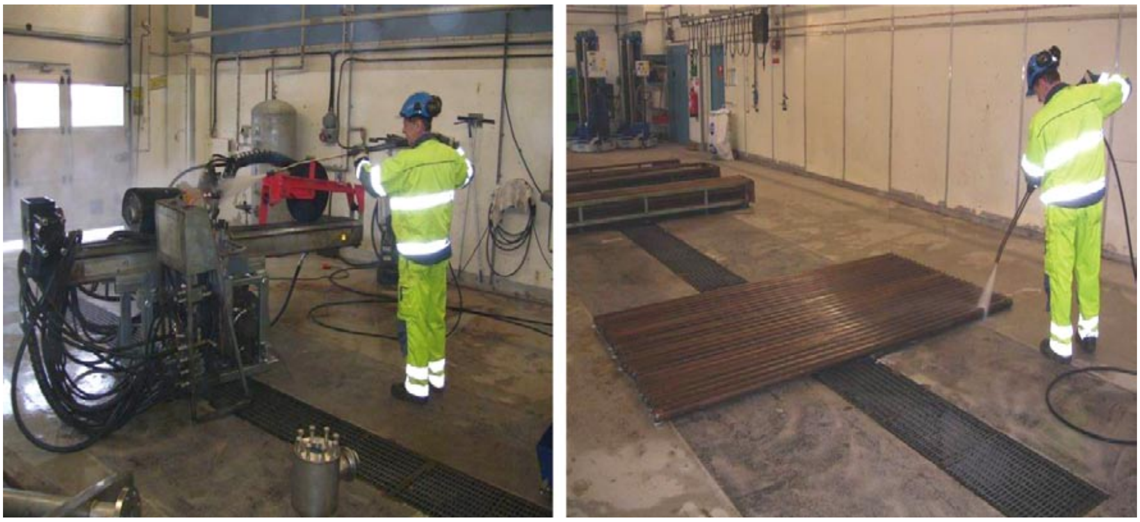


Figure 5-11A. *To the left cleaning with hot water of the drilling machine and, to the right, of drill pipes before transportation to the underground drill site.*

Figure 5-11B. *Left. Cleaning with hot water on ground of the 3 m stainless steel casing. Right. Bolting of the casing to the rock wall after gap grouting in the pre- drilled borehole.*

high groundwater pressures involves an enhanced risk of accidents at work, especially if the borehole also has a large groundwater inflow. An erroneous handling could cause damage both on humans and equipments. One important measure in order to reduce the risk of fatal accidents is to anchor the casing firmly to the rock and to provide the casing outlet with a suitable valve or lid for sealing the borehole.

Regarding borehole KFR105, the c. 3 m long casing is made of stainless steel, $\text{Ø}_o/\text{Ø}_i$ 100/80 mm, and was attached to the rock by cement gap grouting and by mechanical bolting to the rock wall, see Figure 5-12.

Pre drilling was performed with metric B116 dimension that gives a borehole diameter of 116 mm and a core diameter of 92 mm. The borehole direction was settled with to fixed points, one close to the borehole collaring and one backwards at the tunnel wall. A string was attached to the fixed points, and by using a pendulum and a measuring tape (folding rule) the drill rig could be adjusted accurately to the determined direction. The dip was adjusted with an angle gauge, see Figure 5-12.

Figure 5-12. Pre drilling was performed with the B116 dimension that gives a 116 mm borehole diameter and a 92 mm core diameter. The borehole direction was settled with two fixed points, one close to the borehole collaring and one backwards at the tunnel wall, after which a string was attached to the fixed points. By using a pendulum and a measuring tape, the drill rig could be adjusted accurately to the determined direction.

5.4.3 Casing installation

For all previously drilled boreholes (during the 1980's) within the SFR-facility, the borehole casings have been cement grouted. After establishment of the Äspö HRL in Oskarshamn, a large number of SKB boreholes have been drilled underground and at considerable depths. As a consequence, some borehole casings must resist water pressures up to c. 50 bars. To achieve a stable anchoring, the casings at Äspö HRL were glued to the borehole wall and then bolted to the rock wall. However, use of organic chemicals in nuclear facilities must be minimized or completely avoided. Therefore, for the underground boreholes which are part of the SFR investigation programme, the anchoring of casings should be performed by cement grouting combined with rock bolts.

Based on these demands, a simplified application technique was developed for application of cement grout into the gap between the borehole wall and the casing. By using a predrilled borehole of relatively small dimension, 116 mm, the volume of the gap was reduced, resulting in that the inner volume of the 3 m long casing is almost equal with the volume of the gap between casing and the borehole wall. Standard cement and water was first firmly mixed in a bucket and then poured into the end plugged casing before installation in the borehole, see Figure 5-13. A plastic piston was placed on top of the cement column. The sealed casing filled with cement grout was then mounted on centralizers in the predrilled borehole. The plastic piston was pushed inwards by hand with a steel pipe, and the grout was pressed into the gap from borehole bottom up to the borehole collar, see Figure 5-13. To prevent the grout to leak out, a rubber gasket was applied at the borehole collar. Finally, the two rock bolts were tightened. After the cement grout had hardened during a weekend, drilling continued. No leak of water around the casing has been observed after the gap grouting efforts.

5.5 Core drilling

5.5.1 Measurements while drilling KFR105

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.

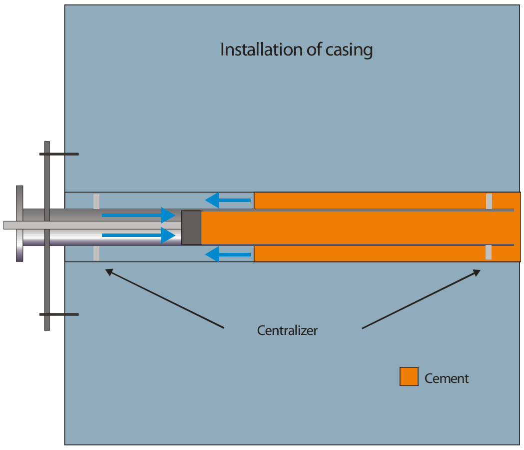


Figure 5-13. Grouting of casing. The casing was filled with cement, after which it was installed and centralized in the pre-drilled borehole. The cement grout was pressed backwards with a plug (a plastic piston), so that the cement was forced into the gap between the outside of the casing and the borehole wall.

