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Drilling of three cored boreholes, KFM25, KFM26 and KFM27 at FKA and drilling of percussion borehole HFM47

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Keywords: Cored borehole, Percussion drilling, Monitoring well.

This report concerns a study which was conducted for Svensk Kärnbränslehantering AB (SKB). The conclusions and viewpoints presented in the report are those of the author. SKB may draw modified conclusions, based on additional literature sources and/or expert opinions.

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Abstract

Three cored boreholes, KFM25, KFM26, and KFM27, were drilled in solid rock located at the Forsmark power plant. The boreholes are aimed for long-term monitoring of hydraulic parameters during building of the deep repository for high-level nuclear waste. In order to improve the efficiency of overburden drilling, a percussion drilling machine was employed. In the pre-drilled boreholes an acidproof stainless steel casing was installed before core drilling commenced.

The first borehole, KFM25, was pre-drilled with percussion drilling technique on the 03rd of September, 2019, whereas core drilling was performed during the period 17th to 19th of September. KFM25 is 100.72 m long, inclined 84.27° and with bearing 140.00°. This borehole reaches about 98 m in vertical distance from the ground surface.

The second borehole, KFM26, was pre-drilled with percussion drilling technique on the 03rd of September, 2019, whereas core drilling was performed during the period 01st to03rd of October. KFM26 is 100.74 m long, inclined 84.88° and with bearing 17.00°. This borehole reaches about 97 m in vertical distance from the ground surface.

The third borehole, KFM27, was pre-drilled with percussion drilling technique on the 04th of September, 2019, whereas core drilling was performed during the period 07th to 09th of October. KFM27 is 100.64 m long, inclined 74.97° and with bearing 322.00°. This borehole reaches about 94 m in vertical distance from the ground surface.

Borehole HFM47, which was drilled during the period September 04th to September 05th, 2019, is 200.40 m long, inclined 85 degrees to the horizontal plane with direction towards SSE, and is drilled with a diameter of 140.5 mm. A water inflow of 6 L/min was encountered during drilling. This borehole was used as a monitoring well/pump well during interference tests across the Singö deformation zone.

Sammanfattning

Tre kärnborrhål, KFM25, KFM26 och KFM27, borrades inom Forsmarks Kraftgrupps område. Borrhålen ska användas för långtidsmmoitering av hydrauliska parametrar medan byggnationen av slutförvarets anläggningar pågår.

KFM25 förborrades med hammarborrteknik den 3 september 2019, medan kärnborrningen utfördes mellan den 17–19 september. Borrhålet är ansatt 84,27° mot horisontalplanet och är riktat mot SE. KFM25 är 100,72 m långt och når 98 m vertikalt under markytan.

KFM26 förborrades med hammarborrteknik den 3 september 2019, medan kärnborrningen utfördes mellan den 1–3 oktober 2019. Borrhålet är ansatt 84,88° mot horisontalplanet och är riktat mot NNE. KFM26 är 10,74 m långt och når 97 m vertikalt under markytan.

KFM27 förborrades med hammarborrteknik den 4 september, medan kärnborrningen utfördes mellan den 7–9 oktober 2019. Borrhålet är ansatt 74,97° mot horisontalplanet och är riktat mot NW. KFM27 är 100,64 m långt och når 94 m vertikalt under markytan.

HFM 47 borrades under perioden 4–5 september 2019. Borrhålet är 200,40 m långt och är ansatt 85° mot horisontalplanet i riktning SSE och borrat med diametern 140,5 mm. Ett mindre inflöde, 6 L/min, noterades under borrningen. Syftet med borrhålet är att det ska användas som pumpbrunn vid interferenstester.

Contents

1 Introduction

The spent nuclear fuel from the Swedish nuclear power plants is planned to be deposited in a geological repository at about 500 m depth in the Forsmark area, close to the Forsmark power plants. To protect humans and environment in the long perspective, SKB recommends an underground repository built in crystalline bedrock.

During the period 2002–2009, SKB performed geoscientific and ecological site investigations at two sites in Sweden, Oskarshamn and Forsmark. After having assessed the Forsmark site as being the most favourable in 2009, a long term monitoring programme of a number of earth science parameters and biological objects was initiated.

In March 2011, an application for building a repository for spent nuclear fuel at the Forsmark site was handed in. At the same time the Spent Fuel Project was initiated with the assignment to plan, build and test the facility.

The facility consists of one part situated above ground, which is connected to an underground part dimensioned to hold 6 000 copper canisters containing spent nuclear fuel, see Figure 1-1. A ramp and different vertical shafts connect the above ground facility with the sub-surface part. The sub-surface area is in turn divided into a central and a deposition area. The design of the facility is described in SKB (2016).

This document reports the data and results gained by drilling the three cored boreholes KFM25, KFM26, and KFM27 as well as percussion borehole HFM47 as part of the preparatory investigation programme of Programme for Spent Fuel Repository at SKB. The drilling operations were carried out at the site shown in Figures 1-2 and 1-3, in accordance with the activity plan AP SFK-19-014.

Controlling documents for performing this activity are listed in Table 1-1. Both activity plans and method descriptions are SKB's internal controlling documents.

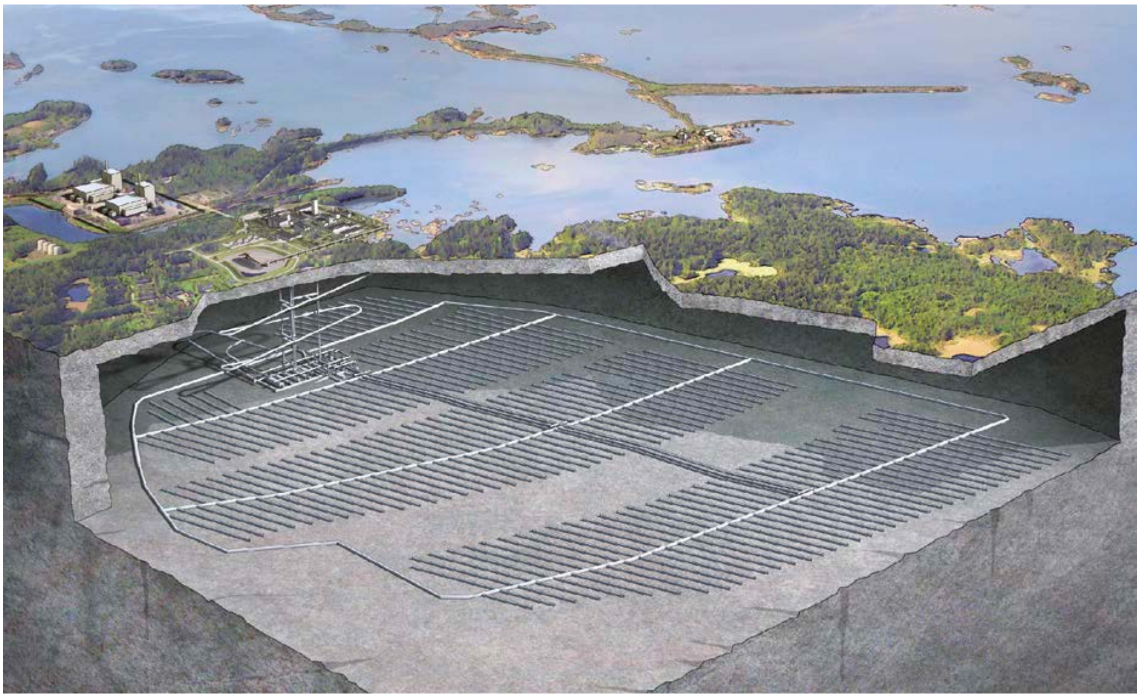

Figure 1-1. *Illustration of a possible design of the Spent Fuel Repository at Forsmark.*

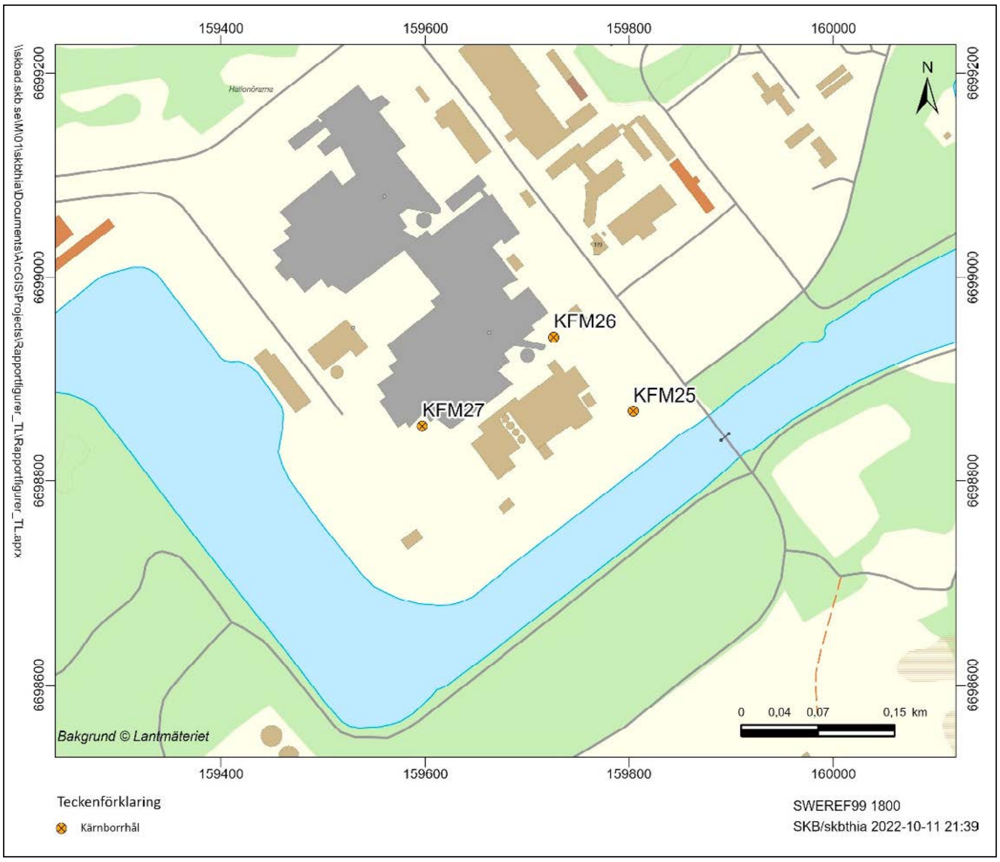

Figure 1-2. Location of the three core drilled boreholes at the Forsmark power plant.

