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Arbeitsbericht NAB 16-11

FEBEX DP: Dismantling of heater 2 at the FEBEX "in situ" test

Description of operations

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Draft

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KEYWORDS

FEBEX-DP, Dismantling, onsite activities, sample techniques, samples

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1 Introduction

1.1 The FEBEX project

FEBEX (Full-scale Engineered Barrier Experiment in Crystalline Host Rock) is a research and demonstration project that was initiated by Enresa (Spain).

The aim of the project is to study the behaviour of near-field components in a repository for high-level radioactive waste in granite formations. The main objectives of the project may be grouped in two areas:

Demonstration of the feasibility of constructing the engineered barrier system in a horizontal configuration according to the Spanish concept for deep geological storage (AGP), and analysis of the technical problems to be solved for this type of disposal method.

Better understanding of the thermo-hydro-mechanical (THM) and thermo-hydro-geochemical (THG) processes in the near field, and development and validation of the modelling tools required for interpretation and prediction of the evolution of such processes.

The project consists of two large-scale tests (see Fig. 1) – "in situ" and "mock-up" (the latter is managed by CIEMAT in Spain) – a series of laboratory tests, and THM and THG modelling tasks.

The full-scale heating test ("in situ" test), to which this document refers, was performed at the Grimsel underground laboratory in Switzerland, also known as Grimsel Test Site (GTS) or Felslabor Grimsel (FLG in German). A complete description of the FEBEX project objectives and test program may be found in the "FEBEX Full-scale Engineered Barriers Experiment in Crystalline Host Rock. Pre-operational stage summary report" (Fuentes-Cantillana et al. 1998a).

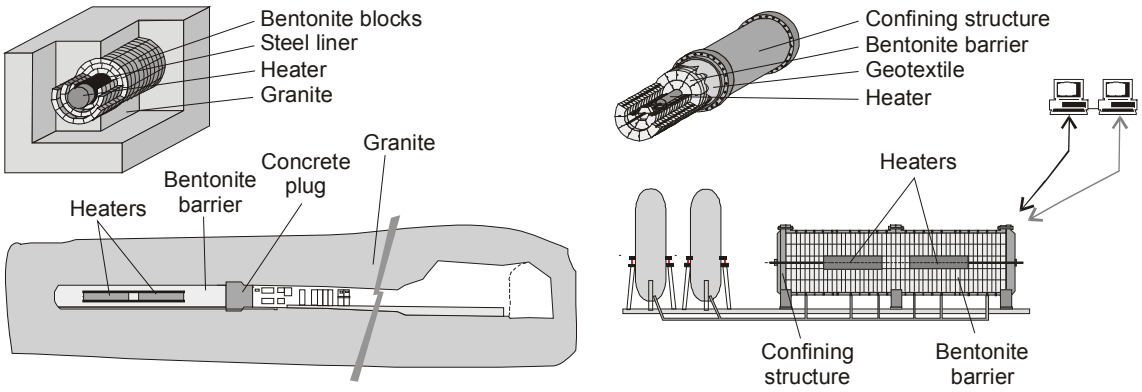


Fig. 1: Overall layout of FEBEX "in situ" test (left) and "mock-up" test (right).

The project started in 1994, and has been supported by the European Commission through consecutive contracts, identified as FEBEX I (contract nº FI4W-CT-95-0006) for the period January 1996 to June 1999, and FEBEX II (contract nº FIKW-CT-2000-00016), from September 2000 to December 2004. Afterwards, NF-PRO took place from January 2005 to December 2007. Finally, in January 2008 the "in situ" test was transferred from Enresa to a consortium composed by SKB (Sweden), POSIVA (Finland), CIEMAT (Spain), Nagra

(Switzerland) and more recently KAERI (South Korea), the FEBEXe Consortium, which supports it currently.

The "in situ" experiment excavation was carried out in 2015 and new partners, interested in taking part in the planned sampling and analysis operations, have been incorporated to the Consortium (now called FEBEX-DP) for that purpose, namely US DOE (USA), Obayashi (Japan), RWM (UK), Andra (France), BGR (Germany) and SURAO (Check Republic).

1.2 Test configuration during FEBEX I

The installation of the "in situ" test was carried out at the GTS. A horizontal drift with a diameter of 2.28 m was excavated in the Grimsel granodiorite especially for this experiment using a TBM (a tunnel boring machine). Two electrical heaters, of the same size and of a similar weight as the reference canisters, were placed in the axis of the drift. The gap between the heaters and the rock was backfilled with compacted bentonite blocks, up to a length of 17.40 m, this requiring a total 115'716 kg of bentonite. The backfilled area was sealed with a plain concrete plug placed into a recess excavated in the rock and having a length of 2.70 m and a volume of 17.8 m^3. Fig. 2 shows schematically the dimensions and layout of the test components.

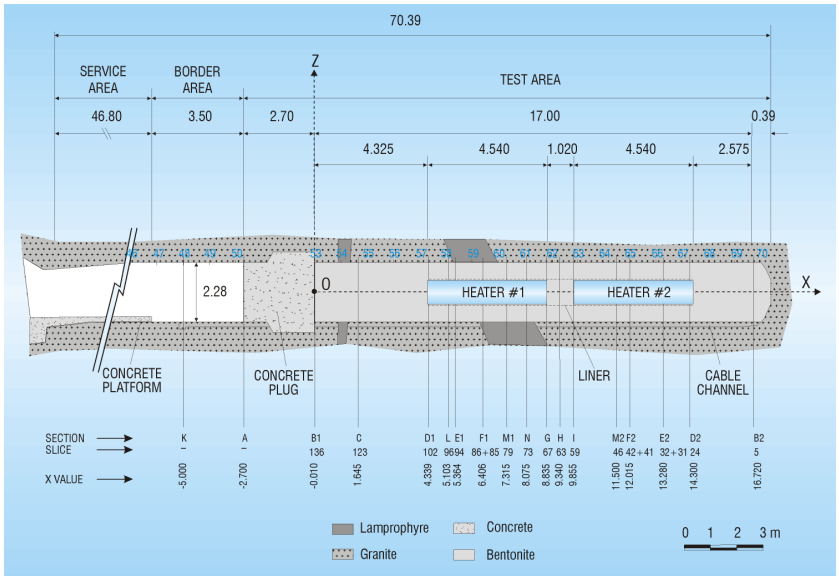


Fig. 2: General layout of the FEBEX "in situ" test (FEBEX I configuration).

A total of 632 instruments were placed in the system along a number of instrumented sections, both in the bentonite buffer and in the host rock, to monitor relevant parameters such as temperature, humidity, total and pore pressure, displacements, ... etc. The instruments were of many different kinds and their characteristics and positions are fully described in the report titled "FEBEX Full-scale Engineered Barriers Experiment in Crystalline Host Rock. Final design and installation of the in-situ test at Grimsel" (Fuentes-Cantillana & García-Siñeriz 1998b).

A Data Acquisition and Control System (DACS) located in the service area of the FEBEX drift collected the data provided by the instruments. This system recorded and stored information

from the sensors and also controlled the power applied to the electrical heaters, in order to maintain a constant temperature at the heaters/bentonite interface. The DACS allowed the experiment to be run in an automated mode, with remote supervision from Madrid. Data stored at the local DACS were periodically downloaded in Madrid and used to build the experimental Master Data Base.

The construction of the concrete plug was completed in October 1996, and the heating operation started on 28 February 1997. A constant temperature of 100 °C was maintained at the heaters/bentonite interface, while the bentonite buffer has been slowly hydrating with the water naturally issuing from the rock. A complete report that includes both the installation of the test and the results gathered after two years of operation is given in "FEBEX full-scale engineered barriers experiment for a deep geological repository for high level radioactive waste in crystalline host rock Final Report" (Fuentes-Cantillana et al. 2000).

1.3 Dismantling of Heater 1 and test configuration afterwards (FEBEX II)

A partial dismantling of the FEBEX "in situ" test was carried out during the summer of 2002, after 5 years of continuous heating. The operation included the demolition of the concrete plug, the removal of the section of the test corresponding to the first heater, and the sealing with a new shotcrete plug. A large number of samples from all types of materials were taken for analysis. A number of instruments were subsequently dismantled, as well as a few new ones were installed. Accordingly, system design was adapted, and the physical layout was changed in order to ease the partial dismantling operation.

The buffer and all components were removed up to a distance of 2 metres from heater #2 to minimize disturbance of the non-dismantled area. A dummy steel cylinder with a length of 1 m was inserted in the void left by heater #1 in the centre of the buffer. Some new sensors were installed in that one additional metre of bentonite buffer.

Additional sensors were introduced in boreholes drilled in the buffer parallel to the drift. To simplify this operation, the new concrete plug was constructed in two phases: an initial temporary plug measuring just 1 m in length, which was built immediately after dismantling, and a second section to complete the plug length to the 3 m planned in the design of the experiment. Unlike FEBEX I, the new plug was a parallel plug, without a recess excavated in the rock, constructed by shotcreting.

The description of the partial dismantling operation is given by the report titled "Dismantling of the Heater 1 at the FEBEX "in situ" test. Description of operations" (Bárcena et al. 2003). The configuration of the test, after completing the partial dismantling operation and construction of the full plug length, is shown in Fig. 3.

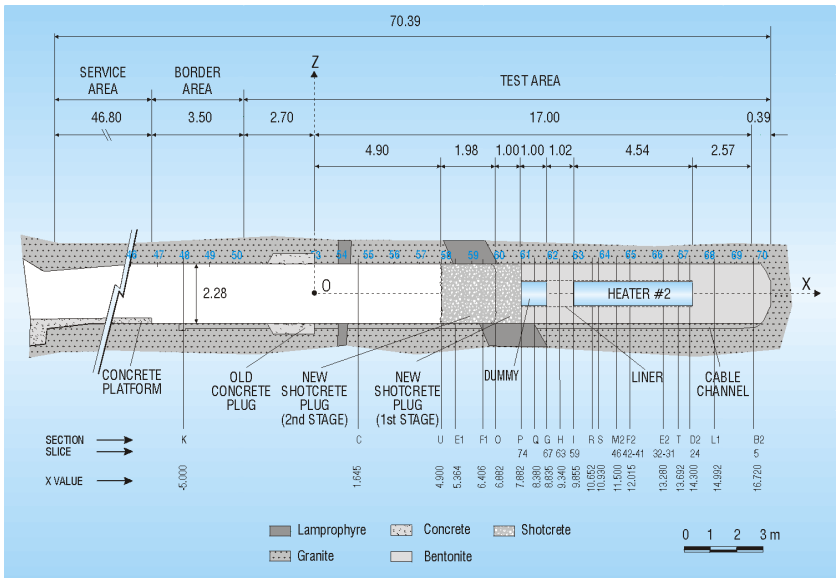


Fig. 3: Status of the FEBEX "in situ" test after the partial dismantling (FEBEX II configuration).

A more complete report that describes the test from the conception up to two years of operation after the partial dismantling is given in the document titled "FEBEX Full-scale Engineered Barriers Experiment. UPDATED FINAL REPORT 1994 – 2004" (Huertas et al. 2006).

1.4 Concept of the dismantling of Heater 2

The objective of the second dismantling operation, carried out throughout 2015, was to dismantle all the remaining parts of the "in situ" test, including the heater #2. This operation includes carrying out a complete sampling of the bentonite, rock, relevant interfaces, sensors, metallic components and tracers to allow the analysis of the barriers' condition after 18 years of heating and natural hydration.

Analytical results will be compared with data obtained from the partial dismantling (Huertas et al. 2006); the monitoring data (AITEMIN 2014) as well as with the results derived from modelling efforts (Lanyon & Gaus 2013). The results are expected to increase the current knowledge and confidence for the FEBEX-DP partners in bentonite performance with a focus on thermo-hydro-mechanical (THM) and thermo-hydro-chemical (THC) processes as well as on corrosion and microbial activity. The reporting of the laboratory analysis and dismantling results is expected to be complete by the end of 2016 with a final integrated report issued in early 2017.

All details about the planned dismantling operation and sampling program are given in the reference documents: "FEBEX-DP (GTS) Full Dismantling Test Plan" (Bárcena & García-Siñeriz 2015a), "FEBEX-DP (GTS) Full Dismantling Sampling Plan" (Bárcena & García-Siñeriz 2015b) and its update (Rey et al. 2015).

All sample logs of the dismantling operation are documented in AN 15-578 Sample Log Book 34 to 62 FEBEX-DP (Abós & Martínez 2015).

1.5 Objectives and contents

This report is intended for documenting the activities carried out and the main results gathered during the dismantling of the FEBEX in situ test.

Chapter 2 provides an overview of the operation, which is detailed in Chapters 3 and 4. Chapter 5 gives insight on the in situ analysis carried out. Chapter 6 describes the samples' handling and shipping. Chapter 7 provides the main conclusions gathered so far. Chapter 8 is devoted to acknowledge the efforts of all participants in this challenging operation and Chapter 9 collects the references used.

2 Overall sequence of operations

Briefly, the sequence of the main operations developed during the dismantling operation was as follows:

Preliminary/preparatory works

Two visits were carried out to check the status of the existing equipment from the previous partial dismantling and to determine the necessary actions to be done before starting the planned dismantling operation. The first visit took place from the 18th to 20th October 2010; the second visit was on the 10.09.2014 in coordination with the last FEBEX-DP meeting held in Wettingen. Results were reported accordingly:

- Dismantling equipment report (dated December 2010)
- On-site equipment plan (dated 15.10.2014)

According to those results, the activities done comprised:

1. Preparation of existing equipment
2. Removal of instrumentation at the plug face
3. Protection of remaining data acquisition cabinets and instrumentation racks within the FEBEX drift
4. Completion of steel tracks up to the plug
5. Marking of the boreholes to be drilled at the plug surface

Details of each step are given in Chapter 3.

Overcoring and long coring

After finishing the preliminary preparations and before starting the dismantling phase a few drillings were made through the concrete plug to obtain unaltered samples.

Three 3 m long cores were drilled through the concrete plug to obtain unaltered samples of the concrete and in particular of the concrete-buffer interface. All these activities were carried out by the GTS team. Details are given in Section 4.1.

Dismantling operation

The dismantling operation itself was then carried out according to the following sequence:

1. Replacement of instruments (relative humidity and temperature) plus installation of video cameras
2. Shotcrete plug demolition (and concrete or concrete/rock sampling) of the first section (2 m long). Fulfillment of the associated quality control documentation during the sampling (samples/instrumentation removal included)
3. Switching off heater #2, one month in advance of heater removal
4. Sampling corresponding to Section 34 and drilling cores through the remaining plug section

5. Shotcrete plug demolition (and concrete or concrete/rock sampling if required) of the second section (1 m long). Fulfillment of the associated quality control documentation during the sampling (samples/instrumentation removal included)
6. Sampling of the concrete/buffer interface (Section 35) and fulfillment of the associated quality control documentation
7. Removal and sampling of bentonite, bentonite/rock interfaces and liner up to the front of heater #2. Fulfillment of the associated quality control documentation during the sampling. This operation includes removing the "dummy canister"
8. Extraction of heater #2
9. Removal and sampling of the remaining bentonite and liner. Fulfillment of the associated quality control documentation during the sampling
10. Shipping of samples

Details of each step are given in Chapter 4.

The dismantling operations were started in GTS after Christmas 2014 – 15 (2nd of February) and finished by 05.08.2015. The daily reports (Kober 2015a) of such activities were started from 17th of February (number 1) and concluded with number 104 issued on 5th of August.

The following table gives an overview of the activities carried out.

Tab. 1: Overall chronology of activities.

Dates	**Team***	**Main activity**	**Document section**
02.02.2015 – 12.02.2015	VML, FJS & AMV	I Preparatory works	I Section 3
17.02.2015 – 26.03.2015	Nagra	I Long coring and overcoring through the plug	I Sction 4.1
06.04.2015 – 17.04.2015	VML & AMV	I Shotcrete plug demolition of the first section. II Sampling of Section 34	I Section 4.2 II Section 4.4
17.04.2015 – 23.04.2015	Nagra	I Interface sampling and concrete coring	I Section 4.3
24.04.2015	MAM	I Switch-off of heater #2 from Madrid	I Section 4.5
27.04.2015 – 30.04.2015	IBB	I Shotcrete plug demolition of the second section	I Section 4.6

Tab. 1: Cont.

Dates	Team*	Main activity	Document section
04.05.2015 – 08.05.2015	IBB & AMV	I Continuation of Shotcrete plug demolition of the second section II Sampling of the concrete/buffer interface	I Section 4.6 II Section 4.7
11.05.2015 – 13.05.2015	IBB, CDR & AMV	I First trial of the removal of dummy canister II Start removal and sampling of the buffer around the dummy canister	I Section 4.8
18.05.2015 – 22.05.2015	VML, FJS, MAM & JLD	I Removal and sampling of the buffer around the dummy canister	I Section 4.8
26.05.2015 – 05.06.2015	IBB, AMV, CDR & JPC	I Removal of dummy canister II Removal and sampling of the buffer up to heater #2 III Extraction of heater #2	I Section 4.8 II Section 4.9 III Section 4.10
8.06.2015 – 19.06.2015	VML, MAM, MLD, FJS, JLD, JMT	I Removal and sampling of the remaining buffer	I Section 4.11
22.06.2015 – 03.07.2015	HA, JPC, AMV & CDR	I Removal and sampling of the remaining buffer	I Section 4.11
06.07.2015 – 17.07.2015	VML, FJS, MAM & JLD	I Removal and sampling of the remaining buffer	I Section 4.11
20.07.2015 – 31.07.2015	HA, JPC, AMV & CDR	I Removal and sampling of the remaining buffer	I Section 4.11
03.08.2015 – 05.08.2015	VML, FJS & JLD	I Removal and sampling of the remaining buffer	I Section 4.11

***AITEMIN Team:**

1. IBB: Ignacio Bárcena
2. HA: Héctor Abós
3. VML: Víctor Martínez
4. CDR: Cristina de la Rosa
5. MAM: Miguel Ángel Manchón
6. FJS: Francisco Javier Sanz
7. JPC: Jose Pedro Carvajal
8. AMV: Antonio Martín
9. MLD: Miguel Llamas
10. JMT: José María Toledo
11. JLD: José Luis Diaz-Lancha

3 Preparatory works

The actions performed on February consisted of the identification, reparation and tests when possible of the different tools and machines to be used.