Flushing water and return water flow rate – water balance

Figure 5-14 displays the accumulated volumes of flushing water and return water, respectively, from the entire drilling period. The accumulated volumes of flushing water and return water are also illustrated in the histogram in Figure 5-15, 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 as high as 2.09, which is reflecting the fact that the borehole is exposed to a hydrostatic overpressure. All flushing water used was recovered together with the accumulated inflow of groundwater to the borehole, which was open during the drilling period.

Figure 5-16 illustrates the system for collecting the return water from the borehole.

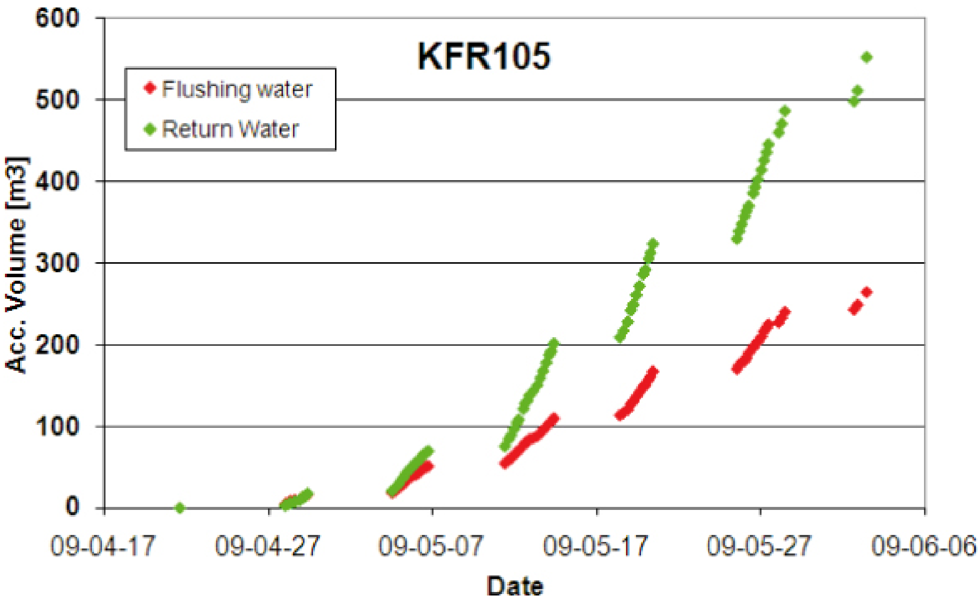


Figure 5-14. Accumulated volumes of flushing water (red) and return water (green) versus time during core drilling of borehole KFR105.

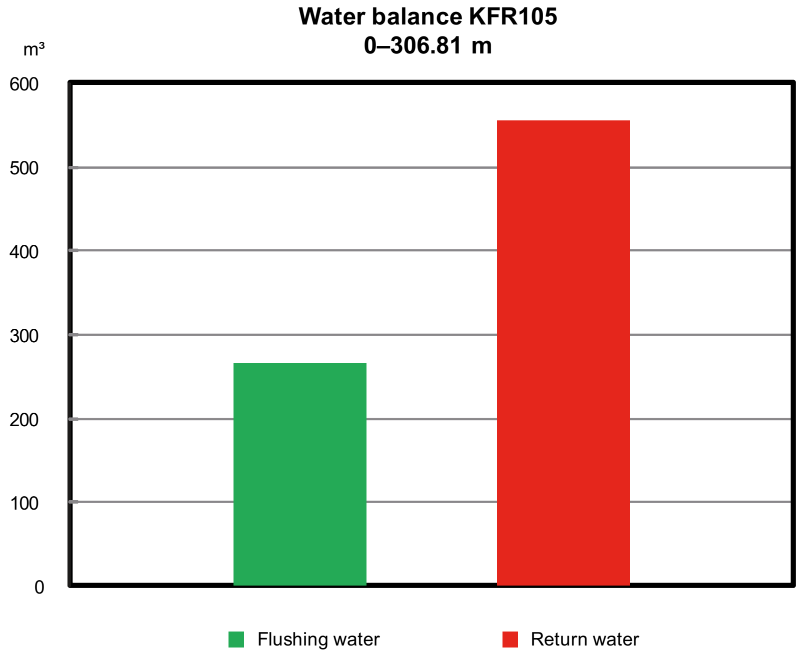


Figure 5-15. Total amounts of flushing water and return water during drilling of borehole KFR105. The total volume of flushing water used during core drilling was amounted to 265 m^3. During the same period, the total volume of return water was 554 m^3. The return water/flushing water balance is then as high as 2.09, due to constant outflow from a borehole drilled from underground and below the groundwater table.

Figure 5-16. The figure demonstrates the driller pulling the inner tube containing 3 m drill core. During this phase of the drilling sequence the return water is evacuated from the drill rods and collected by the water-tight drill platform, from which it is pumped away for flow measurements and sedimentation of drill cuttings. During the drilling phase, the return water is forced through the cross pipe and down to the platform.

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 during the drilling period, see Figure 5-17. A dosing feeder (Figure 3-2) 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. As borehole KFR105 was drilled below the groundwater table, all added flushing water as well as the accumulated inflow of groundwater to the borehole was recovered as a return water outflow at TOC.

According to notations in the logbook, the amount of Uranine added to the borehole was 53 g. When the averages of the Uranine concentration values in the flushing water and return water samples were used to estimate the amount of Uranine added to and recovered from the borehole, the result is 50 g and 66 g, respectively. This indicates 1) that the remaining amount of Uranine added to the borehole is small, if any, and 2) that some remainders of Uranine from drilling the boreholes on ground are still left in the borehole. After finished drilling, water samples collected in connection with the water control program in KFR105 confirmed low flushing water content in the water samples.

Electric conductivity of flushing water and return water

Flushing water during drilling of KFR105, was supplied from the drainage water accumulated in "Nedre bassängen". 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 5-18.