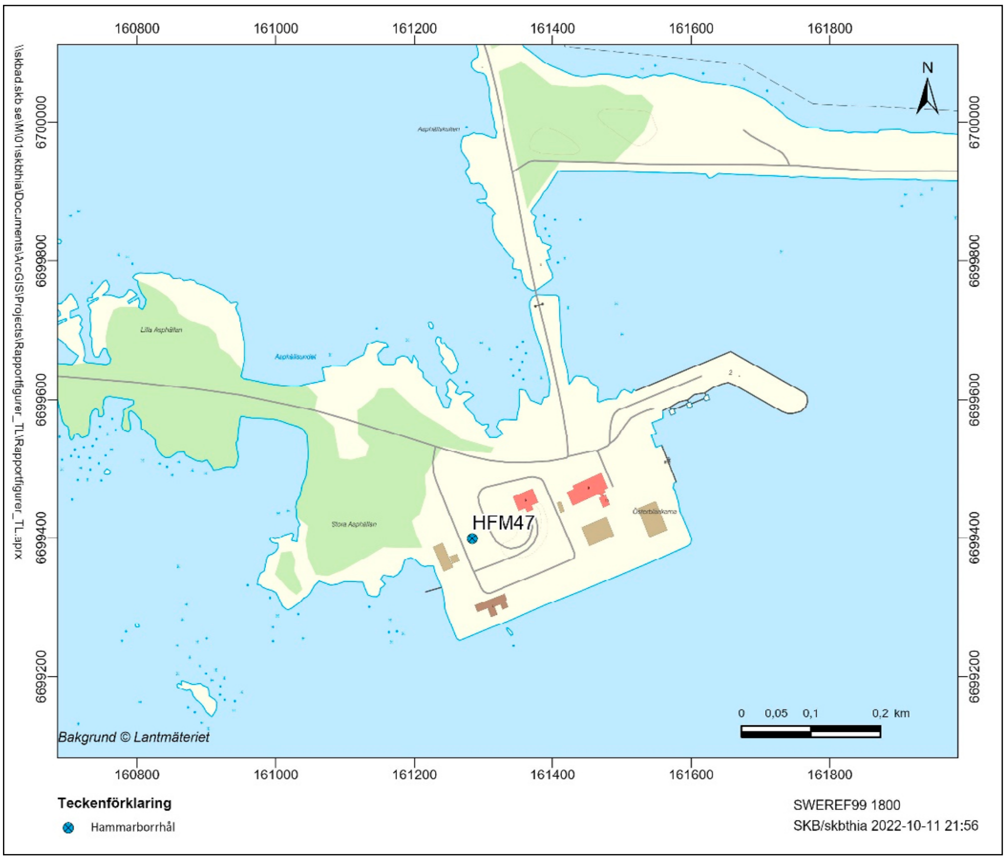

Figure 1-3. HFM47 is located at Stora Asphällan.

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

Activity plan	Number	Version
Borrning av 3 stycken kärnborrhål för övervakning av sättningar i Forsmark	AP SFK-19-014	1.0
Method documents	**Number**	**Version**
Metod Description for core drilling	SKB MD 610.001	2.0
Method Description for percussion drilling	SKB MD 610.003	4.0
Method Instruction for Cleaning Borehole Equipment and certain Ground-based Equipment	SKB MD 600.004	1.0
Method Instruction for Chemical Products and Materials	SKB MD 600.006	1.0
Metodbeskrivning för genomförande av hydrauliska enhålspumpteste.	SKB MD 321.003	1.0
Metodbeskrivning för krökningsmätning av hammar- och kärnborrhål	SKB MD 224.001	2.0

Protek AB, Norsjö, with subcontractor TSB Entreprenad, Sollefteå, Sweden, was engaged for the drilling commission. For the first time a percussion rig supplied with an automatic rod handling system was employed for drilling at the Forsmark site. Support was provided from SKB, FKA and ISS-personnel regarding measurements and tests during drilling.

Three cored boreholes and one percussion borehole were drilled during the period September 3rd to October 9th, 2019. Original data from the reported activity are stored in the SKB primary database Sicada. Data are traceable in Sicada by the Activity Plan number (AP SFK-19-014). Only data from Sicada are accepted for further interpretation and modelling. The data presented in this report are regarded as copies of the original data. Data in Sicada 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.

Due to the fact that the underground facility is located quite close to the nuclear power plants at FKA, it is necessary to document the drilling operations thoroughly. However, also previous drillings within SKB's investigation programme at Forsmark have included comprehensive documentation in the SKB database as well as in written reports, and the same approach is applied in the drilling commission described in the present report.

The construction of the final repository will have a certain impact on the environment, and it is therefore important to install monitoring equipment in boreholes adjacent to the nuclear power plant. The four boreholes accounted for in this report will offer excellent opportunities for that purpose.

2 Scope

The site survey in 2002–2009 was primarily focused on investigating and describing the bedrock at storage depth. Now when the preliminary design of ramp and shaft is completed, a primary focus is directed to understanding the water drainage in the upper parts of the bedrock, and therefore a drilling program was designed and carried out.

The overall objectives of drilling cored boreholes and percussion boreholes at the Forsmark investigation site are the following:

- To enable OPTV logging, as an aid for the geological/rock mechanical characterization.
- To allow hydraulic borehole tests (single-hole tests as well as interference tests) for characterization of the hydrogeological conditions.
- To permit long-term hydraulic and hydrogeochemical monitoring at different levels of the bedrock.

The drilling program associated with Activity Plan AP SFK-19-014 comprised three cored boreholes, KFM25, 26, and 27, as well as one percussion borehole, HFM47, all of which were drilled during the autumn 2019. The three cored drilled boreholes in the vicinity of FKA nuclear power plant were aimed to be used as long-term observation boreholes. The excavation of shafts, ramp and tunnels to the planned final repository for spent nuclear fuel will lead to changes in the water pressure in the surrounding rock mass. The size of the area that can be affected and the size of the water pressure changes depend on how water is supplied to the fractures under the industrial area, and to the sealing of the fractures by injecting the rock closest to the shaft. The changes should be monitored by water pressure measurements in boreholes near the power station. These measurements are started before shaft work is initiated, so that a measurement series is obtained that shows both the initial state with existing seasonal variations and, later, the impact upon the surrounding rock mass during excavation work.

The percussion drilled hole HFM47, adjacent to the VEGA office, was aimed to be used as a pumping-/observation borehole for a series of interference tests. The interference tests were aiming at investigating the possible hydraulic connections in the SFR area west of Singö deformation zone.

3 Equipment

Two types of drilling machines were used for drilling the boreholes in this project. Pre-drilling through the upper sections c. 6–12 metres of boreholes KFM25, KFM2, and KFM27 and percussion drilling of HFM47 was carried out with a HARDAR 5000H percussion drill rig (Figure 3-1). The machine was supplied with a variety of accessory equipment. Core drilling to c. 100 m of the three cored boreholes was performed with a Wireline-N core drilling system, type Epiroc Diamec U6 APC.

In this chapter short descriptions are given of the drilling systems as well as the technique and equipment for gap injection of the borehole casings. Besides, the instrumentation used for deviation measurements performed after completion of drilling, and the equipment applied for measurements and sampling during drilling are briefly described.

3.1 Percussion drilling equipment

The HARDAR 5000H drilling machine (Figure 3-1) is equipped with separate engines for transportation and power supplies. In addition, the drill rig was fitted with an automatic rod handler. This system facilitates drilling, because the helper does not have to lift the heavy drill pipes, especially important in this project when drilling a borehole as long as c. 200 m, which is the final length of borehole HFM47.

Water and drill cuttings were discharged from the borehole by an Atlas-Copco Drill Air Y35, 35 bar diesel compressor. The DTH drill hammer was of type Secoroc 5½", operated by a Driconeq 76 mm pipe string, see Figure 3-2. All DTH-equipment and the drill rig were cleaned with a high-capacity steam cleaner before arriving to the drill site.