The equipment, which remained from the FEBEX construction (1996 – 97) and the partial dismantling (2001 – 2002), was mainly composed of:

- The tracks for the handling and transport of equipment, installed at the FEBEX gallery in 1996, and a set of additional track sections necessary to extend the railway during the dismantling.
- A pulley system located at the end of the tracks, installed during the construction and moved forwards during the partial dismantling.
- An electrical rope winch that was upgraded for the partial dismantling: it was provided with separate drums for each sense of movement.
- The heater extraction car, which was a new vehicle used for extracting the heater from the deposition hole during the partial dismantling.
- The side dump wagon, designed and built to transport concrete pieces and bentonite outside the drift during the dismantling operation.
- A rolling bed for the dummy canister insertion, built and used for the dismantling operation. An auxiliary mobile electrical crane, installed at the entrance of the FEBEX tunnel during the construction phase.

The site and machinery was left ready for the beginning of the dismantling works considering the following comments:

- The necessary equipment for sampling included in the dismantling sampling plan had to be delivered at site.
- An electrical cable larger than the length of the whole drift was needed to feed the extraction car hydraulic winch.
- A new discharge ramp for the wagon had to be produced. The same applies to the tools for transporting the heater after dismantling.

3.1 Handling and transport equipment

The extraction car was cleaned and all bearings were greased A pressure display in the hydraulic winch cabinet was reconnected, reconfigured and left operative. Oil levels in this winch were verified. The cable-pulley system of this winch was also cleaned and greased and the whole system of the hydraulic winch was tested positively (Fig. 4).

The mobile electrical crane was tested to check the functionality of a new pad. Results were positive.

The side dump wagon and the rolling bed were cleaned and painted and wheels and mechanisms greased.

Fig. 4: Hydraulic winch of the extraction car.

The winch engines were released, cabled and tested and the control cabinet of this winch was also cabled and prepared and positioned next to the motors. A light and information stickers were added to the cabinet (Fig. 5). The metallic cable (going into the drift and back to the car) was stretched. New oil was added to the electrical winch motors. The electrical winch was tested by the introduction/extraction into/from the drift of the side dump wagon and the extraction car with no remarkable incidents, both moved softly on top of the rails.

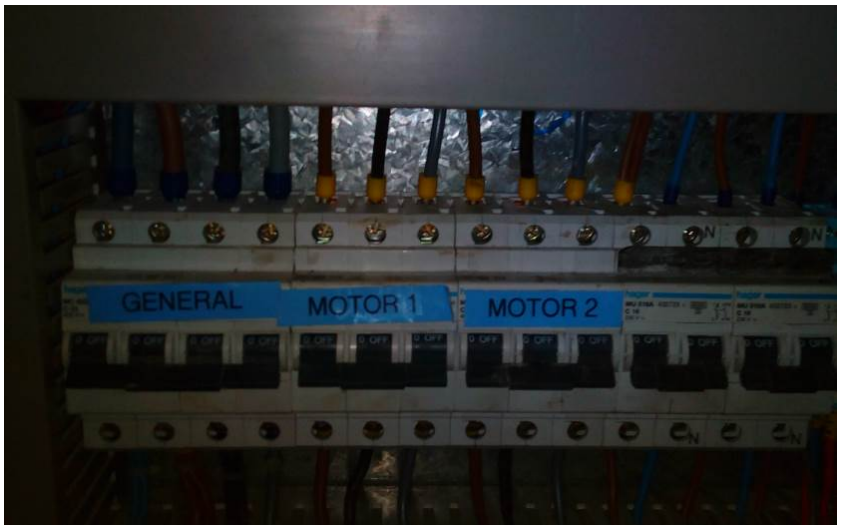


Fig. 5: Switches inside the external winch control cabinet.

A double headed 3-phase connector (5 poles, 32 amperes) was prepared and left below the power cabinet (Fig. 6). The external electrical winch, the hydraulic winch of the extraction car and the mobile electrical crane use this type of connection. Therefore only two of them can be used at the same time. Each of these elements has its own connector but for the extraction car to reach the front of the experiment a cable long enough had to be provided.

Fig. 6: Double headed three-phase connector below power cabinet.

3.2 Plug face preparation

The extensometers and their attachment system were removed from the plug face, as well as several other remains (bolts, etc). The axes and centre of the plug were revealed by means of a levelled laser system and the aid of previous marks on the walls. For this purpose, a portable structure for the positioning of the lasers (laser frame) was developed. This structure consists of a metallic beam that must be installed between two pieces at the right and left of the gallery, where a system of screws is prepared to level the structure so to match the inclination of the gallery itself (Fig. 7). After the positioning of the axes and centre, the location of the first drillings and the overcorings (C-C-32-1 to 6) was sprayed at the plug face (Fig. 8).

Fig. 7: Laser frame installed on lateral fixing on the gallery's walls.

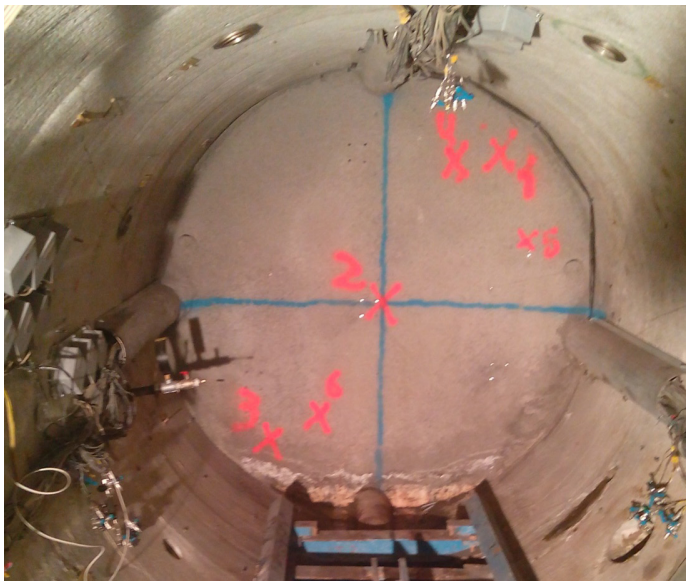


Fig. 8: Marking of drillings and overcorings on plug face.

3.3 Completion of steel tracks

Rail parts were emplaced in the gap formerly occupied by the original plug. The rails were welded to those already in place using a MIG welding machine provided by GTS staff. The bottom parts of the rails were secured by installing a set of wooden feet (thick wooden pieces of about 40 × 40 cm/section) and they were judged stable (Fig. 9). Water was pumped out as much as possible from the area of the former plug and the pump was installed permanently to drain the water from overcore drilling and plug demolition. A metal pathway was put on top of the new rails section for easier personnel movement in the drift.

Fig. 9: Detail of wooden feet and pathway on the newly installed tracks.

Fig. 10: Detail of welded rail sections.

The return pulley was, in addition to being cleaned, greased and smoothed, moved to a position next to the gap of the former plug, so as to ease the installation of drilling and excavation machinery. The return pulley is shown in Fig. 11.

Fig. 11: New position of the return pulley.

3.4 Protection of data acquisition cabinets

Cabinets inside the drift were protected by plastic covers to avoid dust entering them during the dismantling works (Fig. 12).

Fig. 12: Cabinets protected with a plastic sheet.

3.5 Installation of auxiliary data recording units

Before starting the plug dismantling activities, the sensor coded as WCA-01 and located at the service area of FEBEX gallery was changed as the temperature data of the former one was not reliable. The new sensor allowed tracking both relative humidity and temperature in the main drift during the whole dismantling process.

On the 06.04. 2015, three video cameras and a server where installed. They were located at the FEBEX-Drift end, FEBEX-Drift entry and at the on-site lab.

4 Dismantling operations

All information about the sections to be sampled, the codes used for the samples taken and the sampling procedures is given in the Sampling Plan (Bárcena & García-Siñeriz 2015b) and (Rey et al. 2015). An updated list of the sampling section is given here in Annex I. A summary of the daily reports issued for each working day starting on 17.02.2015 (start-up of the long coring through the plug, see next section) can be found in (Kober 2015a). Additional "Extra Reports" detailing specific operations or findings were issued during the dismantling operation (Kober 2015b). Data from installed sensors were continuously monitored during the dismantling phase, and are described in the last data report (see NAB 16-19 Sensor Data Report, Martínez et al. 2016).

4.1 Long coring & overcoring through the plug

Drilling operations for specialised sampling of shotcrete/bentonite interfaces and of the shotcrete plug were performed before the plug was dismantled and before the heater was turned off [see details in NAB 16-10 Plug overcoring]. After the site preparation (Chapter 0), the GTS on-site drilling team installed a work platform and a ventilation system.

The outside surface of the shotcrete plug represents Sampling Section 32 (Fig. 13 and Fig. 14) and this is used as root name for all boreholes and samples recovered by drilling from this level, regardless of the depth location.

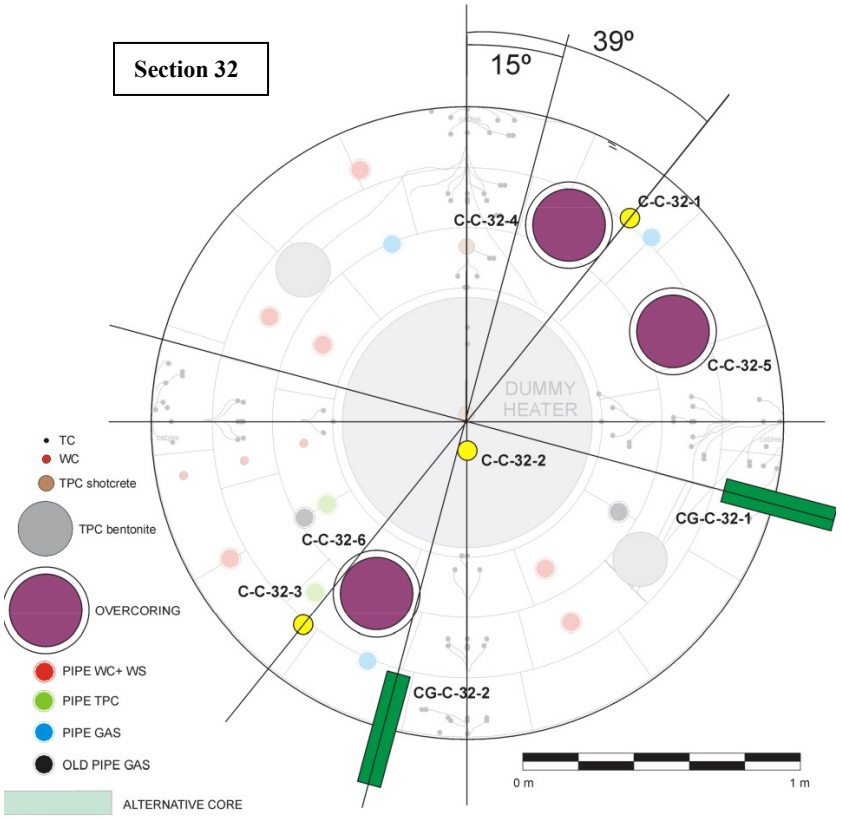


Fig. 13: Dismantling layout of Section 32 (long-cores and overcores).

Tab. 2 lists the various sampling boreholes drilled during this activity, while Fig. 13 is a frontal view of the plug surface with the drilling locations marked.

Tab. 2: Summary of schedule and activities.

Time period	**Borehole**	**Activity**
17.02.2015 –18.02.2015	C-C-32-1	Sampling of shotcrete
18.02.2015 –19.02.2015	C-C-32-2	Sampling of shotcrete
19.02.2015	C-C-32-3	Sampling of shotcrete
24.02.2015 – 03.03.2015	C-C-32-4	Sampling of shotcrete/bentonite interface
04.03.2015 –11.03.2015	C-C-32-5	Sampling of shotcrete/bentonite interface
16.03.2015 –26.03.2015	C-C-32-6	Sampling of shotcrete/bentonite interface

4.1.1 Sampling of shotcrete plug C-C-32-1 to C-C-32-3

The first drilling retrieved 3 long-cores (C-C-32-1 to C-C-32-3, 78 mm OD), drilled at positions shown in Fig. 14 and was accomplished between the 17.02.2015 and 19.02.2015. Total core length was between 2.91 – 2.99 m, see [12], of which the first 2.70 to 2.80 m was drilled by wet conditions whereas the last 10 to 20 cm were drilled under dry conditions. Contrary to the "Sampling Plan" [9], sample C-C-32-2 was positioned 10 cm down the central gallery axis in order to avoid damage of a sensor in the instrumented section G. Drilling was performed without any complications, apart from C-C-32-3, where a constant backflow of water was observed during dry drilling and even for some time after completion of the drilling. It is not fully clear whether this water originated from the previous wet drilling and backflow from the partially porous shotcrete or some wet spots in this region as was also observed at the start of the Section 36 dismantling process.

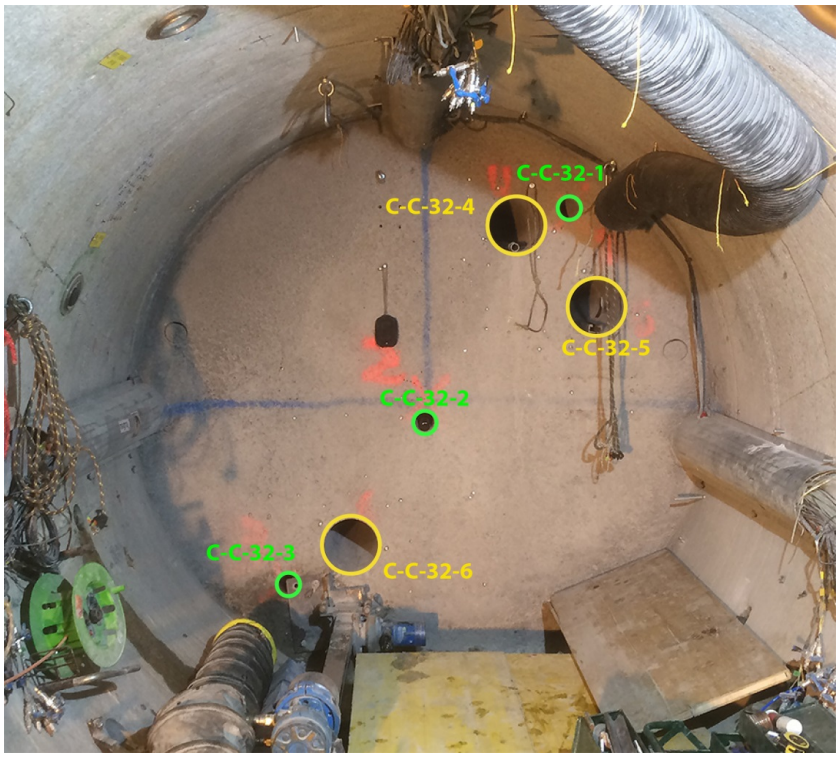


Fig. 14: Location of long core shotcrete boreholes and for shotcrete/bentonite interface sampling. Plug surface represents Section 32.

Note that C-C-32-2 has been shifted away from the gallery centre for sensor protection and the end of the plug.

4.1.2 Sampling of shotcrete/bentonite interfaces C-C-32-4 to C-C-32-6

Drilling operations for stabilised coring started on February 24, 2015, with C-C-32-4 (Fig. 14) and were completed by March 26, 2015, with C-C-32-6. All cores were retrieved in a perfect state of physical and chemical integrity. Details of the drilling procedure and sample preparation are described in a separate report about the shotcrete/bentonite interfaces sampling (Detzner & Kober 2015). A brief summary is provided below.

Fig. 14 shows the situation after completion of the sampling and illustrates the exact borehole locations. Borehole C-C-32-5 was slightly shifted to the left (ca. 5 cm) compared to the original plan to provide sufficient clearance for drilling operations. All three boreholes were arranged around the central steel dummy that marks the location of the former heater (see Fig. 13). Fig. 15 shows the layout in a sectional view, including approach boreholes of 220 mm OD, and the overcoring section of 132/124 mm OD/ID (details below).