KFR105 was drilled sub-horizontally (–10.12°), intersecting a bedrock volume from –106 m to –156 m vertical depth, whereas the "Nedre bassängen" is located at an elevation of c. –140 m RHB 70. The

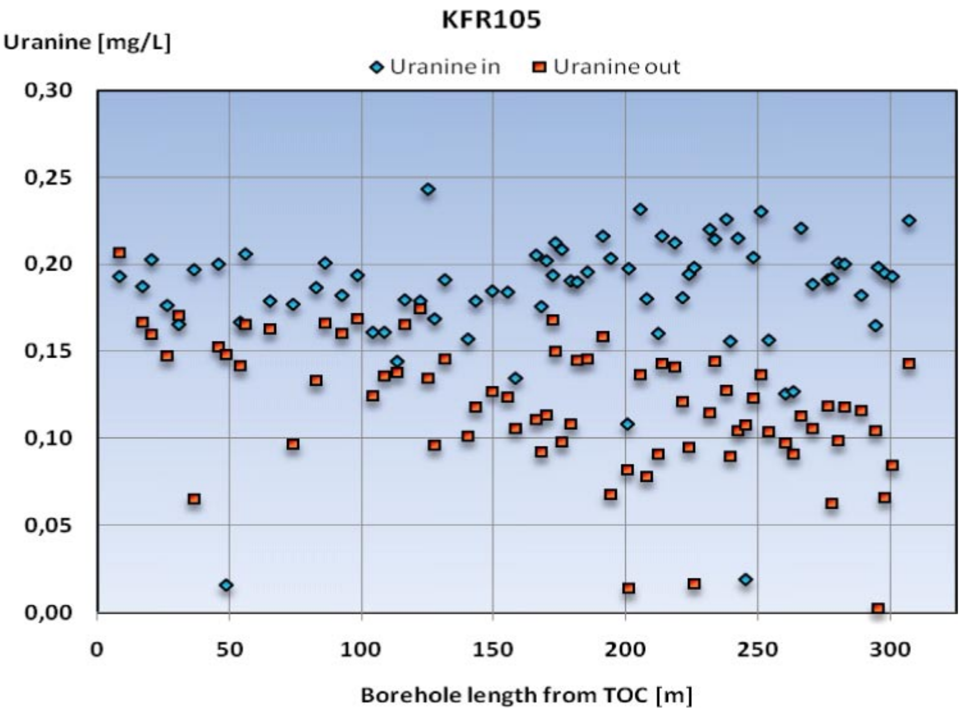


***Figure 5-17.** Uranine contents in the flushing water consumed and the return water recovered versus drilling length during drilling of borehole KFR105. Automatic dosing equipment, controlled by a flow meter, accomplished the labelling with Uranine.*

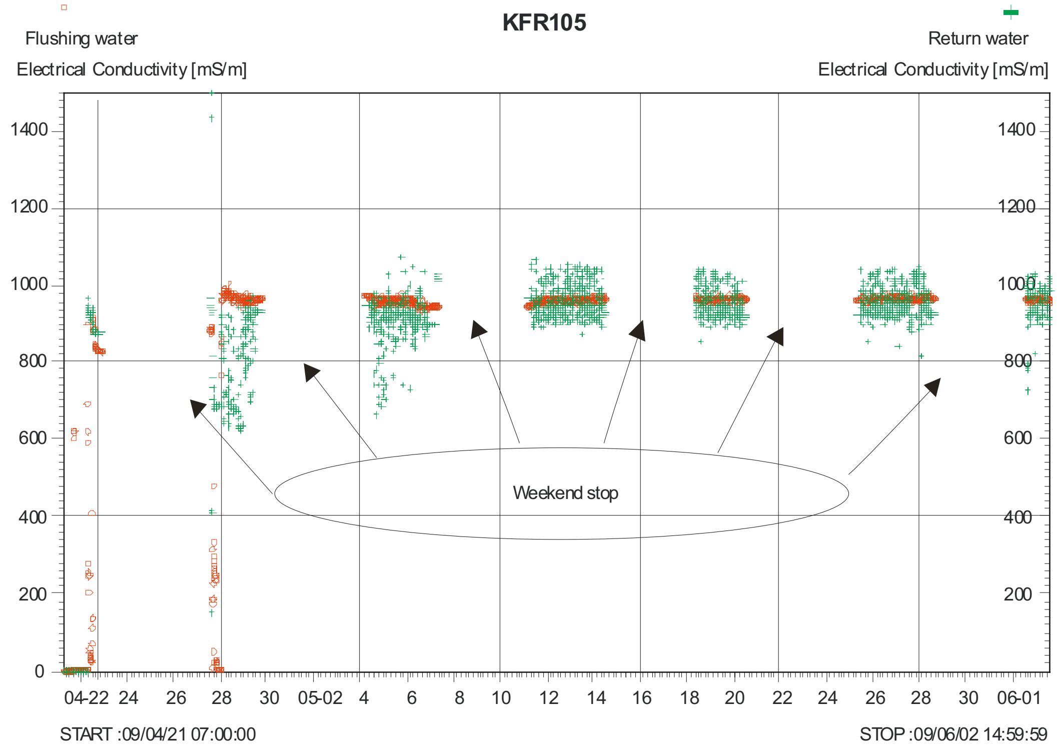


__Figure 5-18.__ Electrical conductivity of flushing water (from "Nedre bassängen") and return water from KFR105.

main volume of drainage water in "Nedre bassängen" is achieved from the Singö zone that penetrates "Byggtunneln", i. e. the entrance tunnel to the SFR facility, at c. 50–60 m vertical depth. It may therefore seem odd that the EC-values of the flushing water with its shallow origin tend to be higher than, or at least as high as, that of the return water. The control program performed during drilling shows that the flushing water used had an EC-value of 925–950 mS/m, see Figure 5-18. As the return water is a mixture of flushing water and groundwater, the EC-values vary slightly, between 900–1,050 mS/m, depending on what portion of groundwater is included in the mixture of a specific sample. When the groundwater inflow to the borehole rose from 3 L/m to c. 12 L/m on May 11th (see Figure 5-19), a minor increase of the EC-value of the return water was observed, indicating a clear correlation between depth and EC. After that, the inflow increased only marginally, and the EC-values remained at an almost constant level to the borehole end.