Figure 3-1. *The HARDAR 5000H drilling machine at drill site KFM27. To the left a casing with a drill ring welded at the casing end. In KFM27 a c. 9 m casing was drilled through the overburden and some metre into the bedrock.*

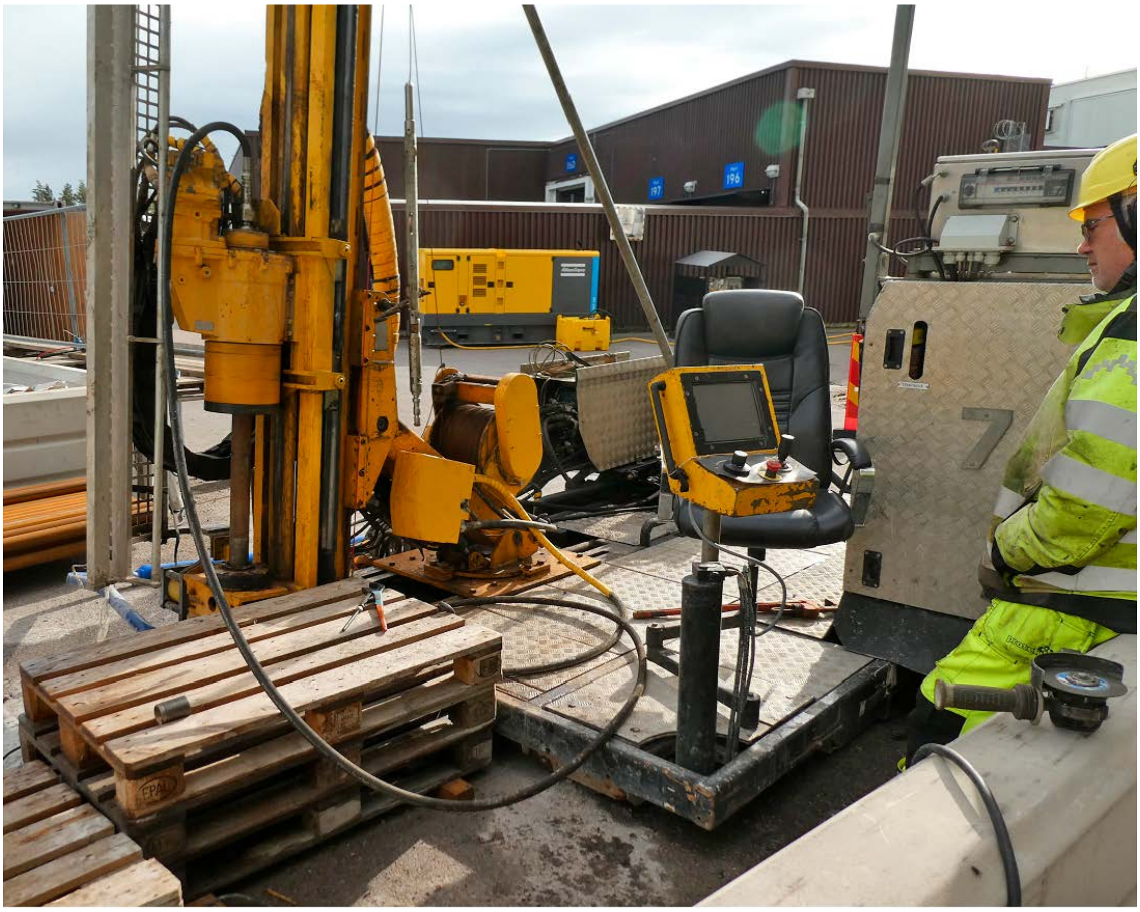

***Figure 3-2.** Drilling rig Diamec U6 APC with the Atlas Copco QAS250 generator in the background.*

3.2 Core drilling equipment

For drilling of the cored parts of boreholes KFM25, KFM26 and KFM27, a wireline-N system, type Epiroc Diamec U6 APC, was employed, see Figure 3-2. The drilling process is operated by an electrically-driven hydraulic system supplied with a computer control. The drill pipes and core barrel used belong to the Epiroc N-size WL triple-tube system with a core dimension of 45 mm. Technical specifications of the drilling machine with fittings are given in Table 3-1.

Table 3-1. Technical specifications of the Diamec U6 APC-system from Atlas-Copco with appurtenances.

Unit	Manufacturer/Type	Specifications	Remarks
Diamec U6 ABC	Epiroc	Capacity for N-size holes maximum approx. 1 300 m depending on drill string dimension	An Atlas Copco QAS 250 diesel-generator supports two hydraulic pumps
Flush water pump	Bean	Max flow rate: 142 L/min Max pressure: 100 bar	

3.3 Grouting technique

In order to prevent surface water and shallow groundwater to infiltrate into deeper parts of the borehole, the normal procedure is to grout the gap between the borehole wall and the casing pipe with cement. The cement application may be performed by different technical approaches and equipment. In KFM25, KFM26, and KFM27 the cement was pumped through a hose in the gap between the inner and outer casing, see Figures 3-3 and 3-4.

Figur 3-3. *Grouting of the gap between the outer and inner casing was performed by pumping the cement through a hose from the bottom of the borehole.*

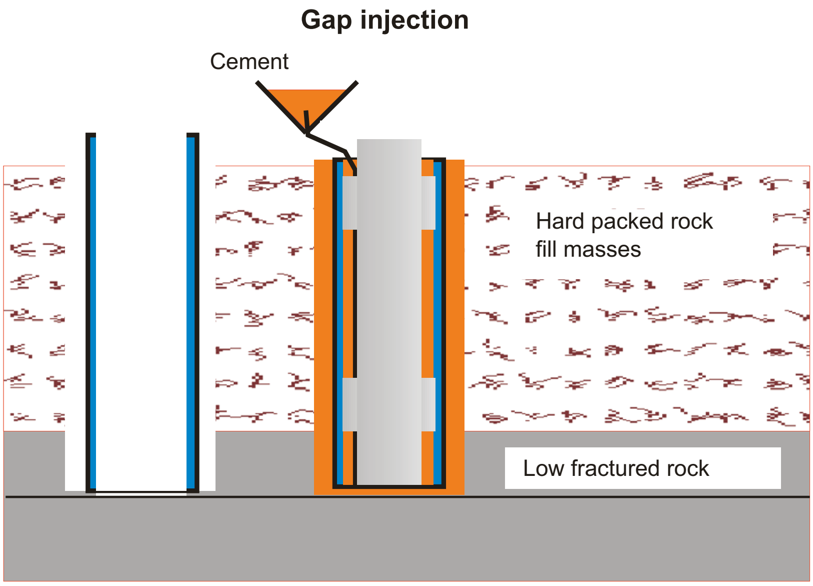

Figure 3-4. *Schematic view of the grouting technique used.*

3.4 Equipment for deviation measurement

After completion of drilling, a deviation measurement was carried out with a Flexi Smart Tool System, which is based on magnetic-accelerometer technique. Azimuth and dip are measured at every third metre. The collaring point coordinates and the measured values are used for calculating the coordinates of the position of the borehole at every measurement point.

3.5 Equipment for measurements and sampling during drilling

Flow measurement during drilling was conducted using a measuring vessel and a stop watch. Drilling penetration rate was measured with a carpenter's rule and a stop watch.

4 Execution

Drilling of boreholes KFM25, KFM26, KFM27, and percussion borehole HFM47, together with a number of undertakings associated with the drilling, followed the controlling documents presented in Table 1-1. Altogether the activity included the following items:

KFM25, KFM26 and KFM27	HFM47
Pre-drilling KFM25, KFM26, and KFM27 • Preparations. • Mobilisation, including lining up the machine and measuring the position. • Casing drilling.	• Preparations. • Mobilisation, including lining up the machine and measuring the position. • Drilling, measurements, and sampling during drilling. • Finishing of work. • Deviation measurements. • Data handling. • Environmental control.
• Installation of inner-casing and grouting.	
Core drilling • Preparations. • Mobilisation, including lining up the machine and measuring the position. • Drilling, measurements, and sampling during drilling. • Finishing of work. • Deviation measurements. • Data handling. • Environmental control.	

4.1 Preparations

The preparations included the Contractor's service and function control of his equipment. The machinery was obliged to be supplied with fuel, oil, and grease exclusively of the types stated in SKB MD 600.006, Version 1.0 (Method Instruction for Chemical Products and Materials). Finally, part of the equipment was cleaned in accordance with SKB MD 600.004, Version 1.0 (Method Instruction for Cleaning Borehole Equipment and certain Ground-based Equipment) at level two, used for SKB boreholes of chemical type (the remaining part of the equipment was cleaned on-site). SKB MD 600.004 and SKB MD 600.006 are both SKB internal controlling documents, see Table 1-1.

4.2 Mobilization

Mobilization onto and at the site started with preparation of the drill site and transport of drilling and accessory equipment to the site. The mobilization also comprised on-site cleaning of all DTH-equipment at level two according to SKB MD 600.004, lining up the machine and making a control of the inclination with a graduated arc and a final function control.

4.2.1 Drilling through overburden drilling

KFM25, KFM26 and KFM27

A Mitsubishi Ultra Maxibit-system (see Figure 4-1) was executed according to SKB MD 610.003, Version 1.0 (Method Description for Percussion Drilling), see Table 1-1.

4.2.2 Gap injection

After installing an acidproof stainless steel casing into the pr-drilled borehole, the narrow gap between the outer and inner casings were grouted with a cement/water-mixture according to the technique illustrated in Figure 3-5.