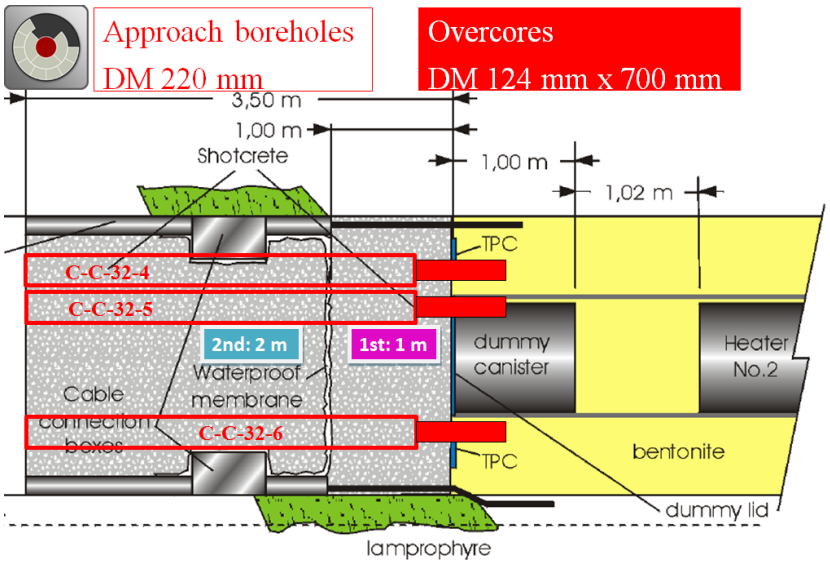


Fig. 15: Section view of boreholes for shotcrete/bentonite interface sampling. Plug surface represents Section 32.

Tab. 3 is a summary of drilling parameters for the three sampling boreholes. Drilling depths are referenced to the plug surface, the location of Sampling Section 32. The depth of the shotcrete/bentonite interface is close to 3.00 m, representing sampling sections between 36 and 37. The final depth is ca. 0.40 m into bentonite, or 3.40 m from the plug surface, close to Sampling Section 38.

Tab. 3: Summary of borehole parameters.

Borehole	**Approach in shotcrete**	**Stabilisation with fibre glass and epoxy resin**	**Overcore containing interface**
	OD = 220 mm	OD = 46 mm	OD = 132 mm
C-C-32-4	0 – 2.66 m	6 × 2.66 – 3.34 m	2.66 – 3.35 m
C-C-32-5	0 – 2.70 m	6 × 2.70 – 3.38 m	2.70 – 3.40 m
C-C-32-5	0 – 2.75 m	6 × 2.75 – 3.40 m	2.75 – 3.41 m

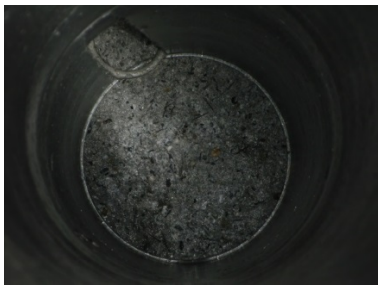
Fig. 16 illustrates the drilling procedure. In short, it includes the following steps:

- Drilling of an approach borehole of 220 mm OD in shotcrete plug to 25 – 30 cm before the interface.
- Core ripping in a manner to provide a flat surface perpendicular to the drilling axis.
- Insertion of a drilling template for 3 small 46 mm diameter boreholes across the interface to a final depth of ca. 3.4 m.
- Insertion of packer system with fibre glass rod and injection of epoxy resin to stabilise the interface region.

- Drilling next 3 small boreholes.
- Stabilisation with fibre glass and resin as before
- Extraction of equipment.
- Insertion of template for overcoring (132 mm).
- Overcoring to a depth of 3.4 m.
- Gentle breaking of core if not loose.
- Retrieval of core with drill barrel.
- Vacuum packing of core and further treatment (see Detzner & Kober 2015).

Pilote borehole for retrieving cores

Approach borehole, 220 mm OD

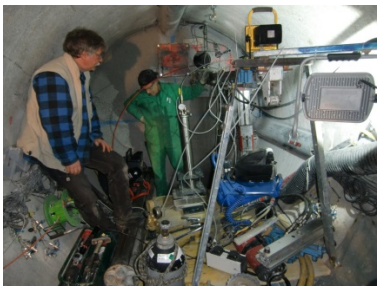


Flat base at ca. 2.7 m depth

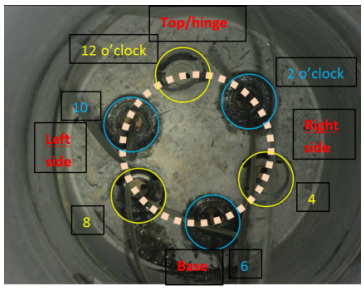
Drilling template for 3 × 46 mm

Packer systems with fibre glass rods

After emplacement of packers systems



Resin injection; drill next 3 × 46 mm



After stabilisation

After overcoring, before core retrieval

Fig. 16: Procedure for fibre glass reinforced overcoring of shotcrete/bentonite interface samples.

Samples were measured and inspected and vacuum-packed on site in plastic foil and plasticized aluminium bags, transported to the University of Bern in cold storage. Sample processing is described in detail in a separate report (Kober 2015b and NAB 16-10 Plug Overcoring). Fig. 17 illustrates the cutting scheme and labelling scheme. In this manner 12 quarter cores of shotcrete sections, of shotcrete/bentonite sections, and bentonite sections were obtained and distributed to partners and their associated analytical teams.

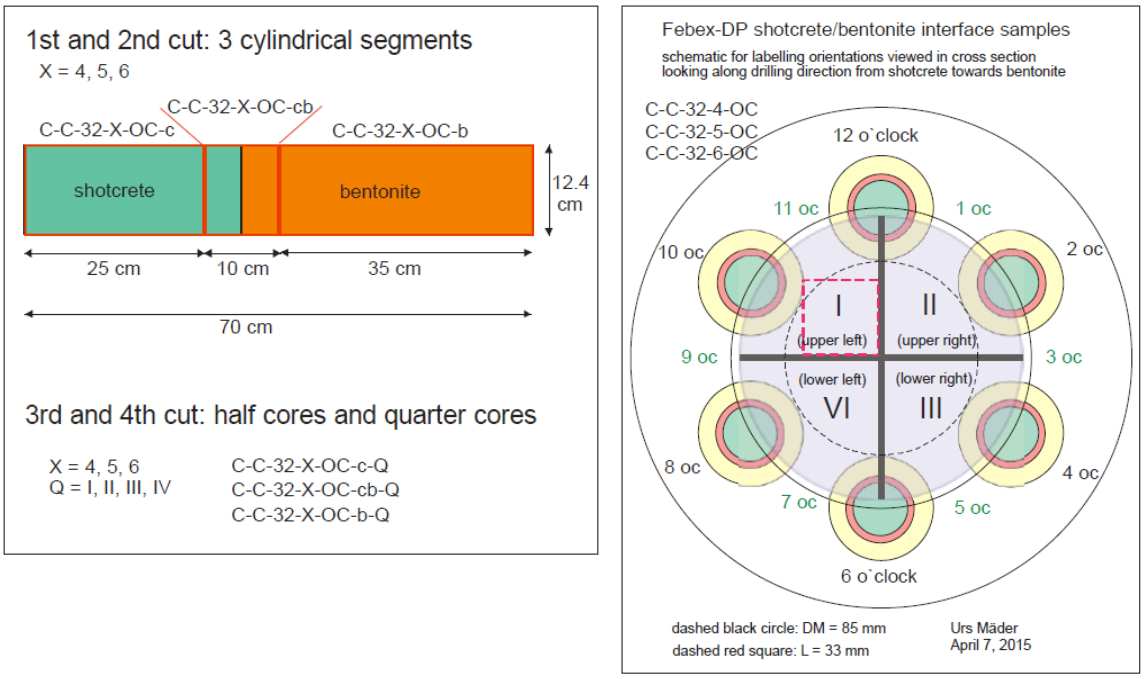


Fig. 17: Cutting and labelling scheme of shotcrete/bentonite interface samples.

Temperatures were measured in boreholes C-C-32-4 and C-C-32-5 at four locations near the shotcrete/bentonite interface (Fig. 18). These temperatures are close to the in situ temperatures because the heater was not turned off yet at the time of drilling. The readings for C-C-32-4 were measured two days after drilling, which may explain the slightly lower readings, although the borehole was provisionally closed to prevent excessive heat loss.

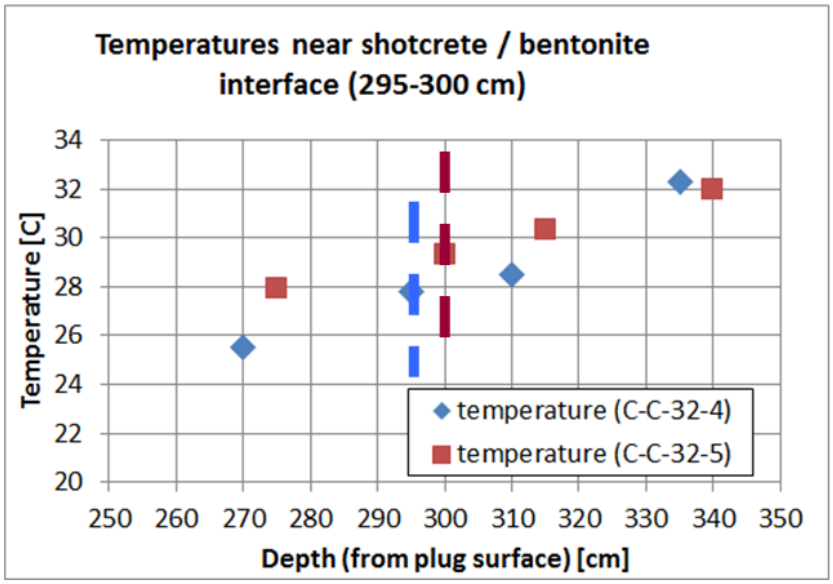


Fig. 18: Temperature distribution near the shotcrete/bentonite interface. The dashed lines mark the position of the interface.

4.2 Shotcrete plug demolition (first part)

The demolition of the shotcrete plug started on 07.04.2015 with the mobilization and installation of the demolishing robot on the plug face. Instead of the manual hydraulic drilling machines used during dismantling of heater #1, for this final dismantling procedure an autonomous arm-shaped little sized robot was selected as it was considered to be faster, safer and more precise.

A specialized local firm, Diamcoupe SA or Diamantbohr AG, was hired for this purpose using a robot Brokk 90 (Fig. 19): one technician was responsible for the control of the robot operations and another worker helped in cleaning the site and discharging the waste. Two AITEMIN people performed the supervision of the work and helped in the waste removal. Nagra staff also provided general support (waste disposal, water pumping installation etc).

Fig. 19: Robot installation on the drift.

The first section of plug comprised approximately two meters of concrete, from Sampling Section 32 to 34. The first part of plug was separated from the next one by an impermeable mat (water proof membrane made of MASTERSEAL X345 polymer compound (Bárcena et al. 2003)) positioned in Section 34.

The position of the plug face was marked on the wall for further reference, see Fig. 20. Cable ducts positions were considered so as to avoid hitting them. The locations of wall total pressure cells were approached by the robot smoothly, trying not break any of the sensors' tails, which contain mercury.

Fig. 20: Marking of plug face on the gallery and left cable duct.

Some amount of concrete debris was left on the bottom part of the tunnel to act as a base and facilitate the robot movement (see Fig. 21). Separately, a layer of 18 cm thickness of concrete was left intact on the lower part of the gallery in order to sample the concrete/rock interface in sections S32 and S33.

The advance of the excavation was leveled off better with the use of the robot than that performed on the dismantling of heater #1 (see Fig. 22). About 12 tons of shotcrete were disposed off in this first part.

Fig. 21: Detail of the base made with concrete debris in order to facilitate the robot movements.

Fig. 22: Detail of the excavation advance and the impermeable mat at the rear of this first part.

There was a problem with the main unit of the robot, which had to be dismantled and repaired to ensure proper tightening of the hydraulic lines. But, generally, the first part of the plug dismantling was achieved in 6 working days. It can be labelled as a fast and secure proceeding.

4.3 Interface concrete/rock coring

The sampling of Section 33 for the concrete/rock (concrete/granite and concrete/lamprophyre) interface was performed on 17.04.2015 in a simplified overcoring approach at positions where concrete was preserved. The sampling plan was adjusted to the position of the granite and lamprophyre and best visually determined intact concrete (Fig. 23).

Overcoring was performed by drilling 3 stabilization boreholes (OD 30 mm) 120° apart, filled with fast (~ 1 h) hardening resin (Sika®) and overcored with diameter OD 85 mm). Both sites had problems for obtaining intact interfaces, resulting in broken cores (concrete part and rock part, Fig. 24). This is likely due to the weak mechanical contact between concrete and rock and also due to the vibration caused by the robot plug demolition (sampling positions were at bottom locations). Another approach in drilling only one central stabilization borehole and overcoring later failed too. Future operations should consider drilling prior to plug demolition and eventually should use 6 stabilization boreholes, which, however, would be more time consuming.

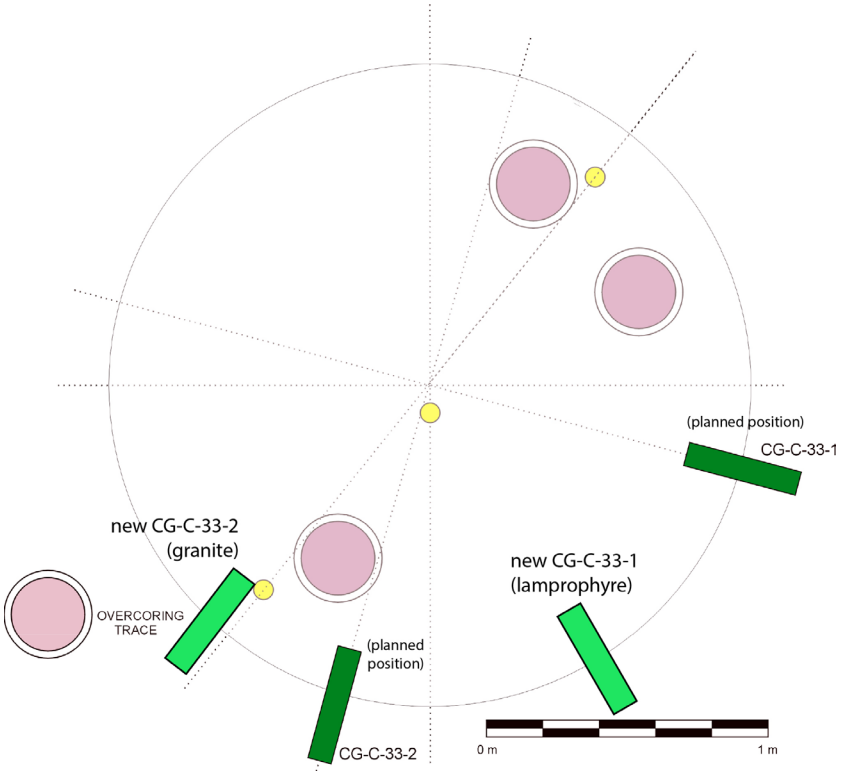


Fig. 23: Section 33 and shifted sampling positions.

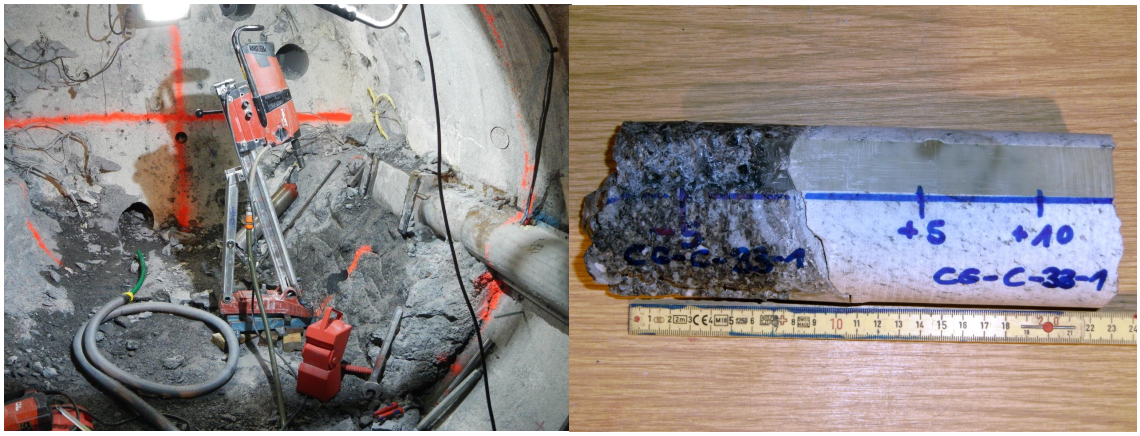


Fig. 24: Drilling of Sample CG-C-33-1 and core obtained (broken at the interface).

4.4 Interface sampling & concrete coring

Sampling of Section 34 was performed on 14.04.2015 for sample extractions and on 21 to 23.04.2015 for the core drillings C-C-34-4 to 12 (see locations at Fig. 25). The first three C-C (C-C-34-1 to 3 planned at low-right part) were discarded in order to keep the recommended width of concrete in the lower part of the gallery for future concrete-rock drillings. Retrieved sensors showed good conditions in general but a few had external corrosion signs (Rey et al. 2016). Pressure decreased at the bentonite/plug interface during this process. More details can be found in Section 4.6.