A possible explanation to the high EC-values of the flushing water in relation to the return water may be that cement has been used frequently in the SFR-facility for stabilizing operations, during which

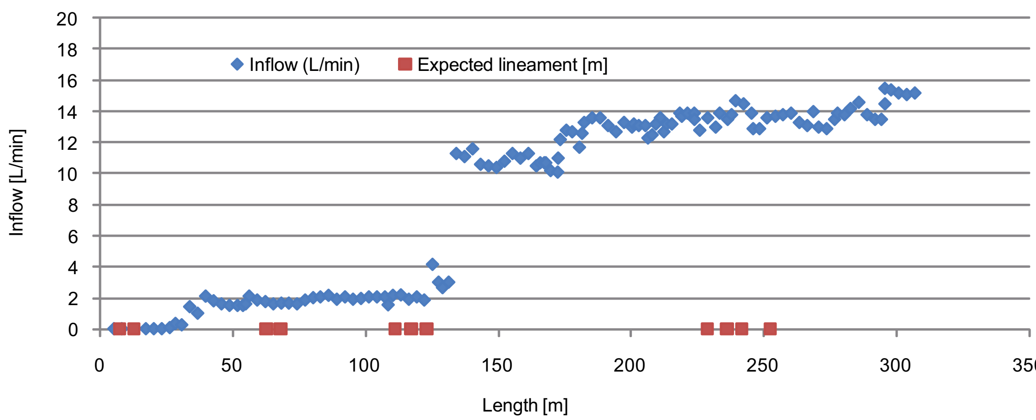


__Figure 5-19.__ Accumulated inflow to the borehole measured after finished drilling but with the drill string still left in the borehole. At c. 135 m (May 11th) an increased inflow of water to the borehole is observed.

long sections of the tunnel roof and wall have been cement grouted. When water leaks into the tunnel system, it eventually solutes part of the grouted cement, which in time may enhance the salt concentration of the drainage water by increasing the contents of mainly calcium and carbonate ions.

Content of dissolved oxygen in flushing water

The concentration of dissolved oxygen in the flushing water was measured and plotted versus time, which showed that concentrations generally in the interval 2–4 mg/L. In order to ensure a continuous inflow of nitrogen to the flushing water tank (cf. Section 3.3.2), it was decided to observe and document the pressure in the nitrogen bottles once a day. The pressure reduction of nitrogen is presented in Figure 5-20.

5.5.2 Core sampling

The average drill core length per run obtained from the drilling was 2.36 m (Section 2.77–306.81 m). No unbroken core was recovered. Fracture minerals were relatively well preserved. A preliminary core logging was performed continuously in connection with the drilling, see Figure 5-21.

5.5.3 Recovery of drill cuttings

The theoretical weight of drill cuttings from KFR105 to 306.81 m is calculated to be 1,952 kg (0.736 m^3), and c. 1,188 kg (0.448 m^3) of that is probably lost in the drainage ditch as no drill cuttings are probably left in the formation due to the continuous outflow of return water.

5.5.4 Deviation measurements in KFR105

The types and measurement principles of the 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 Tool System) were applied for the deviation measurements performed in KFR105.

Normally, the Flexit deviation instrument is connected to a cable winch and is lowered by the gravity force down the borehole, but in a near horizontal borehole like KFR105 (inclined c. –10°) KFR105, this is not possible. Therefore a new system for insertion of logging tools with stiff rods into horizontal boreholes has recently been developed by SKB and was delivered just in time to be used for borehole logging in KFR105, see Figure 5-22.

This insertion system for non-vertical logging consists of a metal frame on which a feeder mechanism is assembled. The frame is anchored in one end to the borehole collar and is at the other end supplied

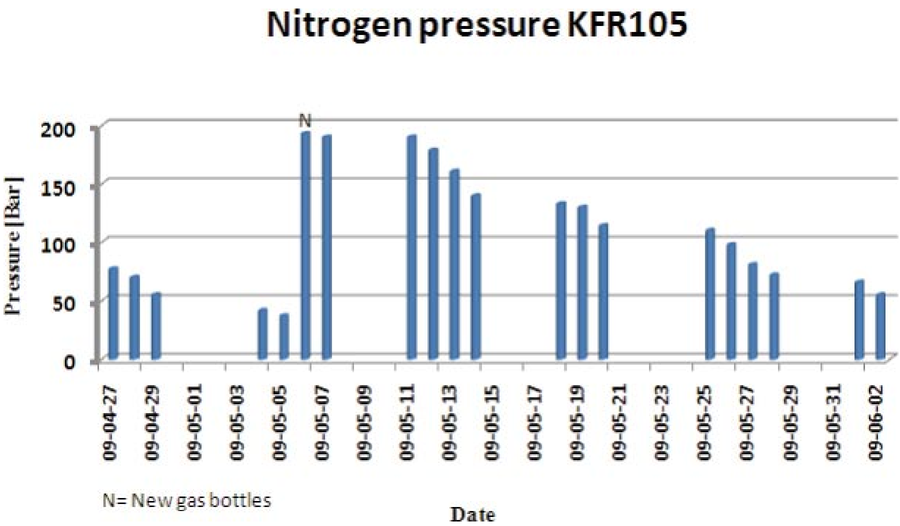


Figure 5-20. *Nitrogen contents (measured as pressure) in the bottles for nitrogen bubbling of flushing water in KFR105A. "N" above bars equals to change of nitrogen bottle batteries.*

Figure 5-21. 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, was conducted after completion of drilling.