Figure 4-1. The Ultra Maxibit system applied on a standard casing was used fro pre-drilling through overburden in KFM25, KFM26, and KFM27.

4.3 Core drilling in solid rock

The core drilling operations included:

1. Preparations.
2. Mobilization, including lining up the machine and measuring the position.
3. Drilling, measurements and sampling during drilling.
4. Finishing of work.
5. Data handling.
6. Environmental control.

4.3.1 Preparations

As for percussion drilling, 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 in accordance with SKB MD 600.004.

4.3.2 Mobilization

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

4.3.3 Drilling, measurements and sampling during core drilling

Core drilling with Ø 75.6 mm of the main part of the borehole serves many purposes, cf. Chapter 2. One of the most essential objectives is to provide (in principle) continuous rock samples, i.e. drill cores, down to the borehole bottom, which allows a lithological, structural and rock mechanical characterization of the bedrock. The drill cores are also used for determination of transport properties of the rock and, sometimes, for the study of chemical characteristics of the pore space water in the rock matrix.

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 the borehole KFM25, KFM26, and KFM27, a 3 m triple tube core barrel was used. The nominal core diameter for the Ø 75.6 mm part of the borehole is 45.0 mm. Minor deviations from this diameter may, however, occur.

4.3.4 Finishing of works

The concluding work included the following items:

1. The boreholes was flushed for about 15 minutes in order to clean it from drilling debris adhered to the borehole walls, settled at the bottom of the hole, injected into the fracture system or suspended in the water.
2. The drill string was pulled.
3. The core drilling equipment was removed, the site cleaned and a joint inspection made by SKB and the Contractor.

4.4 Percussion drilling of borehole HFM47

4.4.1 Drilling through overburden

An Ultra Maxibit-system with casing Ø168.3/159.3 mm was applied for drilling through the overburden and some metres into solid bedrock

4.4.2 Gap injection

When the casing string had been firmly installed in borehole HFM47, the narrow gap between the borehole wall and the external wall of the casing was grouted with a cement/water-mixture according to the borehole technique illustrated in Figure 3-5.

4.4.3 Percussion drilling in solid rock

After the casing was set, drilling could continue and was now performed to the full borehole length with conventional percussion drilling. Before start of drilling, the diameter of the drill bit was measured. In this last drilling step, the initial borehole diameter (approximately the same as the drill bit diameter) is normally 140 mm, see Figure 4-1. However, a diameter decrease of about 1 mm/100 m drilling length is to be expected when drilling in the rock types prevailing at Forsmark.

4.4.4 Sampling and measurements during drilling

During drilling, a sampling and measurement program was carried out, which included:

- Measurements of the penetration rate (one measurement per 20 cm drilling length). The time needed for the drill bit to sink 20 cm was recorded manually in a paper record, see Figure 4-2.
- Performing one observation of discharged groundwater flow rate (if any) and water colour per 20 cm drilling length and a measurement of the flow rate at each major flow change observed. The measured values were noted in a paper record.

The results from the items above were used as supporting data and gave on-site information about rock quality as well as hydraulic and hydrogeochemical characteristics of the penetrated aquifers at the respective drill sites.

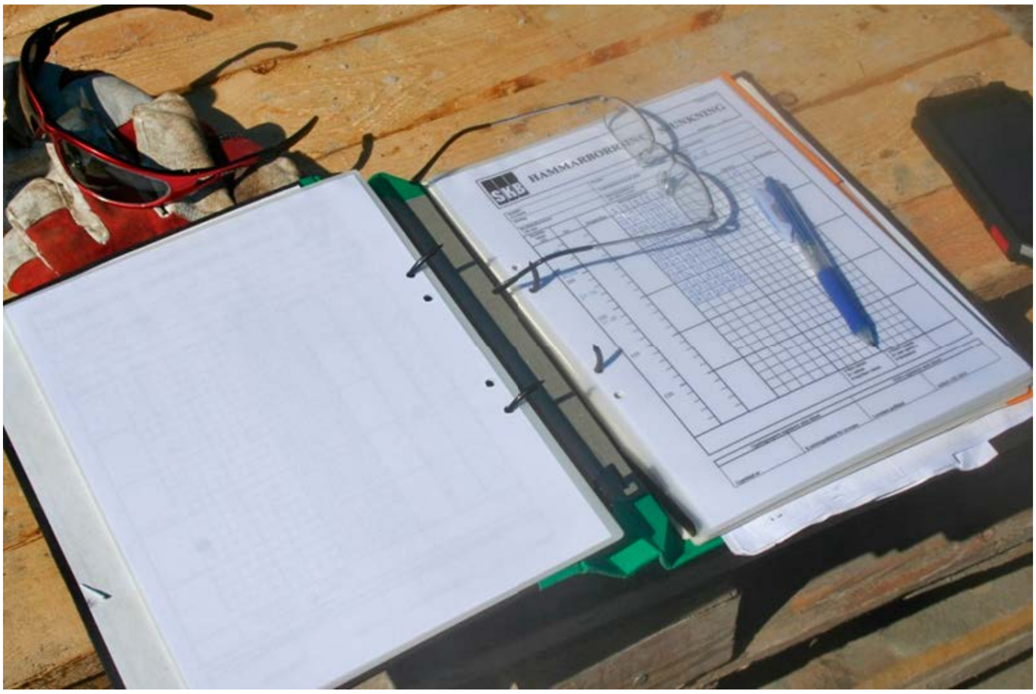

Figure 4-2. *Documentation of penetration rate (one measurement per 20 cm drilling length) and observation of water inflow were recorded manually in a paper record.*

4.5 Finishing of works

Finishing off work included rinsing of the borehole from drill cuttings by a "blow out" with the compressor at maximum capacity during 30–60 minutes. By measuring the flow rate of the discharged groundwater, a rough estimate of the water yielding capacity of the borehole at maximum drawdown was achieved. The drilling pipes were then retrieved from the hole, and the diameter of the drill bit was measured. A deviation survey of the borehole completed the measurement programme during and immediately after drilling. The borehole was secured by a stainless steel lockable cap, mounted on the casing flange, which finishes off the casing. Finally, the equipment was removed, the site cleaned and a joint inspection made by representatives from SKB and the Contractor, to ensure that the site had been satisfactorily restored.

5 Results

All data were stored in the Sicada database, were they are traceable by the Activity Plan number SFK-19-014. A summary of the acquired data is presented in the sections below.

5.1 General

The three cored boreholes presented in this report are located at the industrial area around the FKA power plant in Forsmark. Reasonably, an industrial area must have a solid and hard packed foundation, especially if it is a nuclear power plant to be built there.

Prior experiences have demonstrated that core drilling through an overburden of this composition could be technically difficult and time consuming. Therefore, to speed up the core drilling performance, a percussion drilling machine was employed for drilling through the overburden of all three planned cored boreholes. In addition, also an inner stainless steel casing (Ø88.9/76.3 mm) for these boreholes was installed and cement grouted in a campaign after mounting the outer casing and just prior to start of core drilling.

Earlier in the year, interference tests were conducted in the boreholes around the VEGA- and SFR offices. In order to increase the clarity of the interpretation, the project has requested a further borehole between the existing boreholes. As a percussion drilling machine already was established at Forsmark, it was decided to drill an additional percussion borehole, HFM47, located in front of (130 m) the SKB Vega office.

5.2 Overview of drilling of KFM25, KFM2, and KFM27

Administrative, geometric and technical data for KFM25, KFM26, and KFM27 are presented below in Table 5-1.

Table 5-1. Administrative, geometric, and technical data for boreholes KFM25–27.

Borehole name	KFM25	KFM26	KFM27
Location	FKA, Östhammar municipality, Sweden	FKA, Östhammar municipality, Sweden	FKA, Östhammar municipality, Sweden
Drill start date	Sept 03, 2019	Sept 03, 2019	Sept 04, 2019
Completion date	Sept 19, 2019	Oct 03, 2019	Oct 09, 2019
Drilling periods	Sept 03, 2019 (0–6.08 m) Sept 17 to Sept 19, 2019 (6.08–100.72 m)	Sept 03, 2019 (0–6.15 m) Oct 01 to Oct 03, 2019 (6.15–100.74 m)	Sept 04, 2019 (0–9.03 m) Oct 07 to Oct 09, 2019 (9.03–100.64 m)
Contractor core drilling	Protek I Norr AB	Protek I Norr AB	Protek I Norr AB
Pre-drilling rig	HARDAR 5000H	HARDAR 5000H	HARDAR 5000H
Core drilling rig	Diamec U6 APC	Diamec U6 APC	Diamec U6 APC
Position at top of casing (SWEREF 99 18 00/ RH 2000)	N: 6698868.99 E: 159804.37 Z: 2,66 Azim. (0–360°): 140.00° Dip (0–90°): −84.27°	N: 6698941.42 E: 159726.47 Z: 3,00 Azim. (0–360°): 17.00° Dip (0–90°): −84.88°	N: 6698854.47 E: 159597.05 Z: 2,54 Azim. (0–360°): 322.00° Dip (0–90°): −74.97°
Position at bottom of hole (SWEREF 99 18 00/ RH 2000)	N: 6698861.89 E: 159810.15 Z: −97.64 Azim. (0–360°): 140.25° Dip (0–90°): −84.80°	N: 6698947.96 E: 159730.42 Z: −97.44 Azim. (0–360°): 40.45° Dip (0–90°): −85.60°	N: 6698877.00 E: 159581.94 Z: −94.37 Azim. (0–360°): 327.25° Dip (0–90°): −74.20°
Borehole length	100.72 m	100.74 m	100.64 m
Borehole diameter and length	Ø165 mm between 0.11–6.08 m Ø75.6 mm between 6.08–100.72 m	Ø165 mm between 0.10–6.15 m Ø75.6 mm between 6.15–100.74 m	Ø165 mm between 0.06–9.03 m Ø75.6 mm between 9.03–100.64 m
Casing diameter and length	$Ø_o/Ø_i$ = 139.7/129.7 mm between 0.11–6.08 m $Ø_o/Ø_i$ = 88.9 /76.3 mm between 0.00–6.08 m	$Ø_o/Ø_i$ = 139.7/129.7 mm between 0.10–6.15 m $Ø_o/Ø_i$ = 88.9/76.3 mm between 0.00–6.15 m	$Ø_o/Ø_i$ = 139.7/129.7 mm between 0.06–9.03 m $Ø_o/Ø_i$ = 88.9/76.3 mm between 0.00–9.03 m
Drill core dimension and length	Ø45 mm between 6.08–100.72 m	Ø45 mm between 6.15–100.74 m	Ø45 mm between 9.03–100.64 m
Core interval	6.08–100.72 m	6.15–100.74 m	9.03–100.64 m