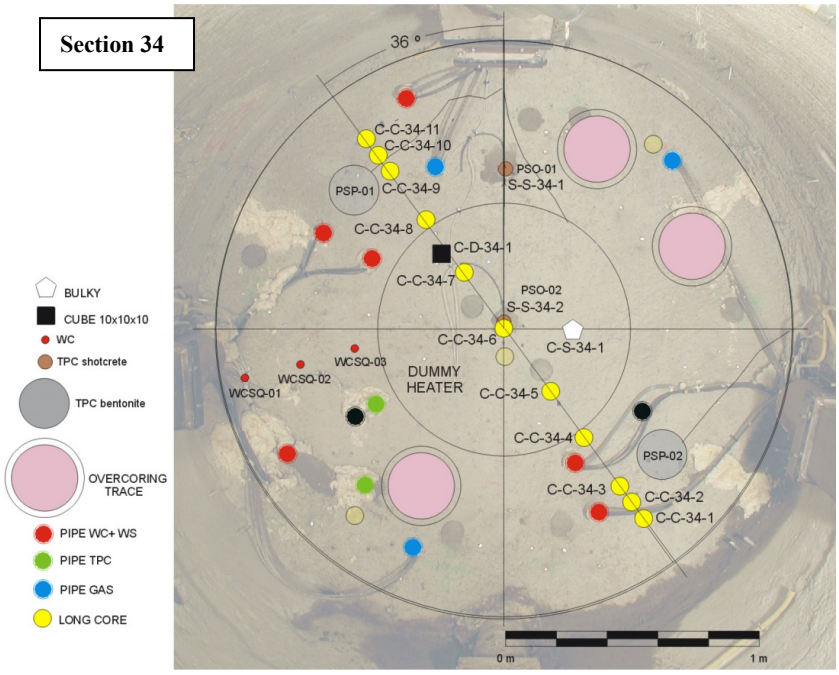


Fig. 25: Dismantling layout of Section 32 (long-cores and overcores) and Section 34 (short cores).

4.5 Switching off heater #2

In order to achieve a temperature level desired for the upcoming dismantling works, heater #2 was switched off on 24.04.2015 after 6'630 days of heating. The designed control temperature of 100 °C at the heater/bentonite interface was targeted to decrease to the range of 25 – 30 °C at the start of excavating the zone, so the power was switched off around one month prior to this date. The switching was made in a single step as done in the partial dismantling, but the temperature decrease was faster in this case. Working conditions were achieved in about 20 days contrary to the 30 days needed during the first dismantling.

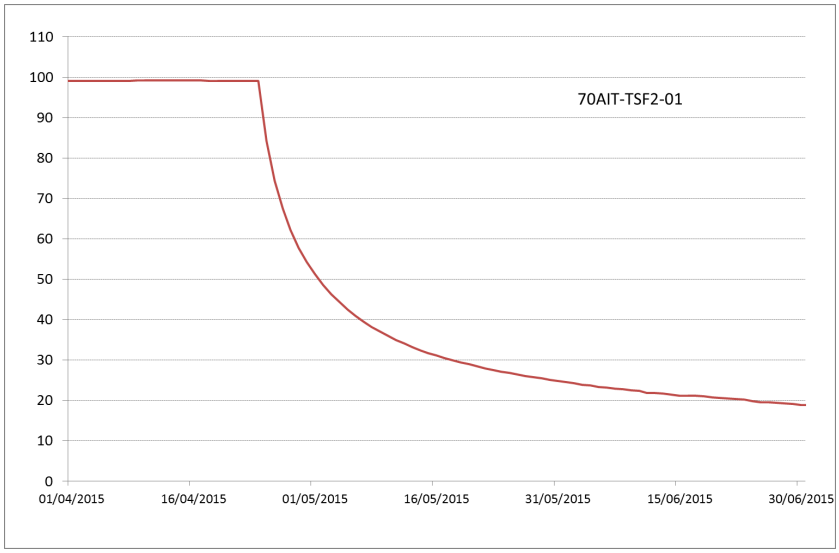


Fig. 26: Control temperature decay after power off.

The temperature and other measurements' evolutions during the dismantling phase are described in the last sensor data report (NAB 16-19 Sensor data, Martínez et al. 2016).

4.6 Shotcrete plug demolition (second part)

The second part of the shotcrete plug excavation comprised Sampling Section 34 (impermeable mat) to Sampling Section 36 (interface plug-bentonite). The same equipment, team and procedure as used in the first part were applied.

This time some little hand-made gypsum markers/trackers were placed in the plug/rock contact to check if this remaining part of the plug (about 1 meter) moved towards the entry of the gallery during the excavation works due to the pressure imposed by the swelling bentonite buffer. It turned out that there was no movement whatsoever. See detail of this tracker on Fig. 27.

Fig. 27: Hand-made gypsum tracker.

Total pressure in the shotcrete/bentonite interface was tracked too during dismantling activities (NAB 16-19 Sensor data, Martínez et al. 2016) and a higher drop of pressure was noticed at the total pressure cells located closer to the interface (instrumented Section P, see Fig. 28) just after starting the demolition of the second part of the plug.

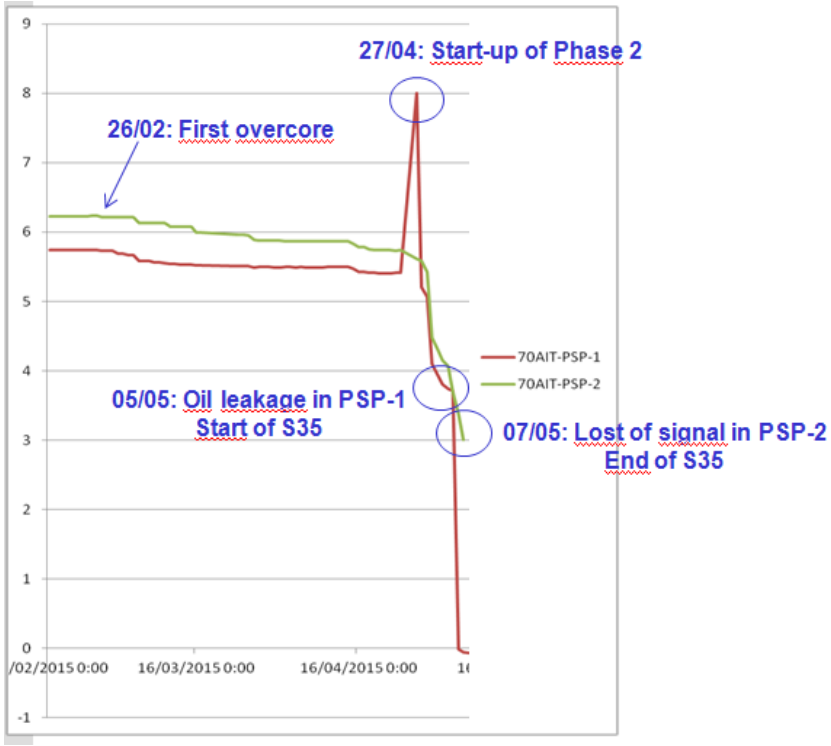


Fig. 28: Record of PSP pressures in MPa during excavation up to 7th of May.

Sampling of Section 35 was performed from 05.05.2015 to 07.05.2015. Bentonite/shotcrete interfaces were drilled with a manual drilling tool in several pieces of 5 cm in diameter.

Bentonite parts presented a bluish colour in the sample part closer to the rock (BC-C-35-2). Concrete and bentonite/concrete bulky pieces (C-S and BC-S) were taken by hand in the planned spots from the excavated parts. BC-S-35-1 was taken in two concrete samples and a bentonite one.

One sample of shotcrete (C-S-35-2) and a few bentonite/shotcrete samples (BC-S-35-2 to 6) were added and taken as agreed with the corresponding partners on-site. The two shotcrete/rock interface samples (CL and CG) were not taken at this time and some amount of shotcrete was left at the planned positions for doing it later on.

This second part of the plug dismantling was done in about 8 workdays; see final status in Fig. 29, making a total of 14 days for the whole plug and related sampling. The whole process is considered to be fast and safe. However, the vibration induced by the robot and the necessary spraying of water to avoid the dust certainly impacted on the successful sampling of an intact shotcrete/rock interface.

Fig. 29: Plug dismantled and dummy face exposed.

4.7 Sampling of the concrete/buffer interface

The concrete/buffer interface of the experiment was represented by Sampling Section 36 (bentonite layer 74) or instrumented Section P. This section was sampled from 07.05.2015 to 13.05.2015. Both pressure cells (PSP-01 and PSP-02) presented good condition but PSP-01 (S-S-36-1, see Fig. 30) was hit during the coring of CC-34-9 producing an oil leakage and loss of data reliability whereas PSP-2 data remained consistent until removal on 07.05.2015 (see Fig. 28).

Fig. 30: View of PSP-01 before removal.

In general, bentonite core samples were taken with a manual drilling tool provided with a suitable crown and obtaining samples of about 4.5 cm in diameter. Sample B-C-36-1 was shifted from the planned position in the centre of the block downwards to avoid hitting sensor WCSQ-03. B-C-36-3 was taken twice because the border between blocks was not clearly distinguished. A new sample (B-C-36-5) not included in the plan was taken on the interface with PSP-01 (see Fig. 31).

Fig. 31: Emplacement of B-C-36-5 in the interface of PSP-01.

Bentonite blocks (B-B-36-01 to 09) were taken quite complete, in two or maximum three big pieces. The exception for this was B-B-36-6 which is the one located just below the liner.

In agreement with the corresponding partner (BGR) sample BC-S-36-1 was not taken but samples B-S-36-1 to 3 were taken instead on 12.05.2015 (Fig. 32). They consisted of some bulky pieces of bentonite along a radius.

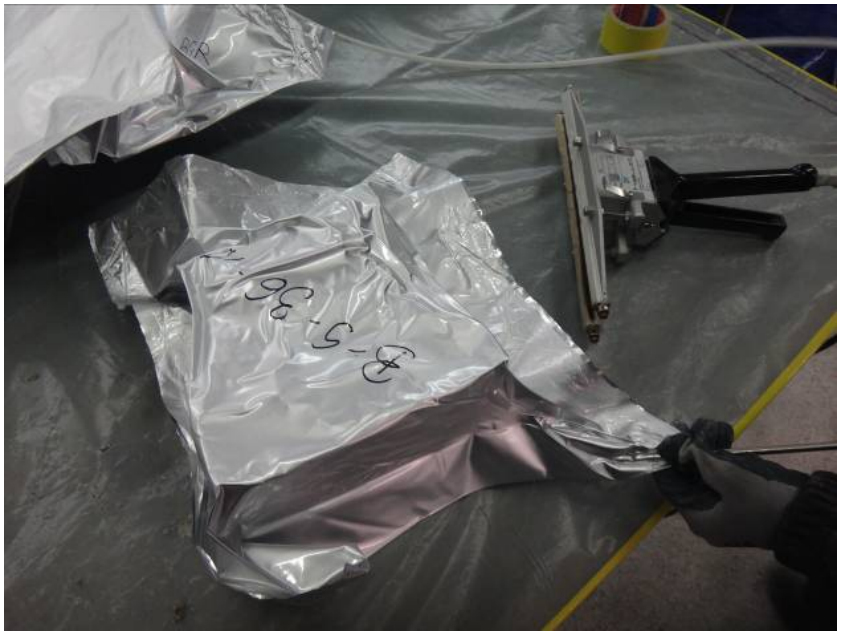


Fig. 32: B-S-36-1 packaging.

Samples BG-S-36-2 and 3 (sampling for tracers: iodided paper) were shifted to bentonite layer 73 because no paper could be retrieved in layer 74 at the planned positions.

4.8 Removal of "dummy canister"

4.8.1 Dismantling of bentonite layers

Initially it was planned to remove the "dummy canister" before starting the dismantling of the bentonite around the liner, but this was not possible because it was stuck to the liner (see Fig. 33) due to the pressure formed by the bentonite and the intrusion of bentonite in the inner gap by the holes of the liner. Therefore, after the removal of the shotcrete plug and stating that the dummy canister could not be removed as expected, the bentonite layers from 74 to 66 around the first liner segment were dismantled (see Section 4.8 and 4.9). These dismantling works were performed from 12.05.2015 to 22.05.2015.

Fig. 33 View of the "dummy canister" (left) and its adhesion to the liner segment (right).

Before finishing the removal of bentonite layers around the liner, the set "liner + dummy canister" was secured with a steel support (Fig. 34) located at the bottom.

Fig. 34: Steel support for the dummy canister.

4.8.2 Removal of the set "dummy canister" and liner

On 26.05.2015 the "dummy canister" plus the surrounding liner section were extracted. The manoeuvre was made with the help of a light wagon that was placed directly on the gallery floor and below the liner. A hydraulic jack was used, emplaced beneath the outer side of the canister, in order to move the assembly up and down facilitating the extraction of one liner segment from the next one.

Once the "dummy heater" was liberated, it fell down into the wagon. With the help of the traction wire and two steel guides put under its wheels, the wagon was carried over the fixed tracks and it could be moved to the gallery entry where the liner was sampled and the set liner + canister was packed and stored (see sequence in Fig. 8).

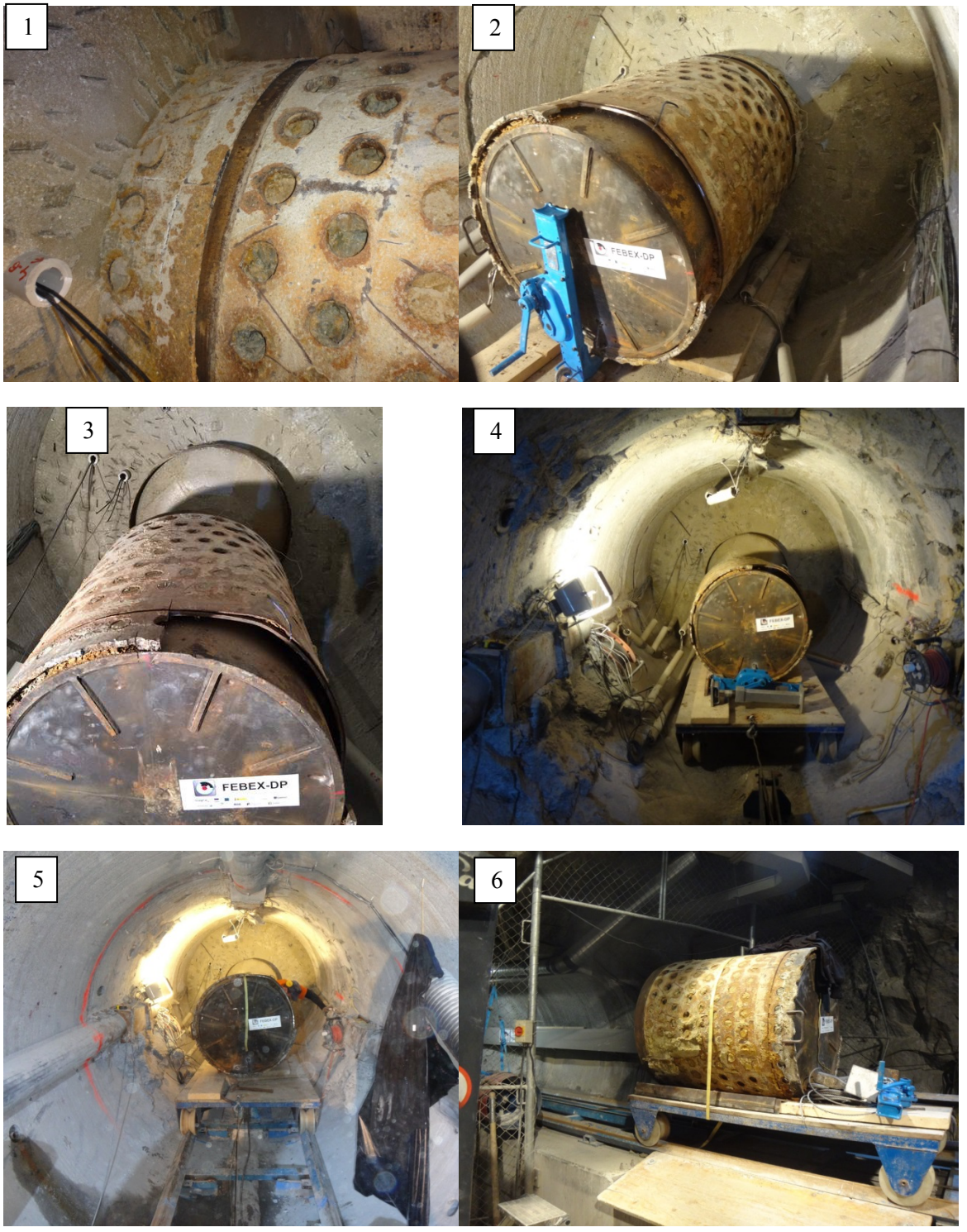


Fig. 35: Photographic sequence of the "dummy canister" extraction.

4.8.3 Sampling in bentonite

Three sections were sampled in this part of the buffer dismantling, from Section S36 to Section S38. Every section was located in a given bentonite block layer or slice.

As planned, two electric percussion hammers were used for the removal of the bentonite layers. As a general rule, two blocks of the inner ring were broken first and removed in order to facilitate the extraction of the surrounding ones.

Dismantling operations in the buffer zone were performed by coordinating sampling needs with the scheduled excavation times. Consequently the excavation/dismantling of bentonite blocks was continuously adapted to sampling needs but it was tried not to slow down the excavation progress too much and not to jeopardize samples' quality.

Therefore, the work was organized so that every day the target bentonite layer was sampled according to the corresponding plan and procedures. Then samples were wrapped and packed as soon as possible to avoid further losses of water. Finally, details about the sampling were documented. Daily work concluded by leaving in place at least one bentonite layer before the next sampling section in order to avoid an exposition to the drift conditions. For the same purpose, ventilation in the working area was minimized to prevent samples from getting dryer.

The instruments contained in the dismantled bentonite buffer were also sampled for analysis but the ones installed in the rock walls or boreholes were left in place, as for instance the total pressure cells installed in the granite wall.