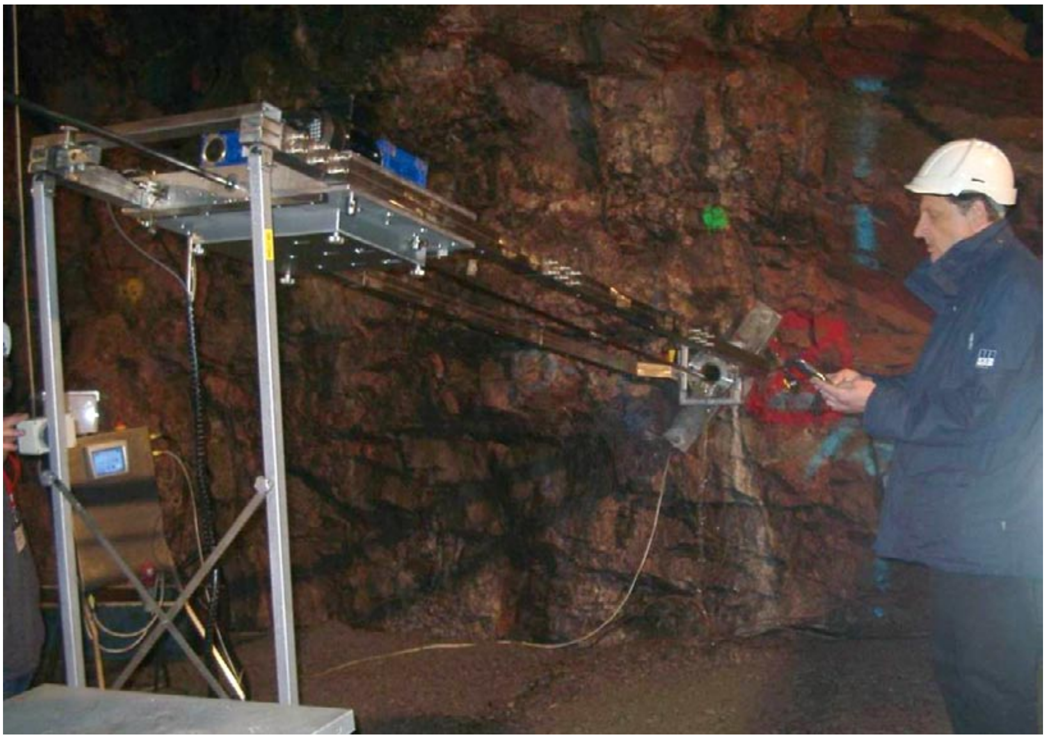


Figure 5-22. The figure shows the new system for insertion of different logging tools with rods to be used in non-vertical boreholes.

with adjustable support legs. When establishing the equipment, these legs are trued up as to get the feeder mechanism in-line with the borehole direction (Figure 5-22).

The feeder mechanism consists of rubber wheels on both sides of the rod string. The wheels, which are electrically driven, can be adjusted for different pressures on the rods for maximum traction. The electric motor can be electronically set for different speed and feeding lengths on a separate control panel (see Figure 5-22 and 5-23). A new set of measuring rods made of stainless steel, dimensions Ø 20 x 2,000 mm length and with non- revolving quick couplings are part of this equipment set-up.

High quality measurements with the Flexit tool demands limited disturbances from the global magnetic field. Several measurement stations around the world provide magnetic field values, generally available on the Internet. For the Forsmark area the closest station is situated in Sodankylä, Finland and this station presents one-minute magnetic field values at www.intermagnet.org. The magnetic field variations during two loggings in June 2nd and two loggings in June 22th 2009 are presented in Figures 5-24 and 5-25 and display only minor disturbances when the Flexit-surveys in KFR105 were performed.