5.3 Geometrical design of drilled boreholes

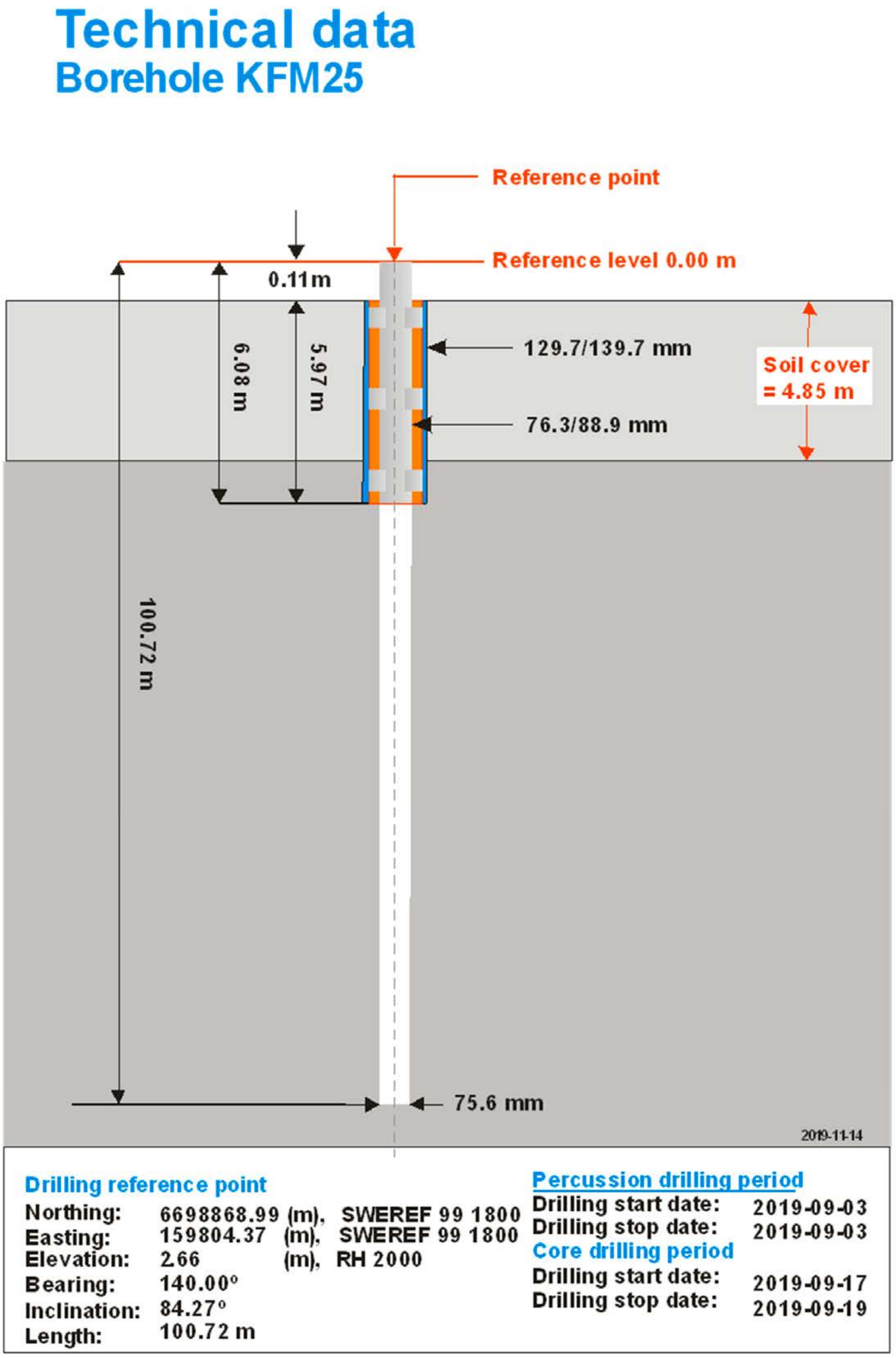

Figure 5-1. *Technical data for borehole KFM25.*

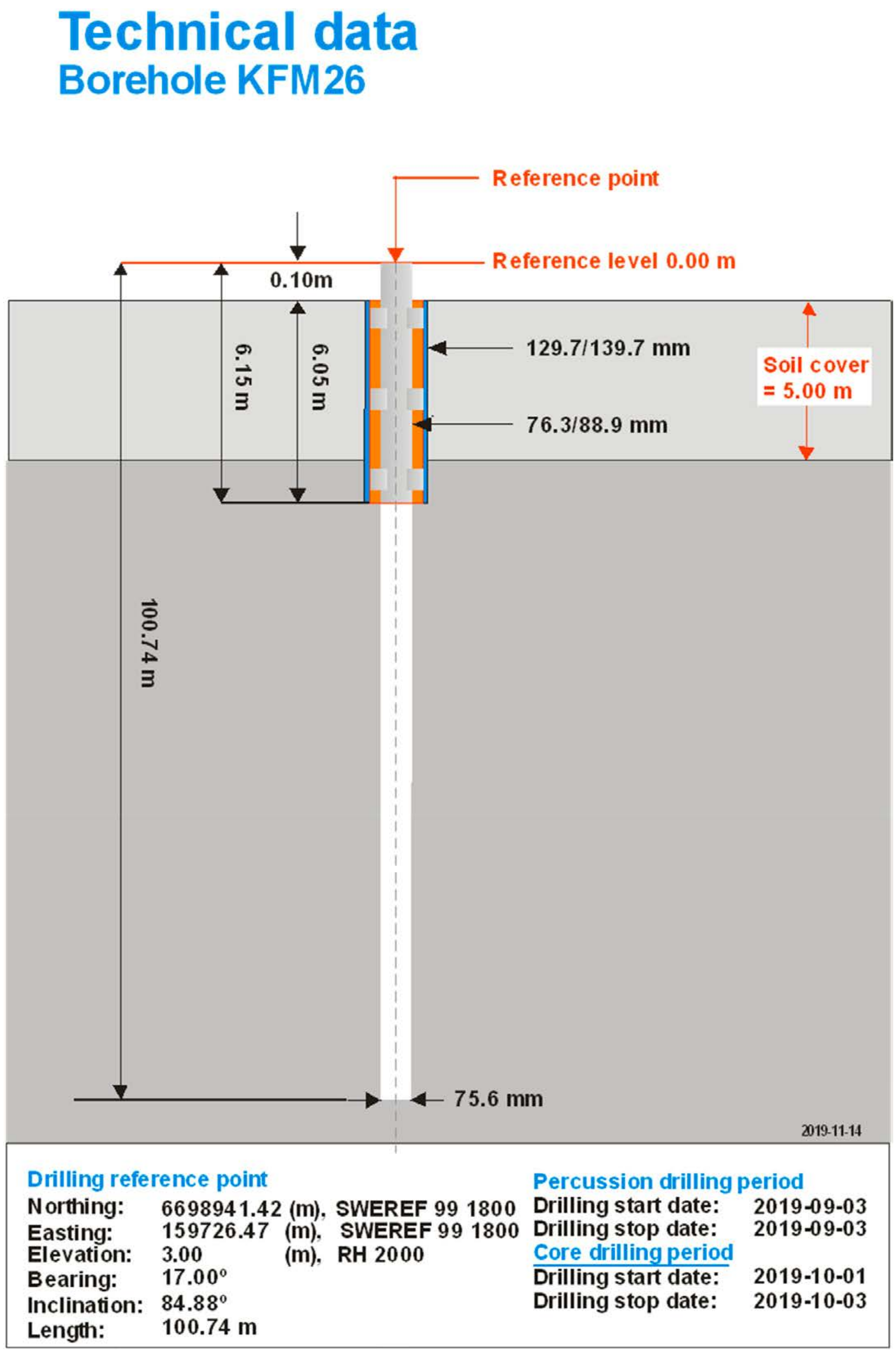

Figure 5-2. *Technical data for borehole KFM26.*

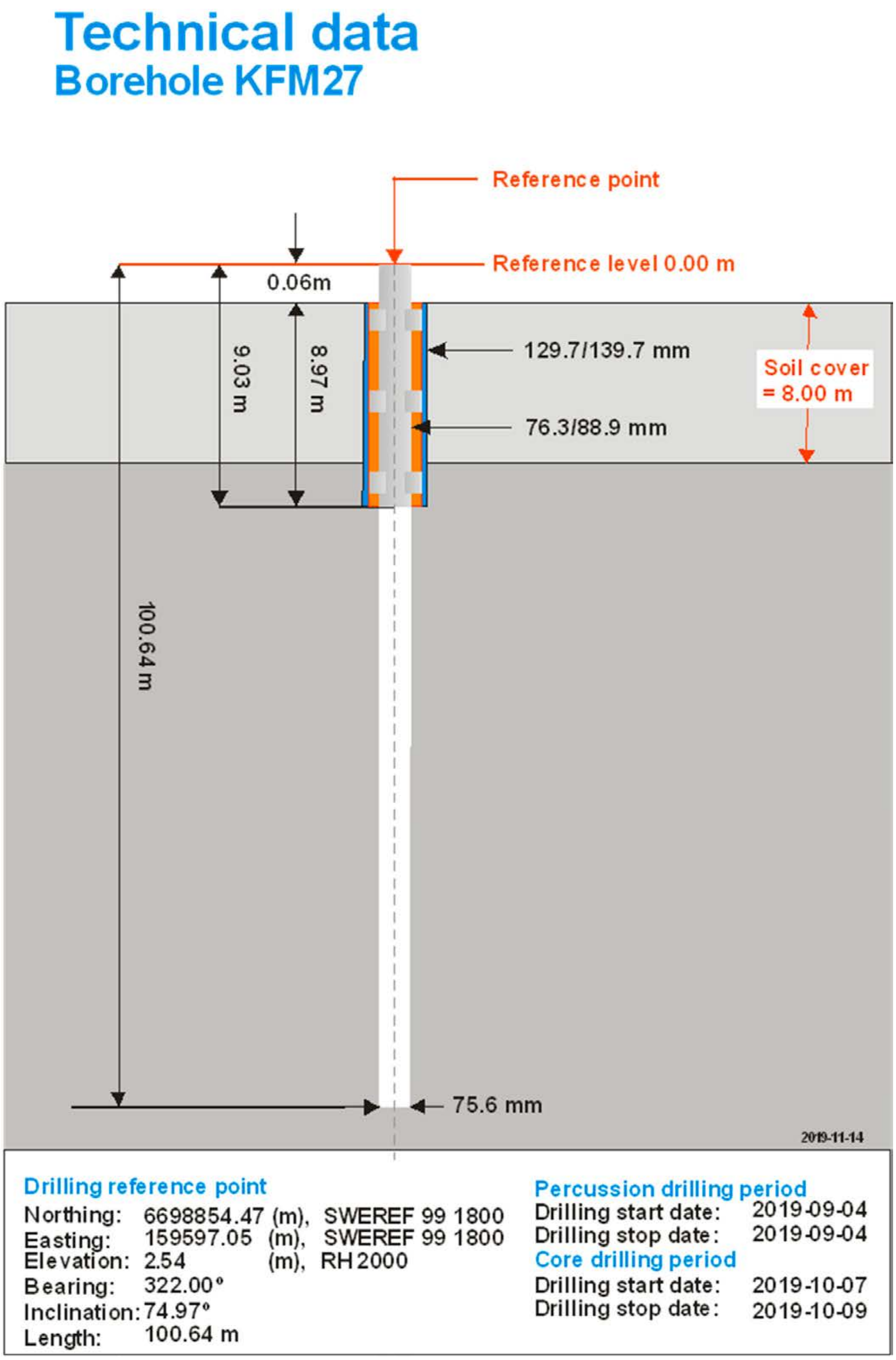

Figure 5-3. *Technical data for borehole KFM27.*

5.4 Installation of inner casing and grouting

When using pre-drilling technique for penetrating the upper part of the overburden and some metre into solid rock, it will also be necessary to install an inner casing of minor diameter when extending the borehole by using core drilling with c. 76 mm diameter. Most of the boreholes drilled are aimed to be used for long time monitoring, meaning that the inner casing must be made of acid resistant and stainless steel, see Figure 5-4.

The 1 m long casings are threaded together to 3 m length. To achieve stability and to centralize the casing, stabilizers are welded on every third metre. In addition, a 16 mm PEM hose is loosely attached to the pipes before being lowered into the borehole with a loading machine. The cement slurry is pumped down through the hose so that the gap between the inner- and outer casings is filled from the bottom an up. As the cement rises, the hose is pulled out of the borehole until the entire gap is filled. The cement volumes used when grouting in KFM25, KFM26, and KFM27 are presented in Table 5-2.

Table 5-2. Grouting of the inner casing in KFM25, KFM26, and KFM27.

Borehole ID	Casing length from to [m]	Cement [dm³]	VCT	Cement type
KFM25	0.00–6.08	50	0.64	Cementa Std
KFM26	0.00–6.15	50	0.64	Cementa Std
KFM27	0.00–9.03	70	0.64	Cementa Std

__Figure 5-4.__ Left: As monitoring boreholes probably will be used for several decades, the inner casing is made of acid proof stainless steel. Right: The casing is lowered into the outer casing, and is centralized by three steerings for every three metres casing length.

5.4.1 Core drilling