Due to a variety of causes, some changes occurred in the planned sampling program as described hereafter:

- Sampling Section S36, located in bentonite layers 74 and 73:
  - BC-S-36-1 was not taken but it was substituted by three pieces located along a radius and cut out by hand (B-S-36-1 to 3).
  - Sample B-C-36-3 was taken twice (3A and 3B) as the required interface between blocks could not be clearly identified.
  - A new sample not foreseen in the sampling plan was taken (B-C-36-5).
  - Samples BG-S-36-2 and 3 could not be taken from the contact between bentonite layer 74 and rock, so they were taken from layer 73. No iodide papers could be retrieved after finishing the removal of layer 74 at the required points (shifted to next layers).
- Sampling Section S37, located from bentonite layer 70 to 68:
  - As it was impossible to take bentonite blocks B-B-37-1 to 3 intact it was agreed to substitute them for 12 cores of bentonite following a radius. These cores were taken not in layer 70, but in the next one (bentonite layer 69).
  - A new bentonite sample (B-S-37-1) was taken. It consisted of a piece of bentonite between the liner and the "dummy canister" showing corrosion products. It was taken where the liner was remarkably curved (see Fig. 33, upper right).
  - A complete block with iodine paper adhered was also taken (BG-S-37-4).
  - Samples of iodine paper, BG-S-37-1 to 3 were taken between bentonite layers 68 and 70.

- Sampling Section S38, located in bentonite layer 67:
  - At this step it was agreed to skip the planned Sampling Section S40 (comprising 4 cores samples) and move those core samples to Section S38. So samples B-C-40-1 to 4 were converted to samples B-C-38-1 to 4.
  - A new sample, B-S-38-1, was taken from the vicinity of the extensometer anchorage, showing two different corrosion areas, see Fig. 36.

Fig. 36: Area sampled for new B-S-38-1.

  - Removal of sensors S-S-38-6 and S-S-38-16 was not done because the dummy canister was still in place (see removal sequence in Fig. 37).
- Sampling Section S39 was planned in bentonite layer 66 but due to the presence of the dummy canister it was agreed to move the samples to bentonite layer 64.

All changes introduced in the sampling plan were agreed with the involved partners. An updated description of the final location of samples in all sections is given in Annex.

Fig. 37: Photos of sampling around the dummy canister.

Photos 1 and 2 show sampling operation and layer dismantling. Photo 3 shows extensometers ready to be dismantled. Photo 4 shows microbiological sampling.

4.9 Removal and sampling of bentonite and liner up to the front of the heater #2

4.9.1 Dismantling of bentonite layers

Once the dummy canister was successfully removed, the bentonite layers between slices 65 and 60 were dismantled too. This completed the planned dismantling of approximately 1.9 meters of buffer to reach the front side of heater #2, that is, 14 layers of bentonite blocks from slice 74 to 60. The rules and procedures applied are the same as described in previous sections.

Blocks not required for analysis were dumped in the site dump wagon, located close to the bentonite buffer front. Once the dump wagon was filled, it was transported along the drift up to the drift entry were the bentonite was dumped into a container placed nearby the concrete platform outside the drift (Fig. 38). When three or four containers were full, the waste bentonite was transferred to an authorized dump site outside the GTS using a truck. About 14 t of bentonite were dumped during the dismantling operation carried out between the concrete plug and the front of heater #2.

Fig. 38: Dumping of bentonite debris.

The x local coordinates for each bentonite layer were registered by means of a laser located at the x = 0 coordinate (Fig. 39, right side). Measurements were taken in three places: along the left and right rock walls (mid-height), with the laser device and at the upper part of the bentonite front using the metric tape placed during FEBEX installation (Fig. 39, left side). Also, each bentonite layer was fully documented (taking photos, making sketches, logs and records of the operations and samples see Section 4.11.3).

Fig. 39: View of the metric tape (left photo) and the laser device (right photo).

At this stage some observations from the buffer dismantling can be pointed out:

- The measured x coordinates were smaller than the ones taken during the construction phase (see Section 4.11.3), with differences decreasing from about 5 cm in bentonite layer 70 to

2.4 cm in layer 60. Small longitudinal grooves in the direction of the gallery axis could also be observed on the surface of the bentonite in contact with the rock, and in the thin film of bentonite that remained adhered to the rock in the already dismantled area (see Fig. 40). These observations suggest a displacement of the buffer (or at least of the exposed part of it) towards the drift entry.

Fig. 40: View of longitudinal marks on the bentonite layer adhered to the gallery.

- As expected, no free water was observed at the bentonite/rock interface, or in the exposed rock in this section.
- The bentonite showed a solid appearance, even in the area close to the rock. No mud or gel was found. The blocks seemed to be quite dry in the centre, producing dust when drilled, and became more humid in the outer ring with a noticeable darker cold grey colour. The consistency of the outer ring was much waxy, while in the inner ring the texture was more friable (less cohesive).
- All the construction gaps were completely closed (see Fig. 41) including the gaps between the blocks, around cables and around sensors (see "Extra Report 7 - The disappeared gaps in bentonite layer 45" (Kober 2015b)).

Fig. 41: View of bentonite layer 63 after installation (left) and during removal (right), Section 41.

Note the gaps closure.

- The outer rings were less visibly segmented compared to the inner ones but even in these outer parts the blocks could be separated at the joints and showed a good mechanical integrity.
- Inner ring blocks were more friable than the outer blocks, so they were difficult to take intact

4.9.2 Sampling in bentonite

The bentonite was sampled in two sections during buffer dismantling, namely Sections S39 and S41, and as explained in Section 4.9 sampling Section S40 was skipped. Again, some changes were necessary in the planned sampling program as described below:

- Sampling Section S39 was planned for bentonite layer 66 but it was agreed to move the samples to bentonite layers 65 and 64 due to the presence of the dummy canister (see Fig. 42):
  - Two blocks, not foreseen in the sampling plan, were taken from bentonite layer 65 at the outer ring.
  - Due to the new location in layer 64, it was possible to sample the blocks emplaced inside the liner and additional cores from B-C-39-37 to B-C-37-56 were taken for analysis. Details about the sampling procedure can be seen in Fig. 43.

Fig. 42: View of bentonite layer 64 during dismantling.

Fig. 43: Details of the bentonite sampling.
Drilling machine at the left side and obtained core at the right.

- Sampling Section S41, was taken as planned in bentonite layer 63:
  - Two not foreseen samples were taken, BM-B-41-1 and 2, consisting in bentonite blocks in contact with the liner and showing some diffusion of oxidation products (Fig. 44).

Fig. 44: Details of the colour aureoles of Fe-oxidation/reduction fronts close to the liner.

4.10 Extraction of heater #2

4.10.1 Equipment used

The machine used for the extraction of the heater from the liner and for its transport along the drift was based on the same one that was used for the emplacement (Fuentes-Cantillana & García-Siñeriz 1998b) and modified already for heater #1 extraction. Modifications included the replacement of the originally installing pushing mechanism for a new system intended for pulling the heater, and the introduction of some capability to adjust the height of the machine.

A general view of the modified equipment is shown in Fig. 45. The basic structure of the vehicle is a robust, low profile chassis having a bed of rollers and rolling balls, adapted to the dimensions of the heater. This chassis, which is basically the same one that was used for the emplacement operation was modified in the bogies' zone, in order to incorporate the possibility of regulating the height of the rolling bed base line. Instead of having a fixed connection, the link between the bogies and the chassis consists of 16 studs that provide a height variation capacity of approximately ± 25 mm, in relation to the original reference level. Also the clamps used to fix the vehicle to the tracks were made more robust, in order to absorb the potential reaction forces that might be generated during the extraction operation.

Fig. 45: Extraction car.

The pulling system was simple and robust too, based on a hydraulic winch installed on board of the vehicle that pulls the heater using a steel rope and a return pulley. The return pulley was attached to the heater front by means of four M20 bolts, using the four threaded holes already existing at the bottom part of the heater front cover, and by welding its support plate to the heater. The winch pulled on it using a steel rope fixed at the other end to the main chassis.

The hydraulic power group, which was also installed on board of the vehicle, allowed for continuous regulation of the pulling force of the winch, such that it was possible to adjust it to the minimum value required to extract the heater. A tensile load sensor was installed at the rope attachment point in order to measure this force.

4.10.2 Main concerns

In view of the difficulties found to extract the "dummy canister" the main concerns regarding the heater extraction operation were:

- Although only limited corrosion and bentonite intrusion in the liner/heater gap were initially expected, because of rather low humidity in the inner part of the buffer throughout the entire operational phase due to the heating effect, when this corrosion and bentonite intrusion of the liner/dummy canister is extrapolated to the heater #2 a larger pulling force than planned might be required to separate them. However, the conditions of the dummy were different: lower temperatures and therefore higher humidity in the buffer.
- In the same way, the potential risk of the liner being deformed by the swelling pressure of the bentonite was not considered relevant initially, since the pressure values recorded at the liner contact were relative low, but again the deformation found in the liner for the "dummy canister" led to consideration of this risk too.

4.10.3 Extraction operation

The extraction of heater #2 took place on 04.06.2015. Once all the bentonite in the previous sections was removed (up to bentonite layer 59) and the heater front cover was uncovered, an initial inspection of the heater situation was carried out (Fig. 46 and Fig. 47).

Fig. 46: View of the uncovered heater front.

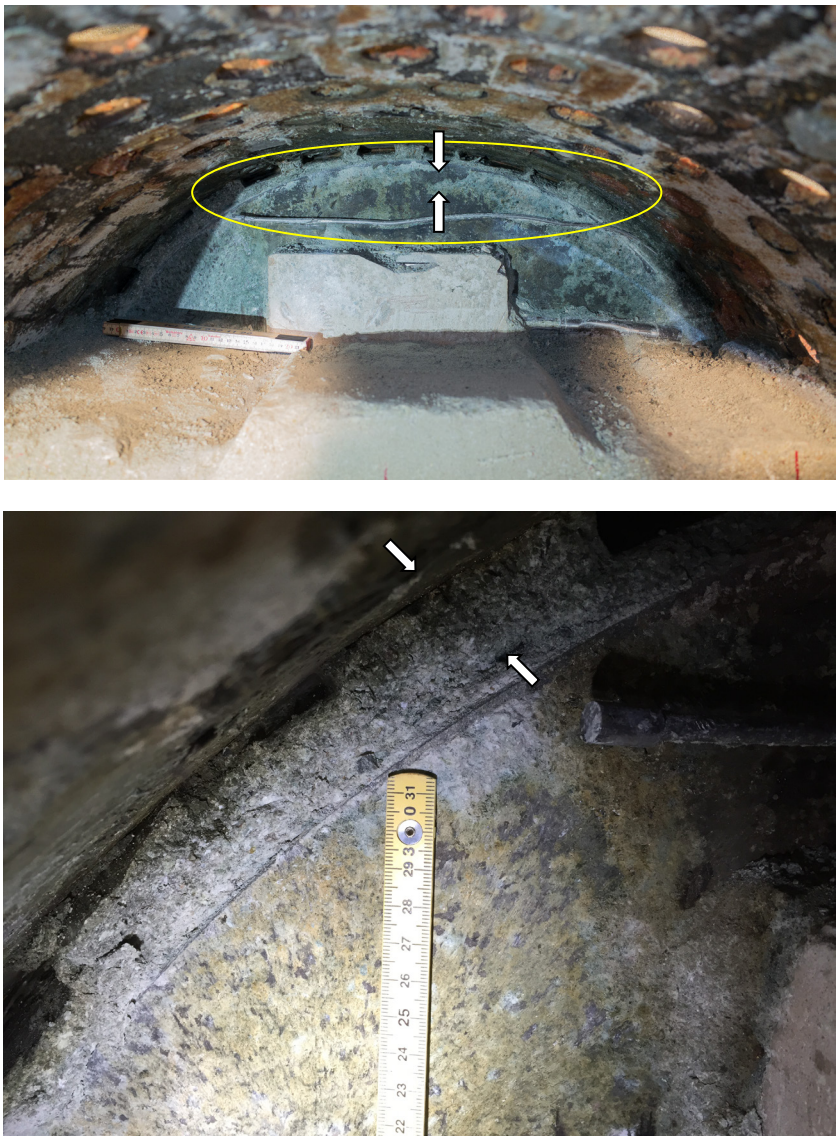


Fig. 47: Detail of the gap filled with bentonite.

The heater was found quite dry but the gap with the liner was filled by bentonite (Fig. 47). Some attempts were made to ascertain the extension of the bentonite along the gap with no success. However, no special difficulties were identified for beginning the extraction of the heater, so the last segment of the track was installed, leveled to the reference position and fixed to the rock floor with spit bolts, reaching up to the bentonite front.

The heater extraction car was adjusted to the nominal level, and it was then introduced into the drift and taken to its position in front of the heater (Fig. 48, left photo). Once in position, it was fixed to the tracks using the clamps located at the rear part, although the slight deviations between the last track segments made it impossible for the clamps to be completely fixed.

The return pulley of the pulling system was fixed to the front cover of the heater by means of four M20 screws, using the four corresponding holes existing in the heater frontal lid that were in relatively good conditions (Fig. 48, right photo). The silicone rubber that had been injected at that time for protection was loose and deformed, but the holes and the threads were dry,

showing some amount of oxidation dust only. The holes were cleaned and tapped again, and the bolts were introduced without any problem. To increase the safety of the attachment, the end plate of the return pulley assembly was welded to the front cover of the heater.

Fig. 48: View of the extraction car already positioned for the extraction manoeuvre (at the left) and detail of the return pulley installed at the heater front (at the right).

Once the return pulley assembly was safely fixed, the pulling system was put in operation and the heater was extracted gently (see Fig. 49, left photo). The peak pulling force recorded was about 4.6 t at the moment of mobilization and decreasing later to 3 – 4 t during the rest of the extraction.

Fig. 49: Extraction of heater #2 (at the left) and general view of the heater at the drift entry (at the right).

The heater appeared to be dry and with little and quite homogenous corrosion. A red dust covered the body of the heater, together with particles of bentonite fallen from the buffer on top of the canister (Fig. 50). The extraction car with the heater #2 was left at the entry of the drift during the rest of the dismantling phase and the heater was enveloped with plastic film in order to preserve as much as possible its conditions.

Fig. 50: Bentonite drops on top of heater back part.

Looking inside the liner all around the former heater location, the bentonite had penetrated the liner perforations at both ends but not in the centre and it was clearly visible (Fig. 51) (see "Extra Report 6 - Impressions from the FEBEX-DP heater retrieval" (Kober 2015b).

Fig. 51: Inner view of the liner once the heater was extracted (left photo) and detail of the bentonite protrusions inside the liner (right photo).

After the extraction of the heater and the collection of the protruding bentonite samples, the front of the liner was closed with a plastic plug (white color in the photos) and the inner temperature and humidity was registered, for further details consult NAB 16–012 (Villar et al. 2016).

The liner showed the same corrosion aspect as the heater body. No significant vertical movement of the liner (and heater) was found because the distance to the rock floor was the same as recorded during the installation. A small deformation was observed in the liner, which had enlarged in the direction of the vertical diameter (Fig. 52).

Fig. 52: Measurements made on the liner segments were the heater was placed and on the previous one.

4.11 Removal and sampling of the remaining bentonite and liner

4.11.1 Dismantling of bentonite layers

After the extraction of heater #2, the buffer dismantling continued up to the end of the FEBEX gallery. Approximately 7.5 m of buffer length was dismantled in this phase, comprising 59 bentonite layers, from slice 59 to slice 1. As usual, the layers were dismantled one by one, and the planned sampling programme was carried out at the same time. The same tools and procedures used so far for dismantling and sampling were applied, but in this case the blocks in the ring around the liner were broken first.

Four liner sections were removed during this part of the dismantling. When one section of liner was nearly released from the surrounding bentonite, the segment was secured in order not to fall down. A provisional track was then placed from the end of the fixed tracks to the bentonite front. Using the provisional tracks, a light wagon was placed and fixed under the liner to be removed. The liner segment was then moved with the help of levers, chains and jacks until its liberation from the next segment. Once liberated, it fell down on the wagon, where it was secured and transported to the gallery entry, where the planned liner samples were taken (see detail in Fig. 53).

Fig. 53: Dismantling of a liner section.

The x local coordinate was registered at both sides of the gallery in those layers where the liner existed and at 5 points aligned in the horizontal diameter when the liner section was ended. Each layer was also completely documented (see Section 4.11.3).

Fig. 54: Sequence of views of the bentonite front from the heater #2 front to the end of the gallery.