***Figure 5-23.** The figures show the feeder to the left and the control panel to the right.*

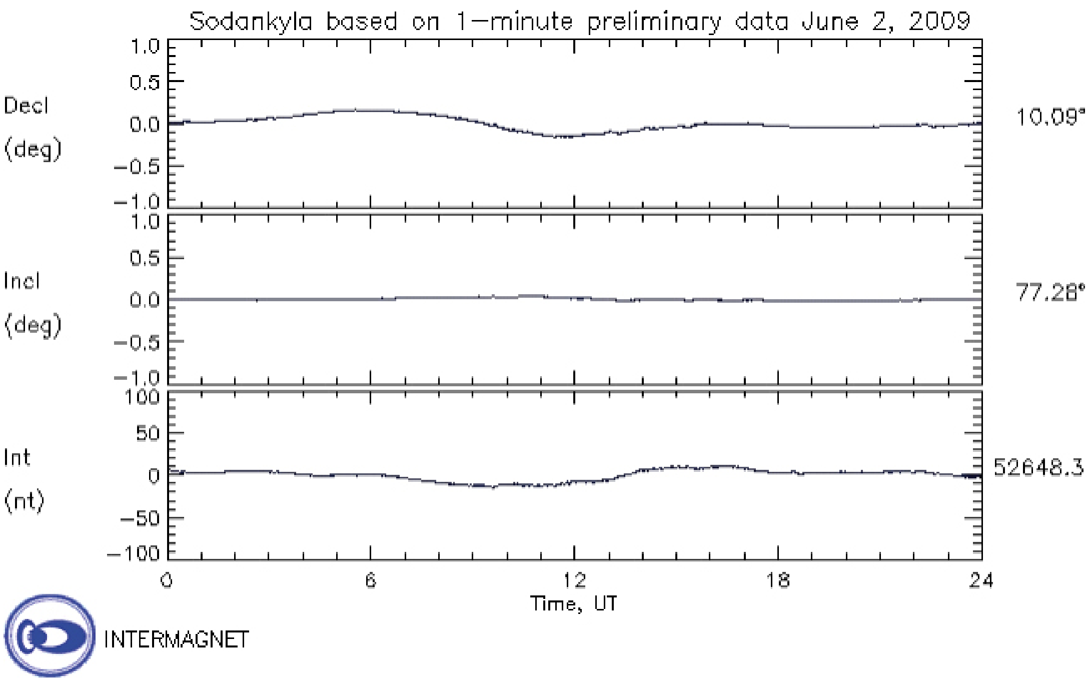


***Figure 5-24.** Magnetic field variations during Flexit surveys performed on June 2nd 2009 in KFR105.*

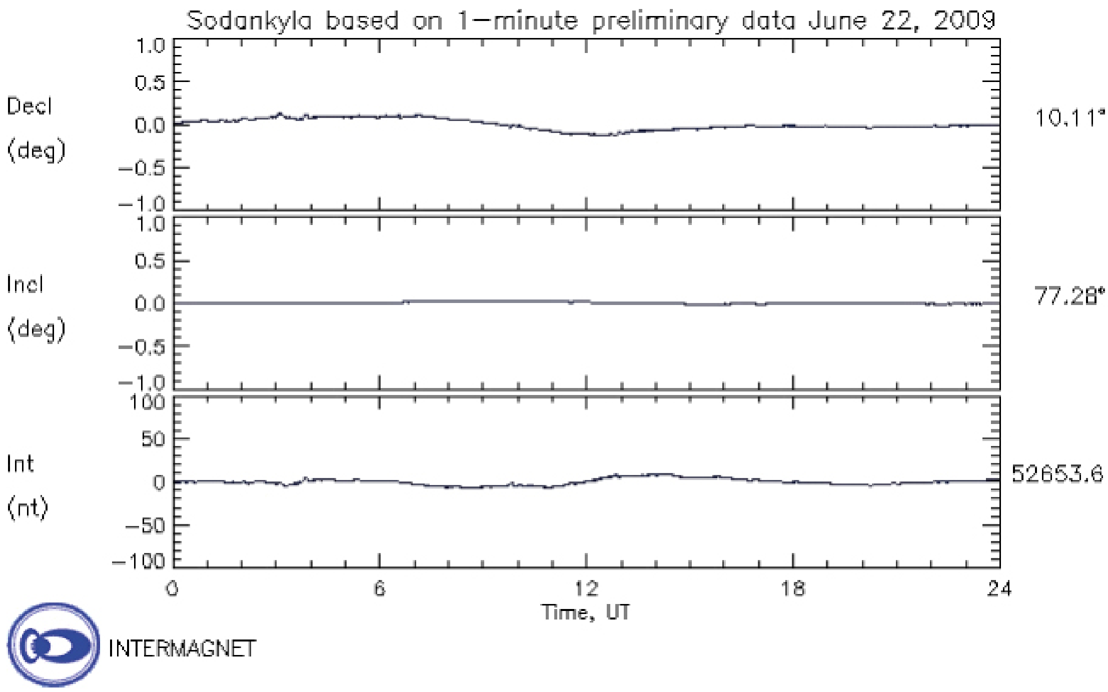


***Figure 5-25.** Magnetic field variations during Flexit surveys performed on June 22nd 2009 in KFR105.*

A description of the construction of deviation data for the core drilled borehole KFR105 is given below.

With the Flexit system, the deviation measurements were carried out every 3 m both downwards and upwards. The used activity marked "CF" in Table 5-2 also includes comments as well as a file describing the measures that have been applied.

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).

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 3 m steel casing which is not the case for the inclinometer measurements (inclination).

Table 5-2. Activity data for all deviation measurements approved for KFR105 (from Sicada). The five magnetic measurements in the borehole were used for calculation of the final borehole deviation file, as well as used for calculation of the deviation uncertainty.

Activity ID	Activity Type Code	Activity	Start Date	Idcode	Secup (m)	Seclow (m)	Flags
13215981	EG161	Maxibor II measurement	2009-06-01 09:00	KFR105	3.00	294.00	CF
13215982	EG161	Maxibor II measurement	2009-06-01 12:30	KFR105	3.00	294.00	CF
13215915	EG157	Magnetic – accelerometer measurement	2009-06-02 15:48	KFR105	3.00	303.00	CF
13215916	EG157	Magnetic – accelerometer measurement	2009-06-02 17:15	KFR105	3.00	303.00	CF
13227998	EG157	Magnetic – accelerometer measurement	2009-06-22 12:26	KFR105	3.00	303.00	CF
13227999	EG157	Magnetic – accelerometer measurement	2009-06-22 13:49	KFR105	3.00	303.00	CF
13228433	EG154	Borehole deviation multiple measurements	2009-07-03 08:30	KFR105	3.00	303.00	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)
13215981	BEARING	3.00	294.00
13215981	INCLINATION	3.00	294.00
13215982	BEARING	3.00	294.00
13215982	INCLINATION	3.00	294.00
13227998	BEARING	12.00	303.00
13227998	INCLINATION	3.00	303.00
13227999	BEARING	12.00	303.00
13227999	INCLINATION	3.00	303.00

Table 5-4. Deviation data from KFR105 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]
KFR105	0.00	6,701,789.85	1,633,072.96	–106.82	–10.14	174.48
KFR105	30.00	6,701,760.45	1,633,075.84	–112.04	–9.90	174.31
KFR105	60.00	6,701,731.04	1,633,078.83	–117.16	–9.83	174.12
KFR105	63.00	6,701,728.10	1,633,079.13	–117.67	–9.83	174.12
KFR105	90.00	6,701,701.64	1,633,081.92	–122.25	–9.63	173.85
KFR105	120.00	6,701,672.23	1,633,085.17	–127.22	–9.54	173.54
KFR105	150.00	6,701,642.84	1,633,088.55	–132.16	–9.36	173.33
KFR105	180.00	6,701,613.43	1,633,091.95	–137.00	–9.24	173.40
KFR105	210.00	6,701,584.02	1,633,095.45	–141.82	–9.20	173.10
KFR105	240.00	6,701,554.62	1,633,099.07	–146.57	–9.00	172.88
KFR105	270.00	6,701,525.21	1,633,102.76	–151.20	–8.71	172.91
KFR105	300.00	6,701,495.77	1,633,106.36	–155.66	–8.29	173.19
KFR105	306.81	6,701,489.07	1,633,107.16	–156.63	–8.23	173.23

* The starting values of inclination and bearing in EG154 are calculated and could therefore show a discrepancy compared to 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 5-26 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 KFR105 shows that the borehole deviates downwards and slightly to the left with an absolute deviation of 10.5 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 that of the borehole collar.

5.5.5 Groove milling KFR105

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 5-5. Uncertainty data for the deviation measurements in KFR105 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
KFR105	6,701,789.85	1,633,072.96	–106.82	0.265	1.138	0.00
KFR105	6,701,760.45	1,633,075.84	–112.04	0.265	1.138	0.59
KFR105	6,701,731.04	1,633,078.83	–117.16	0.265	1.138	1.17
KFR105	6,701,728.10	1,633,079.13	–117.67	0.265	1.138	1.23
KFR105	6,701,701.64	1,633,081.92	–122.25	0.265	1.138	1.76
KFR105	6,701,672.23	1,633,085.17	–127.22	0.265	1.138	2.35
KFR105	6,701,642.84	1,633,088.55	–132.16	0.265	1.138	2.94
KFR105	6,701,613.43	1,633,091.95	–137.00	0.265	1.138	3.52
KFR105	6,701,584.02	1,633,095.45	–141.82	0.265	1.138	4.11
KFR105	6,701,554.62	1,633,099.07	–146.57	0.265	1.138	4.70
KFR105	6,701,525.21	1,633,102.76	–151.20	0.265	1.138	5.29
KFR105	6,701,495.77	1,633,106.36	–155.66	0.265	1.138	5.88
KFR105	6,701,489.07	1,633,107.16	–156.63	0.265	1.138	6.01