The average drill core length per run obtained from the drilling was between 2.78–2.86 m which must be considerable good as the maximum core length is c. 3 m when using a 3 m core barrel, see Table 5-3 and Figure 5-5. Even if the boreholes were only drilled to 100 m length, two to three 3 m long unbroken drill cores were recovered in each borehole. Fracture minerals were relatively well preserved. A preliminary on-site core logging was performed continuously.

Table 5-3. Total core recovery and average core length per run in KFM25, KFM26, and KFM27.

Borehole ID	Core length from to [m]	Core length [m]	Number of runs	Average core length per run [m]
KFM25	6.08–100.72	94.64	33	2.86
KFM26	6.15–100.74	94.59	34	2.78
KFM27	9.03–100.64	91.61	33	2.78

5.4.2 Mammoth pumping of KFM27

Usually, the shallow parts of the bedrock in this area are highly fractured and can often cause complete water loss during core drilling, entailing that flushing water and drill cuttings are forced into the permeable parts of the rock. This happened in KFM27, and at c. 11 m drilling length, all flushing water was lost. On the other hand, during drilling of the other boreholes, KFM25 and KFM26, all flushing water was completely recovered.

Therefore it was necessary, before the drilling activity in KFM27 was concluded, to rinse the borehole in order to minimize the contents of drilling debris or other unwanted material remaining in the borehole. For this purpose, mammoth pumping was applied, see Figure 5-6.

A mammoth pump was lowered into the borehole, and supplied by a 12 bar compressor it was possible to reach a flow rate of 20 L/min. The pumping continued until the recovered return-water was judged by the naked eye to be clean, or with a minimum of content of drilling debris. This sequence was repeated until the pump reached the hole bottom, entailing that the completed borehole was cleaned after c. 4 hours of mammoth pumping.

Figure 5-5. *The split-tube has just been pumped out from the core barrel containing a 3 m long core with 45 mm diameter.*