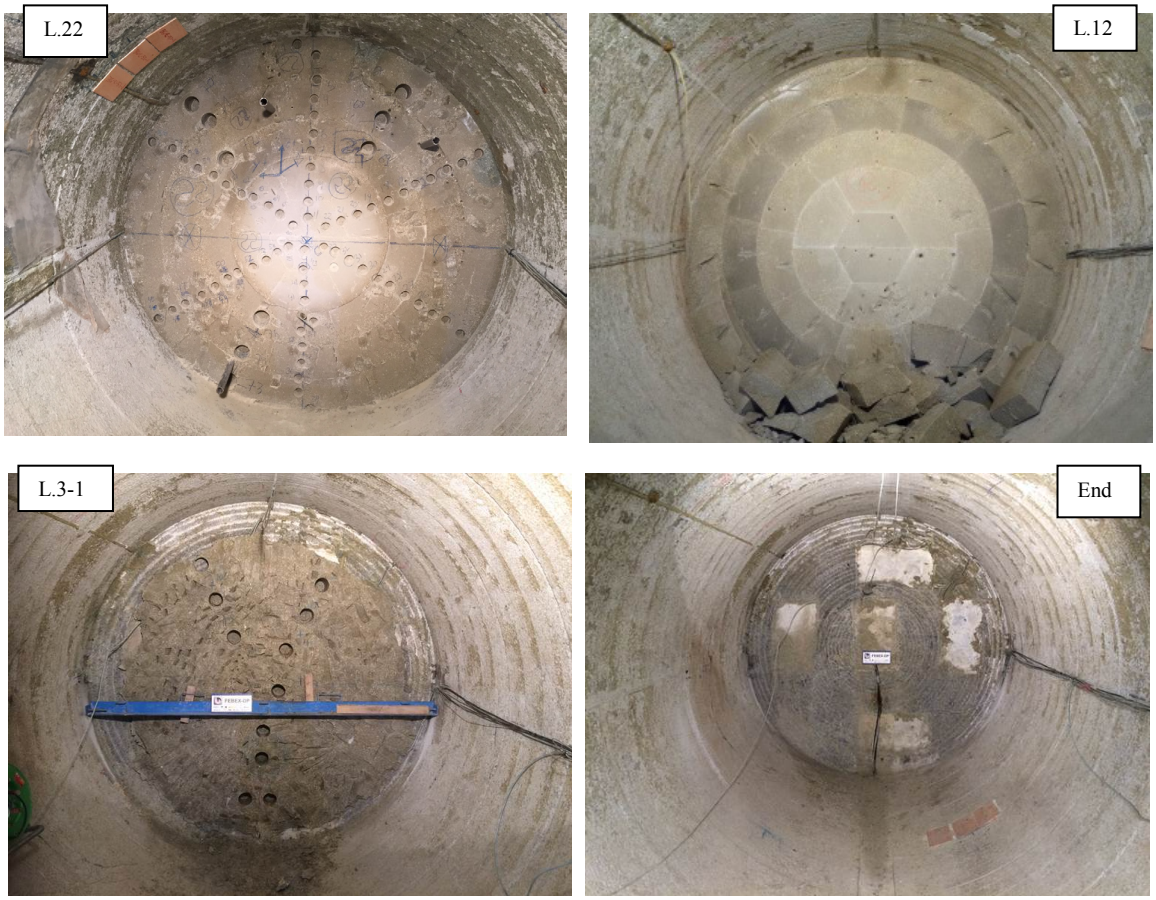


Fig. 54: Cont.

The following observations can be made for this buffer section (see Fig. 54):

- Junctions between the different liner sections showed a gap between 5 and 10 mm.
- Again, measured x coordinates were smaller than the ones taken during the construction phase, with differences increasing from about + 2.4 cm in bentonite layer 59 to - 4 cm in the final layers, likely because of the higher construction voids left in the first slices (see Section 4.11.3).
- The appearance of the bentonite in the heater length section was rather solid, drier in the inner ring in contact with the liner and more humid and darker in the outer ring. From the dismantling operations it also looked more humid in the left upper part of the front all the way.
- From bentonite layer 60 and on, the humidity decreased towards the centre of the heater, keeping constant from the centre to the end of it.
- The inner blocks located in contact with the rear part of the heater where found protruding about 4 – 5 cm inside the liner, showing a belly that continued for 3 layers being progressively less accentuated (Fig. 55).

Fig. 55: Protruding bentonite in the centre of the buffer.

- From the back lid of the heater section, the bentonite blocks where dryer and very easily removed, noticing a very light increase of humidity up to bentonite layer 7. From this layer, humidity increases significantly and the last 4 layers looked completely saturated and appeared like plastic, probably due to the higher voids content in this part. These observations are only qualitative, being the result of the impressions taken during the dismantling.
- No mud, gel or free water was observed, except for:
  - When uncovering bentonite layer 56, an observation borehole at the upper part of the gallery started leaking.
  - The area around the crack meter, (bentonite layer 45), whose case was found filled with water.
  - At the end of the gallery where free water and bentonite mud was detected in contact with the gallery walls (see Kober 2015b) for more details about lamprophyre inclusions and granite cracks in the gallery).
- Block joints were clearly distinguishable in the inner and intermediate ring but all gaps between blocks, at the rock contact and in the cable channels were closed (Fig. 56). The exception for this observation were the last 7 bentonite layers where joints began to be more difficult to observe up to bentonite layer 3 from where it was not possible to differentiate the block joints. Also in the last layers the appearance of the blocks was waxier (see Fig. 57).

Fig. 56: Views of the insertion of inner blocks inside the last liner segment. The blue line shows the step between outer blocks and inner blocks.

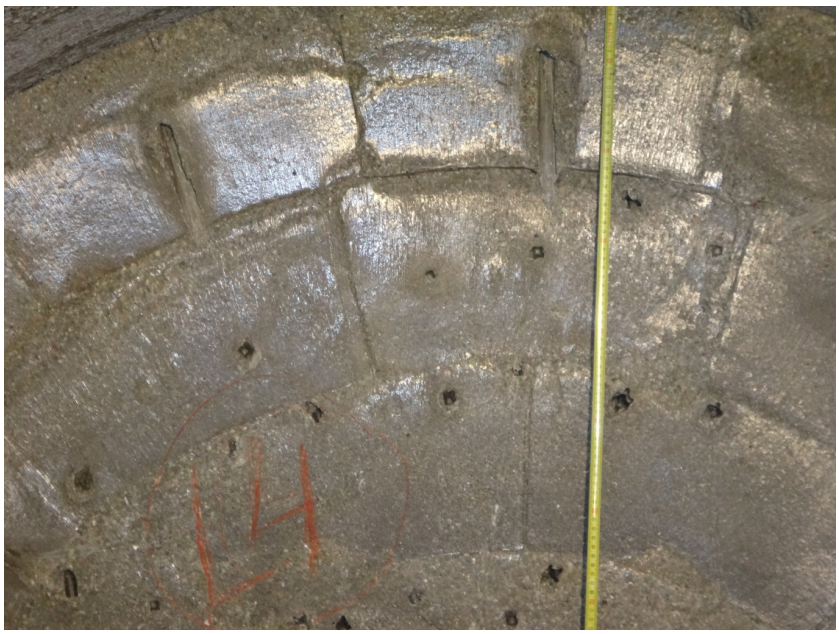


Fig. 57: Waxy aspect of blocks in L4.

- Once the liner section was finished, bentonite blocks were extracted more easily. It was noticed that blocks where much less adhered between them and it was possible to dismantle three or four at the same time.
- The last bentonite layers (4 to 1) were found detached from the drift end while they were being dismantled (Fig. 58). There was a gap of about 3 – 5 cm between the end of the drift and the layer which seemed to be enlarging and was likely due to the release caused by the dismantling of the remaining buffer. It made it necessary to secure the whole set of layers with a metallic bar anchored to the gallery walls to keep them in place. Consequently, x local coordinates measured for these layers are not reliable.

Fig. 58: View of the bentonite detachment at the end of the gallery.

4.11.2 Sampling in bentonite

A total of 21 sections were sampled in this step, from Section S42 to S62. The daily routine was the same as for the previous buffer section.

About 53 t of bentonite were dumped during the dismantling operation between the heater #2 front and the gallery end. The sampling of the entire sections could not be completed in some cases in one run, for instance when three sampling sections occupy three consecutive bentonite layers. In those cases the procedure was modified in order to avoid the exposition to the air of any sampling area by simultaneously sampling various bentonite layers areas by quarters.

The operation of extracting the three intact blocks in one radius proved to be quite difficult as they were strongly confined between the liner and the rock (this difficulty became less when advancing towards the end of the gallery). In some cases due to the difficulty of this extraction it was decided to take cores from the inner block and then break the remaining pieces in order to release the pressure between blocks and allow the removal of the other two (Fig. 59).

This method proved to be too slow, so the best solution when possible was to break and remove the blocks at the adjacent radii in order to allow the extraction of the blocks from the sides. It was especially difficult to extract inner ring blocks in one piece due to their dryness. In those cases (3 or 4 pieces), the block was rebuilt and packaged as a whole.

Fig. 59: Extraction sequence of blocks by taking cores.

Some rock/bentonite sampling was also carried out during this part of the sampling process. As it was not possible to sample the whole core in one go, it was decided to extract the bentonite part first, then mark the area at the wall where the continuation of the sample had to be taken (in the same position were the corresponding bentonite sample had been taken) and finally to protect the rock area with a wooden plate sealed with silicone. Rock samples were taken when the dismantling of the liner sections provided/left/enabled enough space for installing the drilling machine (Fig. 60).

Fig. 60: Granite sampling.

A similar procedure was performed when sampling the bentonite/liner contact: first the bentonite part was sampled and then, when the liner segment could be retrieved, the metal part was cut outside of the gallery (Fig. 61).

Fig. 61: Cutting the liner for metallic samples.

A list of incidents and changes with regard to the sampling plan for each sampling section is includedbelow:

- Sampling Section S42, located in bentonite layer 59:
  - BG-C-42-1 and 2 were supposed to be sampled as cores, but finally were set as swab samples. The swab procedure was not successful, so it was agreed that it will not be used anymore.
  - Several additional samples were taken:
    - BM-S-42-4, sample from the inner blocks in contact with the liner
    - B-S-42-4, composed of two samples in contact with the outer part of the liner
    - B-B-42-4 and B-B-42-5, blocks for the inner part of the liner
    - BM-S-42-Pxx, 10 protrusions of bentonite inside the liner holes
    - M-S-42-1, a piece of resistor cable and duct

Fig. 62: Pushing of Shelby tubes while Sampling Section S42.

- Sampling Section S43, which was located in bentonite layers 57 and 54:
  - Cores B-C-43-37 to 42 where sifted to bentonite layer 54.
  - BG-C-43-1 to 3. Due to the impossibility of taking cores composed by bentonite and granite in only one operation, it was agreed to take first a piece of bentonite in contact with the drift wall (bentonite side). Then the corresponding positions of the cores were marked in the bentonite piece and in the gallery wall. The granite from the gallery wall was protected with a wooden sheet sealed with silicon. Once the dismantling operation advanced and provided/enabled/left space for the installation of the drilling column, the previously marked granite cores were taken. It was not possible to take cores of more than 2 cm in length without using water.
  - BM-C-43-1 to 3. A similar procedure as for the previous samples was used. A bentonite piece was sampled first containing the bentonite sides of the cores and their positions were marked and protected in the liner surface. Once the liner section was extracted, the marked section was cut with the plasma device outside of the gallery.
  - Two new samples not foreseen in the sampling plan (M-S-43-1 and 2) were taken. They consist of metal segments of a drill bit lost during the installation phase.
- Sampling Section S44 that was located in bentonite layer 53:
  - New core, B-C-44-7, was taken while the rest of foreseen cores at S44 were shifted to other locations of the same bentonite layer.
  - The block B-B-44-2 was substituted by 8 cores (5 mm diameter) taken from it due to the impossibility to remove it in one piece.
  - The block B-B-44-11 was substituted by 8 cores (5 mm diameter) taken from it due to the impossibility to remove it in one piece.
  - BM-S-44-4 was an extra sample not foreseen in the sampling plan
  - B-S-44-2 was not taken.
- Sampling Section S45 was located in bentonite layer 49:
  - Samples BM-D-45-1 and 3 were not taken.
  - Samples M-H-45-1 to 4 had to be taken in the heater. It was agreed that any sample from the heater would be taken in AITEMIN's workshops once the dismantling

operations were finished and the heater transported back to Spain (see Fig. 63). Besides, finally these samples' number and positions for the heater #2 samples were changed.

Fig. 63: Metallic sample from heater in Spain.

- Sampling Section S46, which was located in bentonite layers 46 to 44:
  - A new block (B-B-46-5B) was sampled just facing the fisurometer due to the presence of oxidation products in it.
  - B-C-46-1 to 10 were cores supposed to follow the TDR sensors along its whole length (Fig. 64). It was decided to split these cores in two samples: -A for bentonite layer 45 and –B for bentonite layer 44.

Fig. 64: Cores taken following the TDR sensors inside the bentonite buffer.

- Sampling Section S47 that was located in bentonite layers 44 and 43:
  - A new set of samples, not foreseen in the sampling plan, where taken around the fisurometer (Kober 2015b), see Fig. 65.
  - BG-C-47-1 and 2 where not taken at bentonite layer 44, but 43.
  - B-C-46-1B to 10B were the continuation of cores B-C-46-1A to 10A from layer 46.

Fig. 65: Left, samples taken around fisurometer. Right, view of fisurometer location once the protective cap has been removed.

- Sampling Section S48 was located in bentonite layer 42:
  - B-C-48-12 was a core for microbiology analysis that finally was not possible to obtain in good conditions so it was discarded.
  - One of the metallic coupons (M-S-48-3) set was broken before dismantling (see Kober 2015b).
  - B-M-S-48-1 was not taken.

Fig. 66: Metallic coupons in S48.

- Sampling Section S49, located in bentonite layer 40: there are no relevant modifications in this section.
- Sampling Section S50, which was located in bentonite layer 37:
  - B-B-50-2 and 5 were taken as four cores and the rest of the block in order to allow the removal of the rest of the blocks in the same radius.
  - It was foreseen to take around 32 samples of iodide paper in the interface between the bentonite and the rock, but due to the state of the paper it was agreed to diminish this number (8 samples were finally taken).
- Sampling Section S51was located in bentonite layer 32:
  - Three new blocks were taken B-B-51-7 to B-B-51-9.
  - It was foreseen to take around 32 samples of iodide paper in the interface between the bentonite and the rock, but due to the state of the paper it was agreed to diminish this number (8 samples were finally taken).
- Sampling Section S52 that was located in bentonite layer 31:
  - A number of new samples were agreed: blocks B-B-52-1 to 3 and cores for microbiology analysis (B-C-52-37 to 45).
  - Samples M-H-52-1 to 4 had to be taken in the heater. It was agreed that any sample from the heater would be taken in AITEMIN's workshops once the dismantling operations were finished and the heater transported back to Spain. These samples' number and positions for heater #2 were changed (see Annex).
- Sampling Section S53, which was located in bentonite layer 28:
  - New samples to evaluate gaps between blocks were taken (B-C-53-27 and 28).
  - The liner part of samples BM-C-53-1 to 3 was not taken.

  - Locations of cores B-C-53-1 to 6 were changed with respect to the original sampling plan.
- Sampling Section S54 was located in bentonite layer 24:
  - New samples for microbiological analysis were taken (B-C-54-22 to B-C-54-30).
  - New samples of protrusions inside the liner holes (BM-S-54-P1 to P17).
  - Extra samples around the extensometers SHSD2-01 and 03 were taken (Fig. 40).

Fig. 67: Extensometer in S54 and reconstruction of samples behind it.

- Sampling Section S55 that was located in bentonite layer 23:
  - New samples were taken, the vertical diameter of blocks (BB-55-1 to 10).
  - Core B-C-55-1 was not taken.
- Sampling Section S56 was located in bentonite layer 22:
  - 9 new samples for microbiological analysis were taken (B-C-56-67 to 75).
- Sampling Section S57, which was located in bentonite layer 19 (Fig. 68):
  - Cores B-C-57-1 to 6 were taken from a different location than initially planned
  - A new sample containing carvings in the bentonite was picked.

Fig. 68: Protection of Section S57 before beginning of its sampling.

- Sampling Section S58 was located in bentonite layers 15 to 13:
  - New blocks sampled in bentonite layer 13: B.B-58-1 and 2.
  - New blocks sampled: B-B-L15-1 to 4 and B-B-L14-1 from bentonite layers 15 and 14 respectively.
- Sampling Section S59 located in bentonite layer 8 (Fig. 69): no changes regarding the sampling plan.

Fig. 69: Partial dismantling of S59.

- Sampling Section S60, which was located in bentonite layer 5:
  - It was decided not to take samples BG-C-60-1 and 2.
- Sampling Section S61 that was located in bentonite layer 4:
  - Sample BG-C-61-2, the granite was cut with the help of a radial saw because the drilling bit was broken in the previous granite coring (see Fig. 70).

Fig. 70: Granite cut made with radial saw.

- Sampling Section S62 located in bentonite layers 1 to 3:
  - New samples for microbiological analysis: B-C-62-1 to 13. Due to concave shape of the end of the gallery, some of the cores could not be taken (those at the outer ring of blocks i.e 1, 5 and 9)

4.11.3 Recoded bentonite layers displacement

When representing the x coordinate of the bentonite layers taken from the construction with the ones recorded during the dismantling the graph given below is obtained, where positive values indicate a displacement towards the gallery entry, while negative values indicates a displacement towards the end of the gallery (Villar et al. 2016).

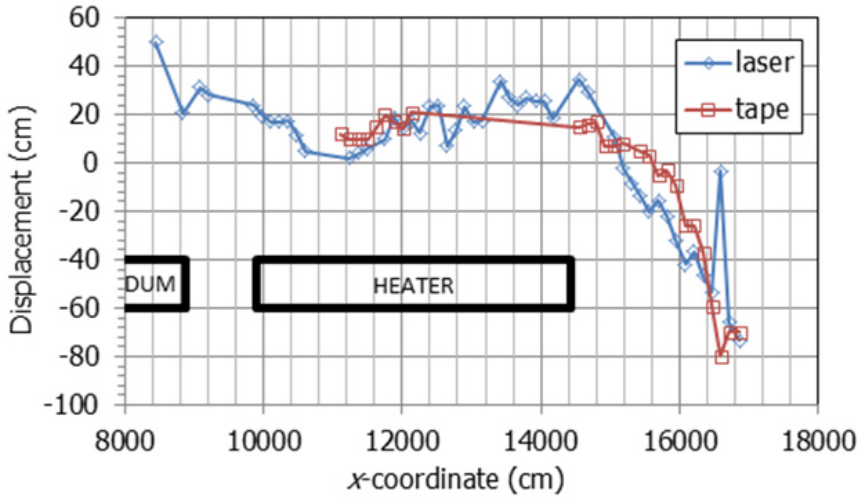


Fig. 71: X coordinates difference between measured while dismantling and as built for the two type data taken: laser measurements and metrical tape on the gallery.