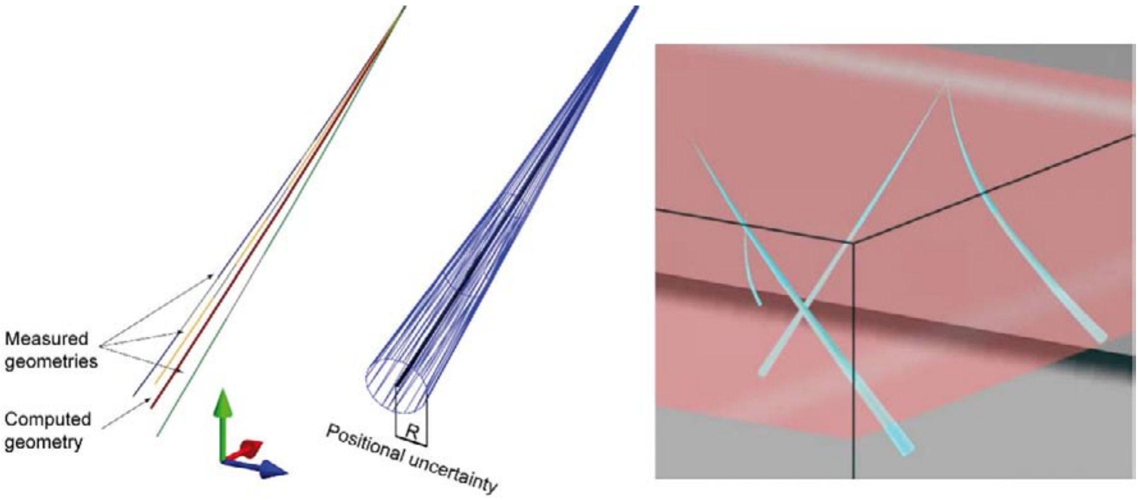


Figure 5-26. The figure to the left is an illustration of the principles for calculating the borehole geometry from several deviation measurements. The two other figures illustrate one of the uncertainty measures used for deviation measurements. In the middle figure, "R" denotes "Radial uncertainty", 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 5-5. 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/).

Table 5-6. Reference grooves in KFR105.

Reference groove at [m]	Detection with the SKB level indicator	Confirmed from BIPS
50	No	Yes *
99	No	Yes *
153	No	Yes *
203	No	Yes *
262	No	Yes *

* BIPS not adjusted.

5.5.6 Risk assessment KFR105

Ensuing completion of drilling activities, an extensive 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 risk observations at all,

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

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

3 = borehole collapse.

Following these compulsory guidelines, the risk assessments after finishing the drilling activities of borehole KFR105 are summarized in Table 5-7. Twenty one sections of borehole KFR105 have been classified as involving a potential risk (1), meaning that the core section is highly fractured and thus associated with a risk for rock fallout.

Table 5-7. Documented sections of potential risk from observations during drilling and preliminary geological core mapping of KFR105.

From length (m)	To length (m)	Risk level (code)	Description	From length (m)	To length (m)	Risk level (code)	Description
0.00	9.00	0		95.30	107.50	0	
9.00	9.50	1	Fractured zone	107.50	108.50	1	Fractured zone
9.50	16.40	0		108.50	126.70	0	
16.40	17.00	1	Fractured zone	126.70	127.00	1	Fractured zone
17.00	43.70	0		127.00	152.30	0	
43.70	44.00	1	Fractured zone	152.30	153.20	1	Fractured zone
44.00	45.55	0		153.20	157.00	0	
45.55	45.85	1	Fractured zone	157.00	157.40	1	Fractured zone
45.85	48.80	0		157.40	172.10	0	
48.80	49.20	1	Fractured zone	172.10	175.00	1	Fractured zone
49.20	55.20	0		175.00	212.90	0	
55.20	55.35	1	Fractured zone	212.90	213.15	1	Fractured zone
55.35	61.75	0		213.15	219.20	0	
61.75	62.10	1	Fractured zone	219.20	219.40	1	Fractured zone
62.10	66.40	0		219.40	233.00	0	
66.40	66.60	1	Fractured zone	233.00	233.30	1	Fractured zone
66.60	83.20	0		233.30	267.60	0	
83.20	83.60	1	Fractured zone	267.60	268.40	1	Fractured zone
83.60	90.20	0		268.40	269.80	0	
90.20	90.40	1	Fractured zone	269.80	280.40	1	Fractured zone
90.40	94.70	0		280.40	306.81	0	
94.70	95.30	1	Fractured zone				

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 KFR105 (complete borehole)