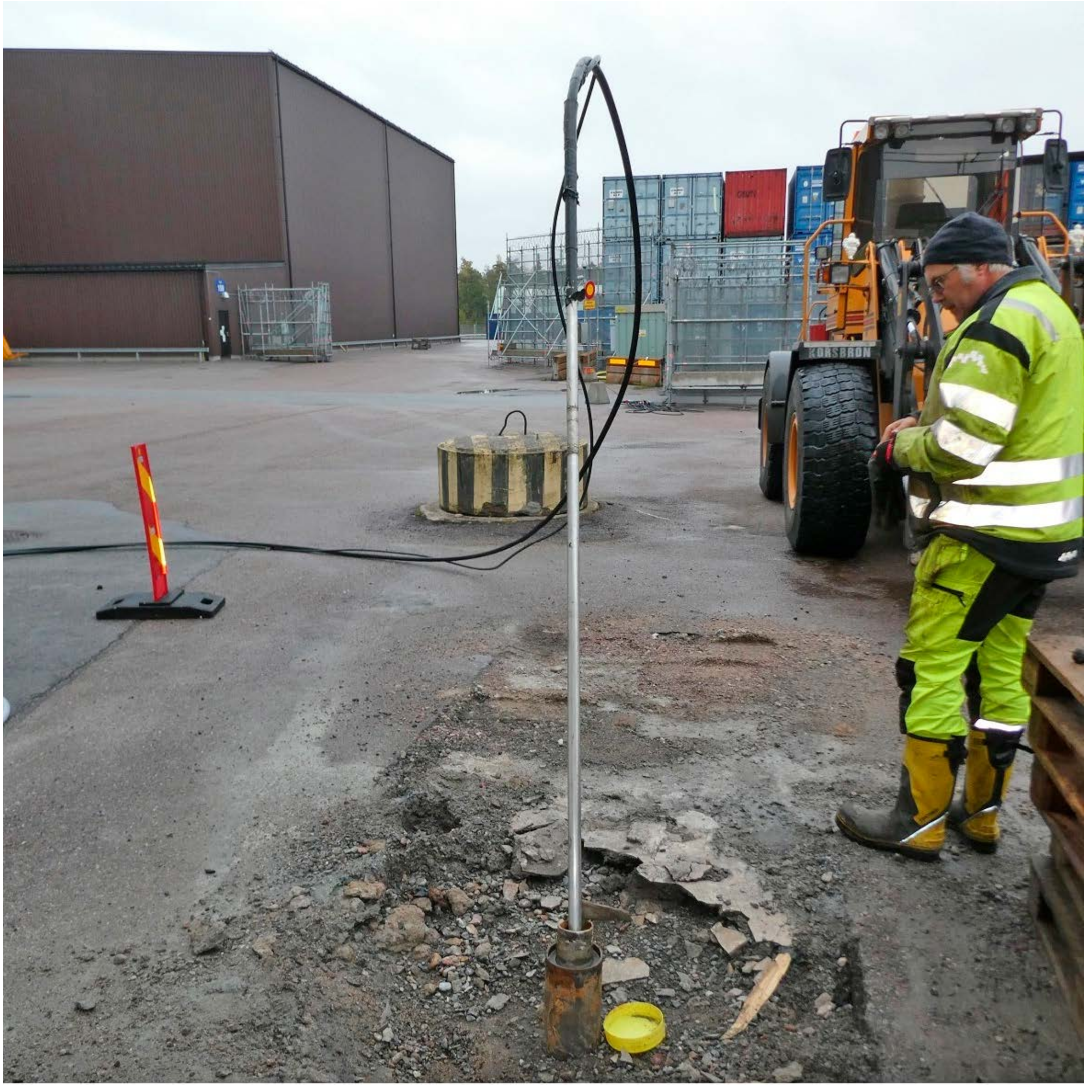

Figure 5-6. The mammoth pump with two hoses (one for the air supply and the second for return water) ready to be lowered into borehole KFM27.

5.5 Deviation measurements

The principal method applied for deviation measurements in the cored and percussion drilled boreholes is based on magnetic accelerometer technique. For the four boreholes in solid rock described in this report the FLEXIT Smart tool system was used. To ensure high quality measurements with the FLEXIT tool, the disturbances of the magnetic field at the site have to be limited. A measuring station in Uppsala gives one-minute magnetic field values available on the Internet at www.intermagnet.org and provides sufficiently accurate information. The magnetic field variations on September 20th, October 4th, and on October10th, 2019, are displayed in Figure 5-7, and show only minor disturbances when the FLEXIT surveys in KFM25 (between 9:00 and 11:00 AM), in HFM47 (12:00 and 15:00 PM), in KFM26 (9:00 and 11:15 AM), and in KFM27 (08:30 and 09:30 AM) were performed.

The deviation measurements in the four boreholes were carried out every 3 m downwards and upwards, to 198 m borehole length in HFM47 and to 99 m borehole length in KFM25, KFM26, and KFM27, respectively.

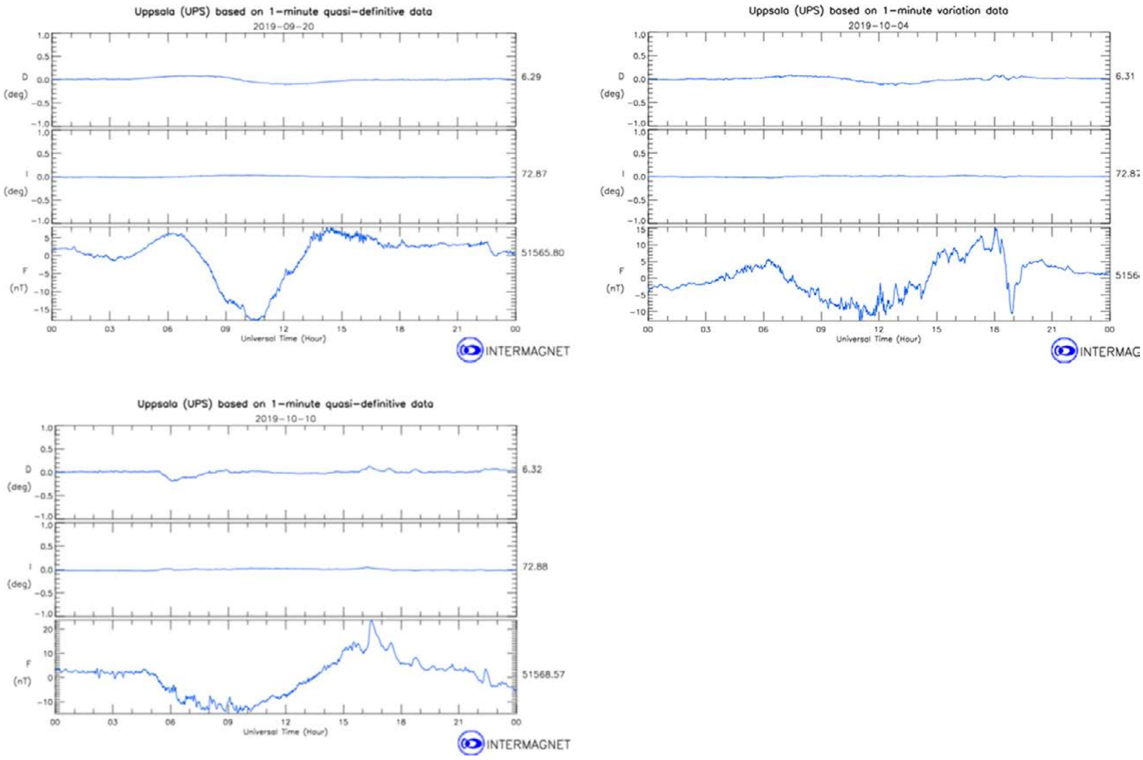

Figure 5-7. *Magnetic field variation during the FLEXIT survey performed on September 20th, 2019, in KFM25 and HFM47, on October 4th, 2019, in KFM26, and on October 10th, 2019, in KFM27.*

The deviation measurements in the four boreholes were carried out every 3 m downwards and upwards, to 198 m borehole length in HFM47 and to 99 m borehole length in KFM25, KFM26, and KFM27, respectively.

The deviation calculations (EG154-file) for borehole KFM25 show that the borehole deviates downwards and to the right with an absolute deviation of 0.92 m (see Figure 5-8) compared to an imagined straight line following the dip and strike of the borehole start point.

The deviation calculations (EG154-file) for borehole KFM26 (Figure 5-8) show that the borehole deviates downwards and to the right with an absolute deviation of 2.5 m compared to an imagined straight line following the dip and strike of the borehole start point.

The EG154-file from borehole KFM27 (Figure 5-8) displays that the borehole deviates upwards and to the right with an absolute deviation of 2.2 m compared to an imagined straight line following the dip and strike of the borehole start point. The borehole is though almost straight in the horizontal direction.

Finally, the EG154-file from borehole HFM47 (Figure 5-11) illustrates that the borehole deviates upwards and to the left with an absolute deviation of c. 72 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 completely straight line with the same inclination and bearing as that of the borehole collaring.

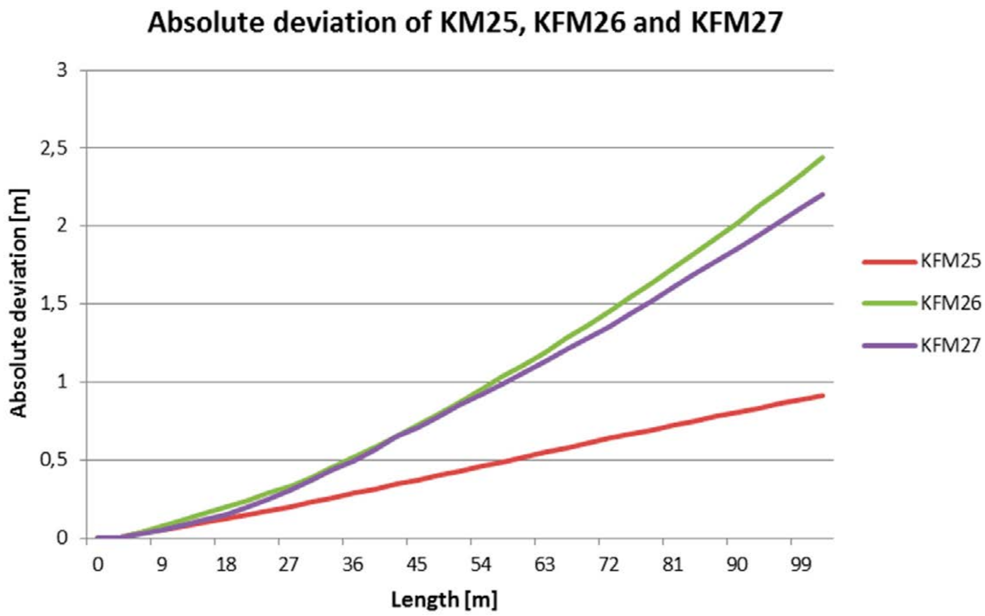

Figure 5-8. *The figure shows the absolute distance defined as the shortest distance in space between a point in the borehole at a certain borehole length and the imaginary position of that point if the borehole had followed a straight line with the same inclination and bearing as that of the borehole collaring.*

5.6 Percussion drilling of HFM47

During the last year several hydrogeological investigations have been executed in the SFR area. In order to achieve significant responses from the interference tests, an extra monitoring borehole has been requested. As a percussion drilling machine already was established at Forsmark, it was convenient to drill an additional percussion borehole, HFM47, located in front of (130 m) the SKB VEGA office, see Section 5.6.2.