5 In situ analysis

5.1 Equipment used

The laboratory that was installed for the planned in situ analysis of water content and dry density of the bentonite samples consisted of following equipment:

- Weighing scale with 2'000g of range and 0.01g of accuracy
- A natural convection oven of 100 l capable of reaching 200 °C
- Thermo hygrometer with range of -5 °C to 50 °C and 20 % to 95 % RH

Auxiliary tools:

- Brush to remove all the shavings
- Cutting tools as knifes, cutter, palette knife and saw.
- Clock to control the time it took to analyse the sample.
- Safety accessories such as a mask with Mercury vapors filter and gloves.
- Analysis tools such as liquid mercury, stainless steel vessel, calibrated table, containment tray, pyrex vessels, syringe and glasses.

As shown in Fig. 72, the laboratory was installed in a ventilated place of GTS, very close to the location of the computers that control the FEBEX in situ test, due to use of mercury for the in situ analysis. The floor was covered with a plastic carpet (blue colour in the figure below) to contain the mercury in case it would overflow from the trays by accident.

Fig. 72: In situ laboratory, general view at the left hand side and detail of the equipment at the right.

In order to complete the collected data, two portable humidity sensors were located inside the liner once the heater was extracted. One of them was located at the back of the liner while the other one was located at the front. The front sensor was shifted towards the back while dismantling advanced. The recorded data is given by Fig. 73 (Villar et al. 2016).

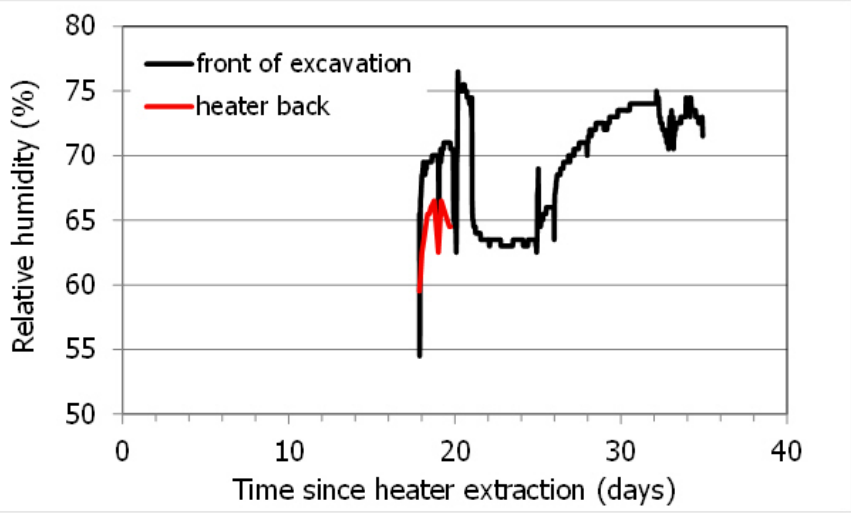


Fig. 73: Data gathered from the portable humidity sensor inside the liner during dismantling.

5.2 Samples collection

As described in the Sampling Plan (Bárcena & García-Siñeriz 2015b), eleven sections were selected for doing in situ analysis and Tab. 4 lists the total number of samples that were analysed. All samples are bentonite and two subsamples were analysed from each one. For some positions in S37 (6 in total) and S39 (20 in total) the inner part of the sample was sent to SKB for verifications of analysis methods.

Tab. 4: Samples taken.

Section	**S37**	**S38**	**S39**	**S40**	**S43**	**S45**	**S49**	**S52**	**S55**	**S56**	**S58**	**S61**
Number of samples	36	3	36	4	36	36	36	36	3	66	66	66

First of all, the locations of the samples to be taken were marked in the bentonite section, according to the sampling book (Bárcena & García-Siñeriz 2015b), with a stainless steel stencil. Then the samples were collected using a hand drilling machine provided with a crown drill bit, as shown in Fig. 74.

Fig. 74: Samples extraction with crown drill.

Once removed, the samples were covered with transparent film to avoid humidity loss until they were analysed, as shown in Fig. 75.

Fig. 75: Covered samples with film.

All samples taken for in situ analysis were cylindrical and about 5 cm long and 5 cm in diameter.

5.3 Samples preparation and analysis

After the collection of the samples, their names/codes and positions were registered in the log book.

As the humidity at the surface of the samples could be altered by the extraction mechanism, providing potential errors in the water content and dry determination, they were reshaped by cutting/removing the edges.

As shown in Fig. 76, the preparation procedure followed three steps:

1. The samples were cut in two subsamples of about 2.5 cm long each one.
2. Each subsample was molded removing the superficial layer.
3. The subsample was cleaned with a brush to remove the shavings.

Then the samples were ready for the water content and dry density determination.

Fig. 76: Samples preparation.

The gravimetric water content (w) is defined as the ratio between the weight of water and the weight of dry solid expressed as a percentage.

The procedure to measure water content was as follows:

1. Measure the tare of the crystal glass to be used by weighting it in the scale.
2. Place the subsample in the glass to get the total weight.
3. Introduce the glass with the sample in the oven, as shown in Fig. 77 (right hand side), set at 110 °C.
4. After 48 hours, the glass with sample was extracted from the oven and weighted again.
5. The difference in weight, dry solid, was used to calculate the water content in percentage.

Fig. 77: Procedure for water content determination, weighting at the left hand side and introduction in the oven at the right.

Dry density (ρ_d) is defined as the ratio between the weight of the dry sample and the volume occupied by it prior to drying.

As shown in Fig. 78, the procedure to obtain the dry density was as follows:

1. Measure the tare of the crystal glass to be used by weighting it in the scale.
2. Place the subsample in the glass to get the total weight.
3. A recipient well filled with mercury is weighted.
4. The subsample is immersed in the recipient with the mercury and the amount displaced is weighted to determine the volume of the subsample, as established in UNE Standard 7045 "Determination of soil porosity".
5. Dry density was obtained from the mass and volume of the subsamples.

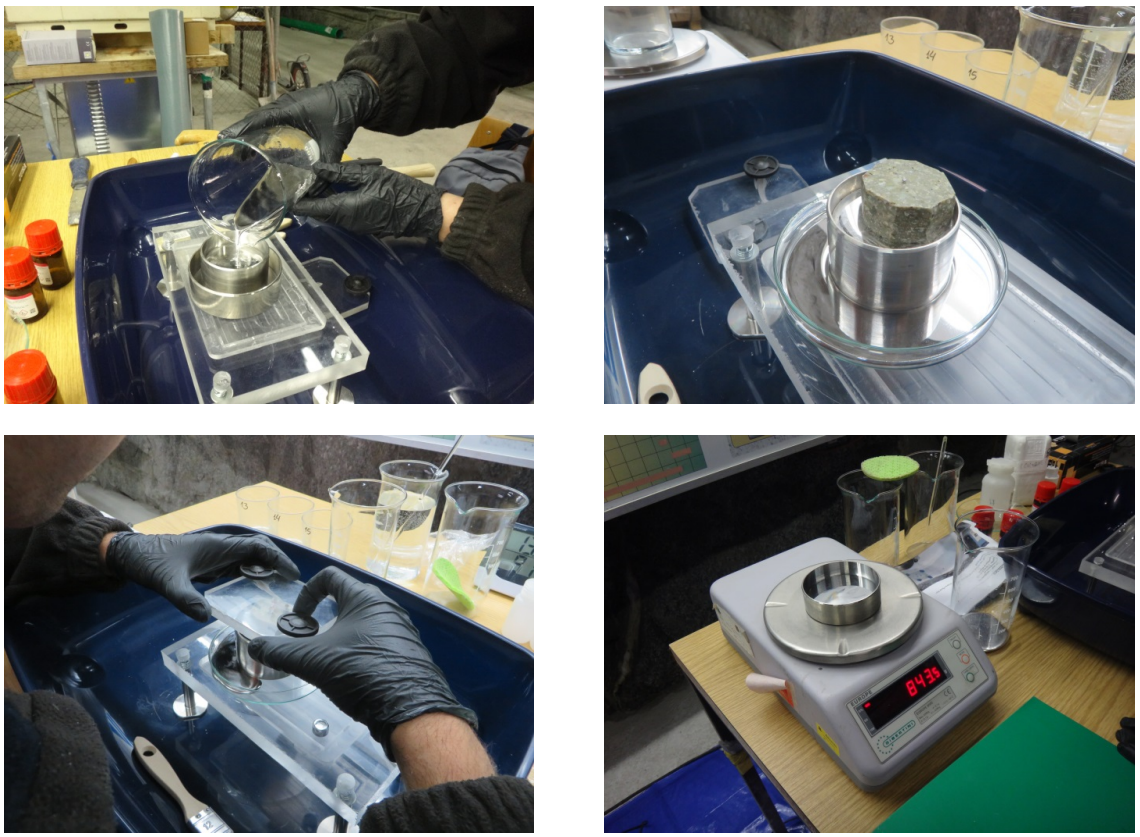


Fig. 78: Some steps of the procedure followed to determine the dry density.

5.4 Results

The results of water content and dry density determinations were recorded in an Excel sheet. An example of these measurements and results are shown for samples coded B-C-56-25-1 & 2. Tab. 5 shows the measurements taken during the samples preparation and Tab. 6 the results obtained from calculations. All results can be found in a specific report prepared by CIEMAT (NAB 16-12, Villar et al. 2016).

Tab. 5: Example of records obtained during in situ analysis.

					Measurements					
Samplecode	**z(cm)**	**y(cm)**	**Date**	**Time**	**m_t (g)**	**m_1 (g)**	**m_r(g)**	**m_3 (g)**	**Date**	**m_2 (g)**
B-C-56-25-1	-39.5	-77	21.07.2015	10:55	177.69	214.48	68.05	316.37	23.07.2015	206.94
B-C-56-25-2			21.07.2015	10:57	177.42	233.32	68.05	448.84	23.07.2015	221.82

m_t: tare
m_1: tare + sample mass
m_r: holder tare
m_3: holder + released mercury mass
m_2: tare + dry sample mass

Tab. 6: Results of in situ analysis.

Results								
Samplecode	**m_h**	**m_s**	**m_w**	**m_{Hg}**	**V_m**	**P** (g/cm^3)	***W*** (%)	**ρ_d** (g/cm^3)
B-C-56-25-1	36.79	29.25	7.54	248.32	18.26	2.01	25.8	1.60
B-C-56-25-2	55.9	44.4	11.5	380.79	28.00	2.00	25.9	1.59

m_h: humid sample mass
m_s: dry sample mass
m_w: water mass
m_{Hg}: released mercury mass
V_m: sample volume
ρ: density
w: water content
ρ_d: dry density

6 Sample handling and shipping

6.1 Sample handling

Procedures for the sampling and handling of samples during the dismantling were described in different reference sampling documents (Bárcena & García-Siñeriz 2015b) and mainly (Rey et al. 2015). Reference documentation was complete and useful during the operation but, as expected, the initial plan needed adjustments during the operation. The following tables show the modifications, if any, made with regard to the initial procedures for each type of sampling.

A limited description of the samples labelling code is given below. T-Y are the two initial letters for each sample codification:

T:
- B: Bentonite
- C: Concrete
- G: Granite
- L: Lamprophyre
- M: Metal
- S: Sensor
- BC: Interface Bentonite-Concrete
- BG: Interface Bentonite- Granite
- BL: Interface Bentonite- Lamprophyre
- BM: Interface Bentonite-Metal
- CG: Interface Concrete-Granite
- CL: Interface Concrete- Lamprophyre
- CM: Interface Concrete-Metal
- GM: Interface Granite-Metal
- LM: Interface Lamprophyre - Metal

Y:
- B: Block
- C: Core
- D: Dice (cube shape)
- S: Any shape

For metal samples: T: Liner, H: Heater

Tab. 7: Types of samples and codes for shotcrete.

	Type of sample	**Codes**
Bentonite	Cylindrical cores*	C-C and CG-C
	Cylindrical cores overcoring*	C-C
	Cubes	C-D
	Bulky/broken pieces	C-S and BC-S

* See Section 4.1 for samples highlighted in yellow.

Tab. 8: Modifications made for cubic samples of shotcrete.

Cubes C-D	
Main requirements	**Performed**
• A big enough bulky piece will be gathered during plug demolition. • A radial saw will be used to cut the cube from the bulky piece at the workshop. • Water will be avoided.	• A bulky irregular piece was taken in the desired area and packaged. • The cube will be extracted at laboratories. • Robot demolition was water-aided.

Tab. 9: Modifications made for bulky samples of shotcrete.

Bulky or broken pieces C-S and BC-S	
Main requirements	**Performed**
• Pieces taken during the work of the demolition robot	• As planned

Tab. 10: Types of samples and codes for bentonite.

	Type	**Code**
Bentonite	Short cylindrical cores	B-C
	Short cylindrical cores for microbiology	B-C/B-S
	Intact blocks	B-B
	Bentonite/Metal scrapes	BM-S
	Cubes	B-D/BM-D/BG-D
	Contact bentonite rock cores	BG-C
	Contact bentonite rock cores for microbiology	BG-C
	Contact bentonite concrete cores	BC-C

Tab. 11: Modifications made for short cylindrical core samples of bentonite.

Short cylindrical cores B-C	
Main requirements	**Performed**
• **Samples of 30 mm long** (in situ analysis) - To be taken with a crown of 70 mm • **Samples > 30 mm long** - Overcoring with a crown > 80 mm - Use a metallic tube that will be pushed-in the bentonite using a hammer or hydraulic piston to protect the sample from alteration. - The metallic tube will be covered with plastic caps to avoid desiccation.	• A crown of 54 mm was used with manual drilling machine and the length was between 5 and 7 cm. • A crown of 89 mm or 54 mm was used depending on the sample. • As planned • Samples for density analysis just packed with plastic during the waiting time for onsite lab measurements.

Tab. 12: Modifications made for short cylindrical core samples of bentonite for microbiology.

Short cylindrical cores for microbial analysis B-C, B-S	
Main requirements	**Performed**
• Overcoring with a crown > 80 mm • Use a metallic tube that will be pushed-in the bentonite using a hammer or hydraulic piston to protect the sample from alteration. • The metallic tube will be covered with plastic caps to avoid desiccation. • Storage between 4 °C and 8 °C	• A crown of 89 mm was used. • As planned • Argon flushing when packaging • Storage as planned

Tab. 13: Modifications made for blocks samples of bentonite.

Intact block B-B	
Main requirements	**Performed**
• Dismantling of the blocks around the required ones first with an electric hammer • A complete block or part of a block is necessary. • Sharp knife to use to extract the block	• It was not always possible to take three blocks from the same radius without severe damages in one of them. As an alternative, cores were taken from one of the blocks before starting to dismantle the radius. • Knife use was not functional.

Tab. 14: Modifications made for scrapes or bulky samples of bentonite.

Scrapes or bulky contacts BM-S	
Main requirements	**Performed**
• Palette or spoon to extract the bentonite in contact with the metal	• As planned

Tab. 15: Modifications made for cube samples of bentonite.

Cubes B-D, BM-D, BG-D	
Main requirements	**Performed**
• Dismantling of the block around the required area • Use of a knife or a saw to extract the cubes from the corresponding block • Cube of 10 cm x 10 cm × 12 cm • No use of water in any case	• Due to the conditions of the bentonite, the use of saw or knifes were not effective for big cuttings. • The cubes were taken as near as possible to the required dimensions but with irregular shapes. • No water was used.

Tab. 16: Modifications made for bentonite-rock samples.

Bentonite/rock cores BG-C	
Main requirements	**Performed**
• Overcoring with Ø > 60 mm • Insertion in metal tube of inner Ø between 50 and 70 mm • Removal of the bentonite core • Overcoring of the rock using a barrel and water if permitted • Between 50 and 70 mm diameter • After drilling re-joining/connection of rock and bentonite parts and packing together	• A big enough piece of block was selected at the planned position. • The block perimeter was marked at the rock surface. • The piece of block was sampled and packed. • The marked area of rock was protected with a wooden plate and silicon cords. • Rock core was taken at the marked area when the bentonite layer dismantling allows the positioning of the drilling machine. • Rock cores were 50 mm in diameter and between 15 and 25 mm in length. • No water was used.

Tab. 17: Modifications made for bentonite-rock samples for microbiology.

Bentonite/rock cores for microbial analysis BG-C	
Main requirements	**Performed**
• Overcoring with Ø > 90 mm • Insertion of metal tube of Ø inner 80 mm • Retrieving of the bentonite adhered to the rock using a scraper. • Overcoring of the rock using a barrel Ø inner > 80 mm to minimise thermal alteration. • 70 mm diameter × 120 mm length • After drilling reconnection of rock and bentonite and packing together. • Storage at T between 4 °C and 8 °C	• No cores were taken for the bentonite part, swab sampling was used instead. • No good results from the first couple of swabs taken, so it was decided not to take them in the following sections.

Tab. 18: Modifications made for bentonite-concrete samples.