Title CORED DRILLED BOREHOLE KFR105

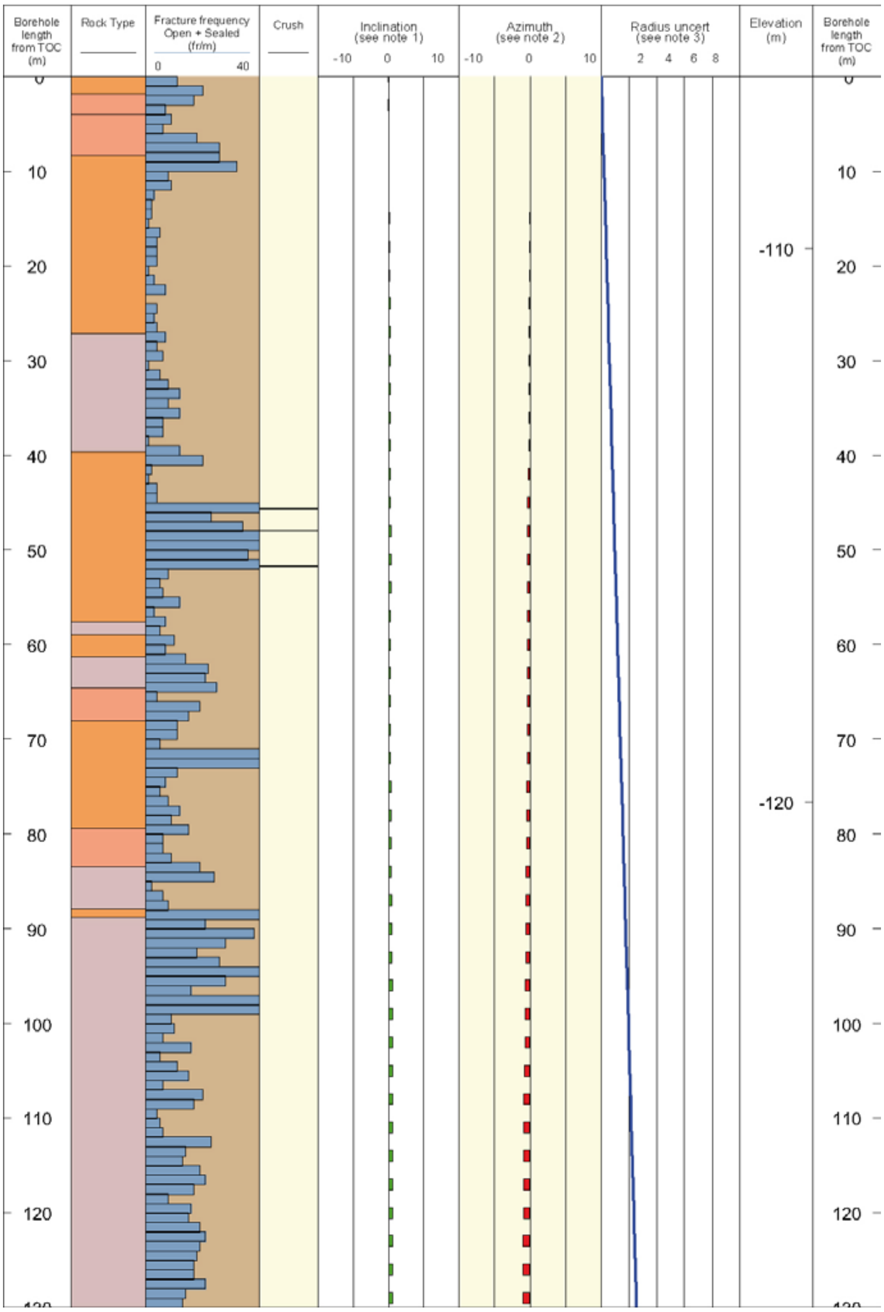
Svensk Kärnbränslehantering AB

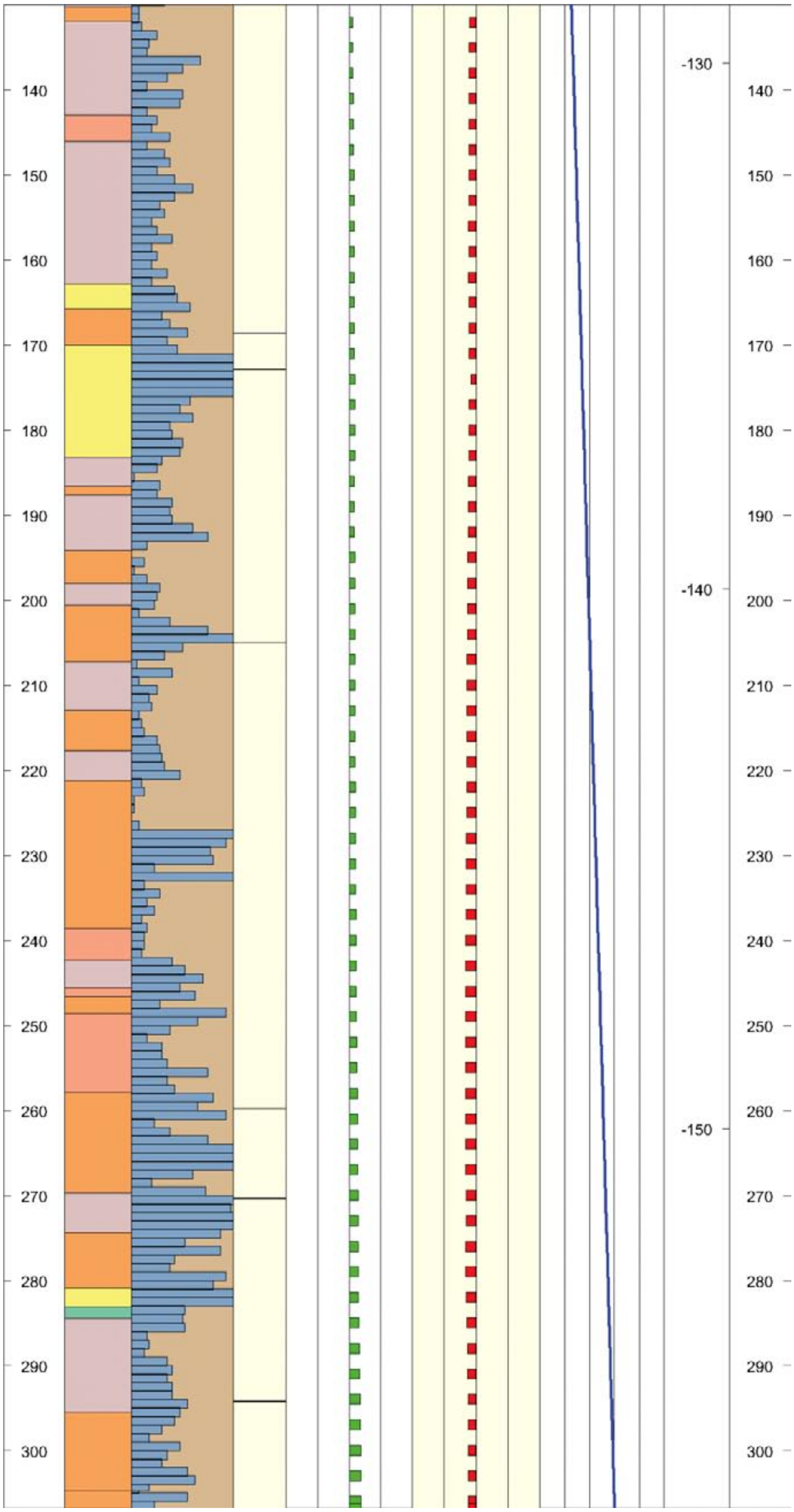
Site	FORSMARK - SFR	Coordinate System	RT90-RHB70
Borehole	KFR105	Northing [m]	6701789.85
Diameter [mm]	76	Easting [m]	1633072.96
Length [m]	306.81	Elevation [m]	-106.82
Azimuth [°]	174.48	Drilling Start Date	2009-04-21
Inclination [°]	-10.12	Drilling Stop Date	2009-06-02
		Plot Date	2009-10-15

ROCK TYPE

- Granite, fine- to medium-grained
- Pegmatite, pegmatitic granite
- 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.

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