5.6.1 Overview of drilling of HFM47

Administrative, geometric and technical data for HFM47 are presented below in Table 5-4 and Figure 5-9.

Table 5-4. Administrative, geometric and technical data for borehole HFM47.

Parameter	HFM47
Drilling period	From 2019-09-04 to 2019-09-05
Borehole inclination (collaring point)	−84.42° (− = downwards)
Borehole bearing	150.00°
Borehole length	200.40 m
Borehole diameter	From 0.20 m to 12.07 m: 0.190 m From 12.07 m to 200.40 m: decreasing from 0.1405 m to 0.138 m
Casing length	12.07 m
Casing diameter	$Ø_o/Ø_i$ = 168.3/158.3 mm to 12.07 m
Drill bit diameter	Start of drilling: 0.140.50 m End of drilling: 0.138.0 m
Collaring point coordinates (system RT90 2.5 gon V/RHB70)	Northing: 6699398.78 m Easting: 161283.41 m Elevation: 3,52 m.a.s.l.
Soil cover	10.00 m

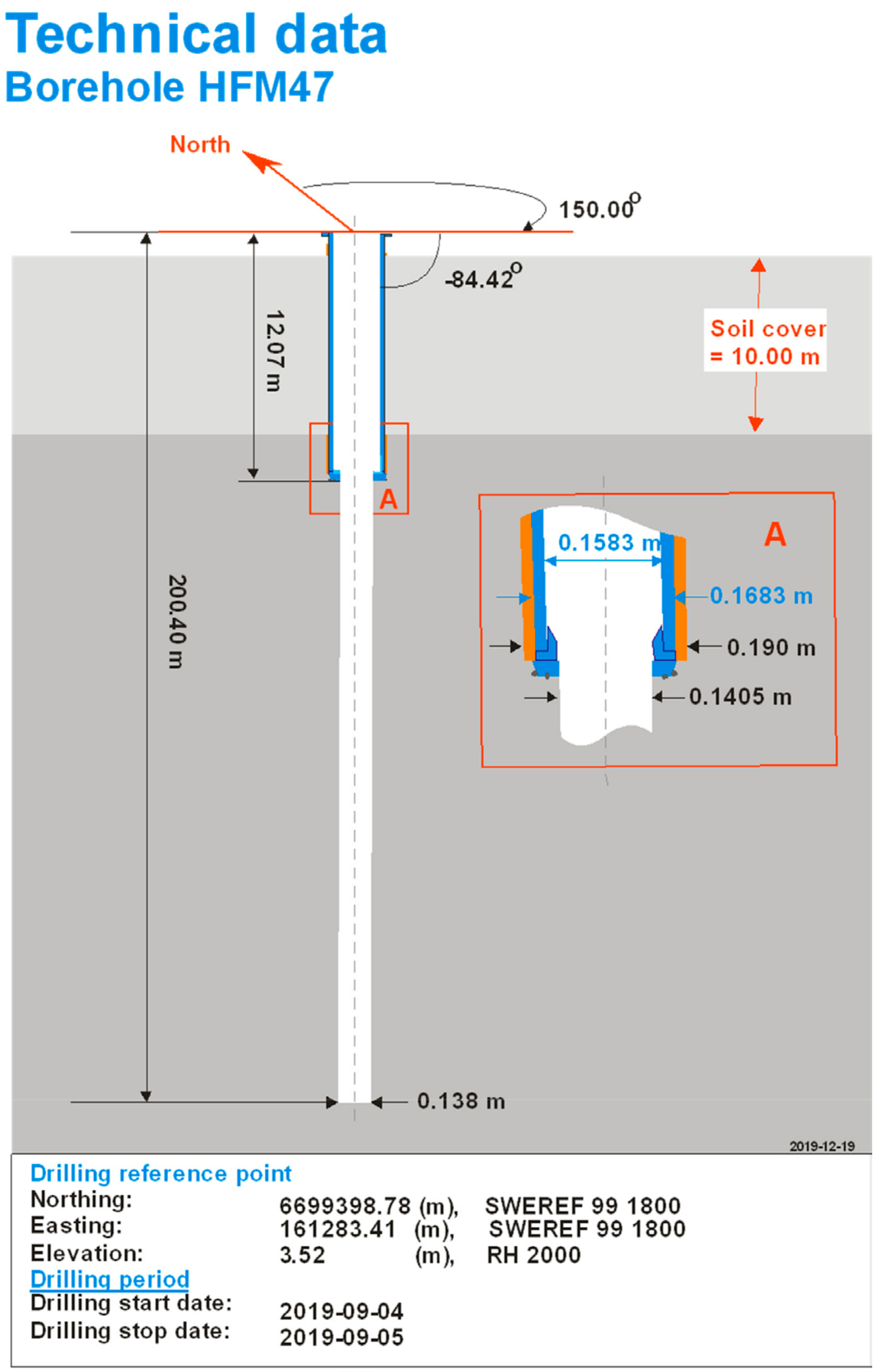

Figure 5-9. *Technical data for borehole HFM47.*

5.6.2 Percussion drilling of HFM47

Usually the shallow part of the bedrock in the Forsmark investigation area contains several water yielding fractures, resulting in large water-inflows in a majority of the existing percussion drilled boreholes in the area around the SKB VEGA office. Results from recently performed interference tests pointed out the need of an additional monitoring borehole in between the existing boreholes in this area. Therefore, as a percussion drilling machine already was established in Forsmark aimed for predrilling at FKA, it was decided to use this rig also for drilling of a 200 m long borehole, HFM47, located 130 m in front of the VEGA office, se Figure 5-10.

__Figure 5-10.__ Right. The HARDAR 5000H drilling machine at drill site HFM47, close to the VEGA office. Left. With a total water-inflow of only c. 6 L/min it is difficult to clean the borehole from drilling debris after completed drilling. For effective flushing it was therefore necessary to add water in order to get the borehole cleaned.

In borehole HFM47 the bedrock surface was reached after 10 m drilling through the soil layer, a soil depth corresponded well with a nearby geotechnical borehole, QFR000047. The casing was drilled to 12.03 m, i.e. a couple of metres into solid rock. The gap between the rock- and casing wall was grouted with 25 L cement-slurry. After hardening of the cement over nigh, the percussion drilling started with a new drill bit (Ø140.5 mm that had decreased to Ø138 mm diameter at the borehole end).

During drilling in borehole HFM47, a minor water-inflow of 6 L/min was encountered at 69 m drilling length. This inflow was kept at roughly the same level also after completed drilling to 200.4 m.

The result from the deviation measurement of HFM47 shows that borehole has a direction significantly upwards, with the initial inclination −85.4° and the inclination −47° at the borehole end. Figure 5-11 shows that the absolute deviation is c.72 m compared to the straight line. Calculation of the elevation indicates that the borehole reaches to c. 173 m vertical depth from TOC.

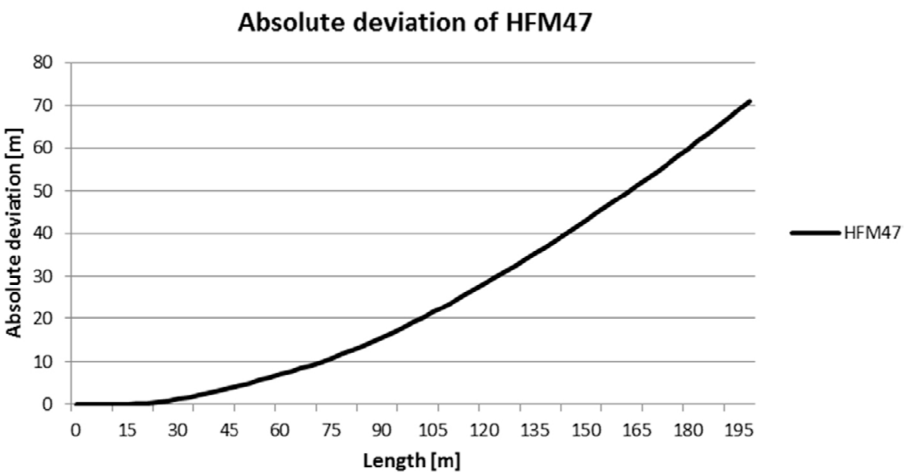

__Figure 5-11.__ The figure shows the absolute distance defined as the shortest distance in space between a point in the borehole at a certain borehole length and the imaginary position of that point if the borehole had followed a straight line with the same inclination and bearing as that of the borehole collaring.

References

SKB's (Svensk Kärnbränslehantering AB) publications can be found at www.skb.com/publications.

SKB, 2016. Detaljundersökningsprogram vid uppförande och drift av Kärnbränsleförvaret. SKB R-16-10, Svensk Kärnbränslehantering AB. (In Swedish.)

Arkitektkopia AB, Bromma, 2022

SKB is responsible for managing spent nuclear fuel and radioactive waste produced by the Swedish nuclear power plants such that man and the environment are protected in the near and distant future.

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