Bentonite/concrete contact BC-C	
Main requirements	**Performed**
• Use of multipurpose hole saw type drilling crown of 70 mm. • Drilling fluid in the concrete part can be water, but is necessary to avoid this in the bentonite part. • Sample packed on a half PVC tube in order to protect it during transport.	• Samples with 2 cm of bentonite and 2 cm of concrete were taken. • The fiber reinforcement of the shotcrete was a handicap for the sampling because it creates a link between the desired samples making their extraction difficult.

Tab. 19: Types of samples and codes for metal.

	Type	**Code**
Metal	Heater/liner samples	M-S/M-H/M-L
	Corrosion probes	M-S
	Sensors	S-S

Tab. 20: Modifications made for heater/liner samples.

Heater/liner sampling M-S, M-H, M-L	
Main requirements	**Performed**
• Samples to be taken in a workshop	• Liner samples were cut at GTS with a plasma cutter • Heater samples have been taken at a workshop in Spain

Tab. 21: Modifications made for samples taken from corrosion probes.

Corrosion probes M-S	
Main requirements	**Performed**
• If possible, take it with the containing block	• The containing blocks were severely damaged, see "Extra report 9" (Kober 2015b).

Tab. 22: Modifications made for samples of sensors.

Sensors S-S	
Main requirements	**Performed**
• Labeling of sensors • Removed by hand • Visual inspection • In situ verification before and after removal • The cables will be extracted from the bundles running along the gallery walls and the cable will be cut at both sides of the plug.	• As planned • As planned • As planned • Verification before removal was made for TDR and thermocouples only (Rey et al. 2016). • Cables were cut around two meters away the sensor. • Thermocouples and TDR cables were cut after verification of TDRs (AN 16-169, Sakaki 2016).

Tab. 23: Types and codes for other samples.

	Type	**Code**
Other	Contact bentonite metal cores	BM-C
	Contact bentonite metal cores for Obayashi	BM-C
	Filter papers	BM-S

Tab. 24: Modifications made for bentonite-metal samples.

Contact bentonite metal cores BM-C	
Main requirements	**Performed**
• Overcoring with Ø > 60 mm • Insertion of metal tube of 50 mm inner diameter. • Use a metallic case filled with epoxy resin to cover the metal surface and the bentonite core. • Cutting the liner with a plasma tool.	• A fragment of bentonite in contact with the liner was selected and the perimeter marked on the liner surface. • The bentonite sample was taken and packaged. • Once the segment of liner was liberated and carried outside of the gallery, the sample of metal was cut with a plasma cutter. • Cut surface was always bigger than the marked area to minimise thermal alteration.

Tab. 25: Modifications made for bentonite-metal samples for Obayashi.

Contact bentonite metal cores for Obayashi BM-C	
Main requirements	**Performed**
• Overcoring with Ø > 70 mm • Insertion of metal tube of Ø inner 50 mm • Cutting the metallic cap with a plasma tool.	• A piece of the heater cap was cut instead.

Tab. 26: Modifications made for filter paper samples.

Filter papers BG-S	
Main requirements	**Performed**
• Keep the integrity and the bentonite film adhered to the filter paper. • Use of knife, scissors and scraper. • 20 cm x 20 cm	• Removed by hand. • Samples were taken in different positions in each layer where the filter paper was found. • Small pieces, 20 cm × 20 cm were impossible to take.

Apart from little modifications made in some cases, a few sampling procedures were found unpractical or unrealistic, in particular those related to getting the bentonite/metal or bentonite/rock interface samples.

In general, it was not easy to mark the orientation and position of samples directly on them so in most cases this was marked on the plastic film envelope instead.

6.2 Packaging and shipping

An large enough area (Fig. 79) located next to the concrete platform outside the drift, at the opposite side of the dump container, was used to prepare the samples' boxes and packages to be sent from the Grimsel URL to the partners´ laboratories.

Several wooden boxes were designed, produced and delivered from Spain taking into consideration the expected material to be sent per partner. These boxes contained protection material to ensure the integrity of their content. In addition, two fridges were provided by Nagra at the GTS office for storing those samples that needed refrigeration.

Fig. 79: Area for preparing the shipment of samples.

Nonetheless, as the excavation progressed, it became clear that the planned boxes/packages for storing the samples were not sufficient: the size of several samples was increased (see tables with modifications), some partners requested partial shipping of samples and the changes introduced in the sampling program led to an increase of the number of samples.

Shipments were made as follows:

- Some samples were directly picked out by the interested partner; this was the case for some samples requested by BGR or CIEMAT.
- Some samples were sent from the GTS directly to the interested partner; this was the case for Swiss partners (Bern University, ETHN), for those located in UK, Germany and Sweden, and for the refrigerated samples.
- Three big shipments were done with all the samples and material requested by Spanish partners. For logistical reasons, in some cases the samples were sent directly to the destination partner and in other cases it was sent to AITEMIN facilities to be distributed internally in Spain.
- Refrigerated samples required special packaging and a dedicated transport to keep the samples' integrity during the transport.

- Transoceanic shipments to USA and Japan were made in close coordination (AITEMIN-Nagra) and the one to USA was first sent from GTS to Spain and then from Spain to destination to minimise costs.
- Some additional small volume shipments were done at the end because of mistakes in boxes' assignations or samples forgotten at the GTS.

Delivery times for local/regional shipments, those in the European Union, were acceptable: a couple of days. Shipment of refrigerated samples turned out to be rather complex because they had to be delivered at destination within 48 hours and were very expensive too.

Overseas transport presented a lot of problems including customs management, third-party delivery policies and the estimation of delivery times, which required more manpower dedicated to arrange, coordinate and track the shipments.

As a conclusion, packing and shipping the samples was much more complex than anticipated and the efforts required for samples preparation, coordination and tracking plus the involved costs for samples shipping were clearly underestimated.

7 Conclusions

7.1 Plug dismantling

Shotcrete plug demolition took only 16 working days. It was done according to the program both from the technical and operational points of view. No relevant difficulties were encountered apart from a few short stoppages at the end due to an electrical cable that was damaged and an oil leakage in the robot.

The use of a demolition robot was more effective (faster and cheaper) that the hydraulic splitter, which was used for previous dismantling, providing the required accuracy and care which could avoid damage to cables, sensors and gas pipes.

On the other hand, some minor disadvantages were:

- The need of wetting the concrete to avoid dust emission
- The vibration of the robot affecting the concrete/rock contact

7.2 Heater removal

Removal of the "dummy canister" was longer than expected because it was stuck to the liner due to the pressure exerted by the bentonite and the intrusion of bentonite in the inner gap through the holes of the liner. Therefore, the set dummy-liner was excavated all around before removal. This operation was planned to take 3 days but it took 9 days.

Although legitimate doubts were raised as a consequence of the difficulties encountered when extracting the dummy, the extraction of the heater was done as planned; using the pulling machine designed for this purpose, and without major difficulties. However, the intrusion of bentonite in the inner gap through the holes of the liner was evident at both sides of the heater (colder areas) but not to such an extent as to make it impossible to pull it from the liner. It seems obvious that the filling of the inner gap by the bentonite was on-going so it was only a matter of time before the heater would not have been extracted simply by pulling. This fact is relevant when thinking about the reversibility of the waste deposition.

7.3 Buffer dismantling

This operation was slower than expected, although it was delayed 13 working days only, due to different factors:

- The difficulties for extracting the dummy canister (excavation around)
- Some delay to receive a few tools
- The external support for debris evacuation was canceled and assumed by AITEMIN due to operational reasons.
- Some adjustments required to perform the sampling procedures
- The request of additional samples
- Some additional dissemination activities with almost no relevant impact

Dismantling and evacuation tools were demonstrated to be appropriate for the purpose.

No mercury leakage was experienced this time but some sporadic and low volume water inflow was encountered. These were found mainly accumulated in the cable bundles.

7.4 Sampling and in-situ analysis

In situ analyses were carried out as expected, although they demanded more efforts that initially planned due to different reasons:

- During dismantling it was agreed to double the number of analysed samples.
- Inclusion of new sampling sections
- Additional precautions demanded for mercury handling during in situ analysis

Bentonite was found more homogeneous in general (radial) but not longitudinally.

Damage from the operation itself seem to be less that in FEBEX I, so the dismantling was better controlled, probably due to the previous work done to optimize the sampling and methods and the use of less intrusive tools.

Sensors looked in better condition than the ones gathered during the first dismantling: lower corrosion or mechanical damages except the crack meter, which was not correctly sealed against the wall during installation. No corrosion by bacteria was found this time, which could be related with less voids left around the sensors in this part of the buffer.

Reference documentation was complete and useful to develop the operation but as expected, the initial plan required adjustments during the operation, nevertheless a good collaboration between the partners made the process easy. Cooperation with the partners demanding samples was very good too, they showed flexibility when changes were requested. In particular the help of CIEMAT was very valuable.

Cooperation with Nagra was successful; in particular personnel at the GTS helped a lot for reaching the objectives.

7.5 Lessons learned

Log documentation was too complex and heavy to fill-in, the procedures should be simplified. Manual filling should be replaced with electronic forms to speed-up the process and minimise errors.

The requirement for partner presence during sampling was frequently not met, this slowed down the process because sampling procedures needed changes. On the other hand when the partner was present this often led to additional samples being taken during the dismantling operations. In conclusion, the assistance of partners during sampling was useful and improved the speed of the dismantling when problems arose but sometimes it was just the opposite because they tended to ask additional samples.

Some sampling procedures were found unpractical/unrealistic, in particular those related to the bentonite/metal or bentonite/rock interfaces. Alternatives based on procedures similar to the one used for taking unaltered samples of concrete/bentonite (see Section 4.1) should be developed for taking the bentonite/metal and bentonite/rock contacts if feasible, however, the time needed to obtain stabilised samples would be considerably longer.

Packing and shipping of samples was more complex than anticipated. Efforts required for samples preparation and involved costs for samples shipping were underestimated. In particular, shipping of refrigerated samples was very complex and expensive because they needed to be delivered within 48h.

Coordination and arrangement from Spain of samples to be shipped from Switzerland to other countries turned out to be very difficult and increased the costs. It should be done from the origin country in the future.

Finally, it should be stated that it was beneficial to have the same contractor onboard for the dismantling as the one who did the installation 20 years ago and the partial dismantling 13 years ago, thus providing a lot of knowledge (though some went missing) and helping to save time and improve the quality of the entire operation.

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CIEMAT team:

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UAM team:

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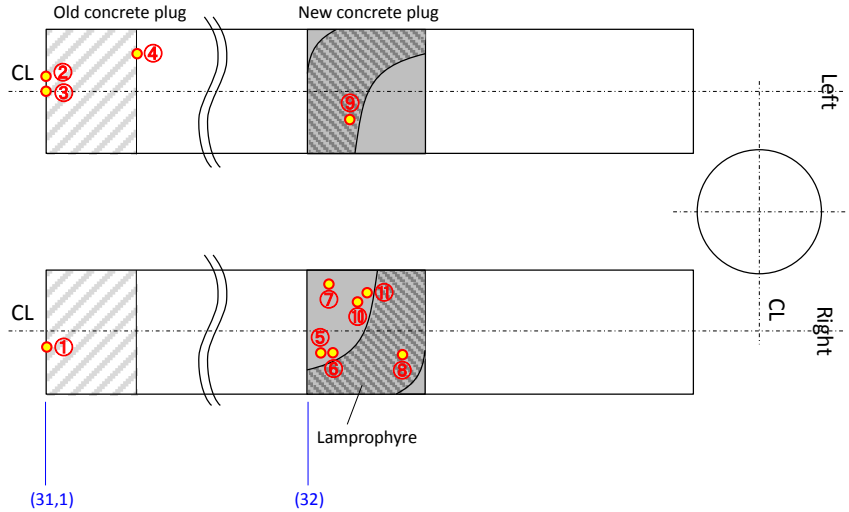
Annex

Updated sampling section

SAMPLING SECTION 31	LOCATION		
	"Actual" x coordinate:	Instrumented section: U	Bentonite slice: NA
SAMPLES			
Code	Nº of samples	Type	Destination
CG-C-31,1-1 & CG-C-31,1-2	2	Shotcrete/Rock	Obayashi

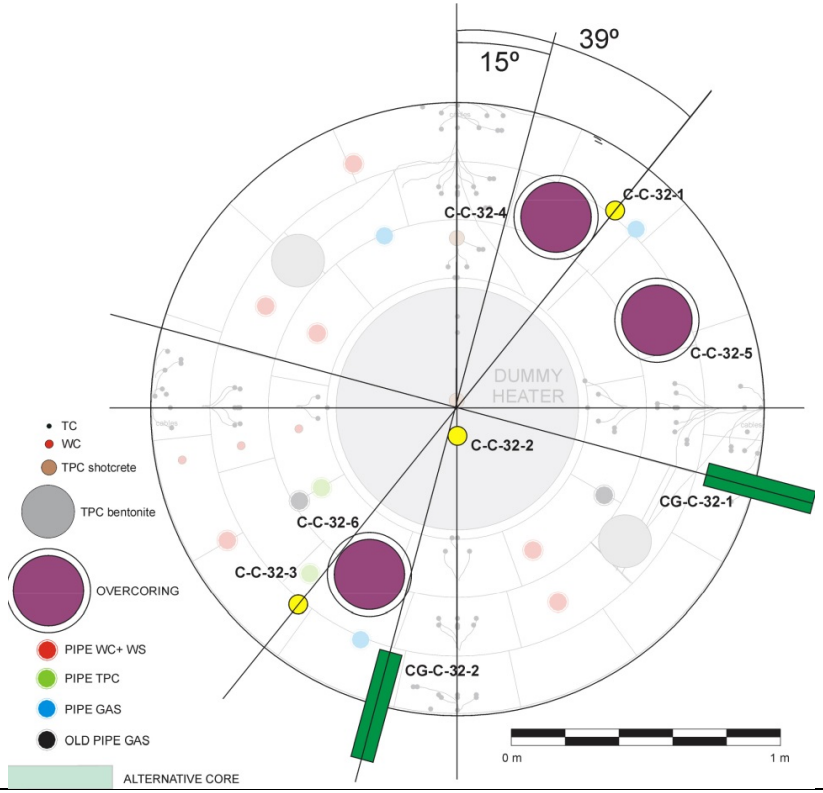
See "Extra Report 11- Sampling the of plug-concrete/rock (C/R) interface by stabilized overcoring - Sample splitting and Distribution" (Kober 2015b)



DISMANTLING PHOTO

SAMPLING SECTION 32	LOCATION		
	"Actual" x coordinate:	Instrumented section: U	Bentonite slice: NA
SAMPLES			
Code	Nº of samples	Type	Destination
C-C-32-1 to C-C-32-3	3	Shotcrete	CIEC
C-C-32-4	4	Shotcrete	SKBC, rest not decided
C-C-32-5	4	Shotcrete	CIEM, OBAY, COMI &UDOE
C-C-32-6	4	Shotcrete	CIEM, OBAY, UNIB &UDOE
CG-C-32-1 to CG-C-32-2	2	Shotcrete/Rock	OBAY

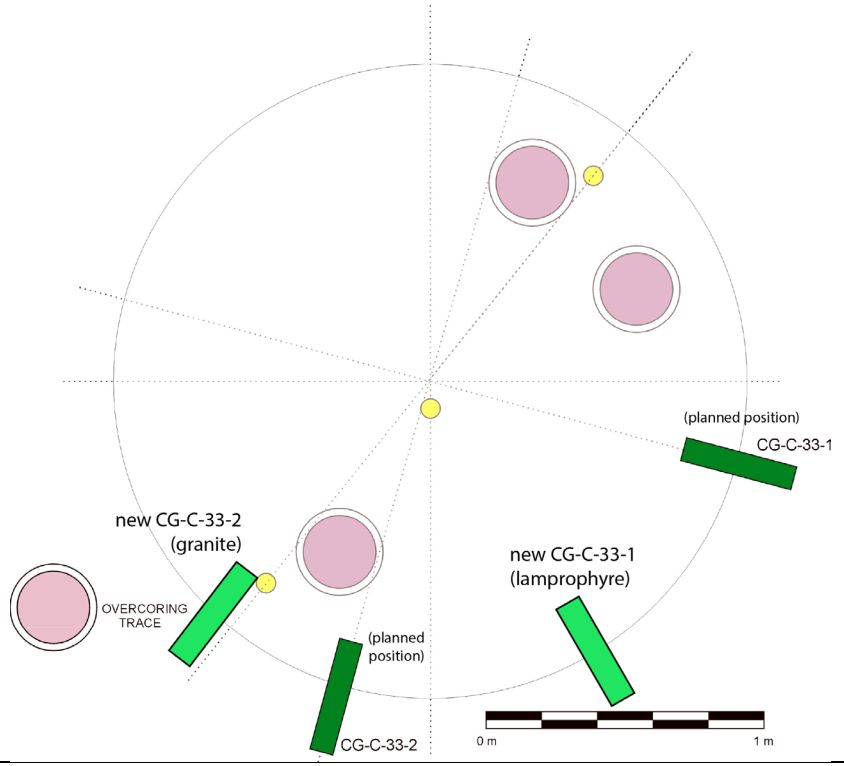
DISMANTLING FIGURE



DISMANTLING PHOTO

SAMPLING SECTION 33	LOCATION		
	"Actual" x coordinate:	Instrumented section: NA	Bentonite slice: NA
SAMPLES			
Code	Nº of samples	Type	Destination
CG-C-33-1 and 2	2	Shotcrete/ Rock	Obayashi

DISMANTLING FIGURE



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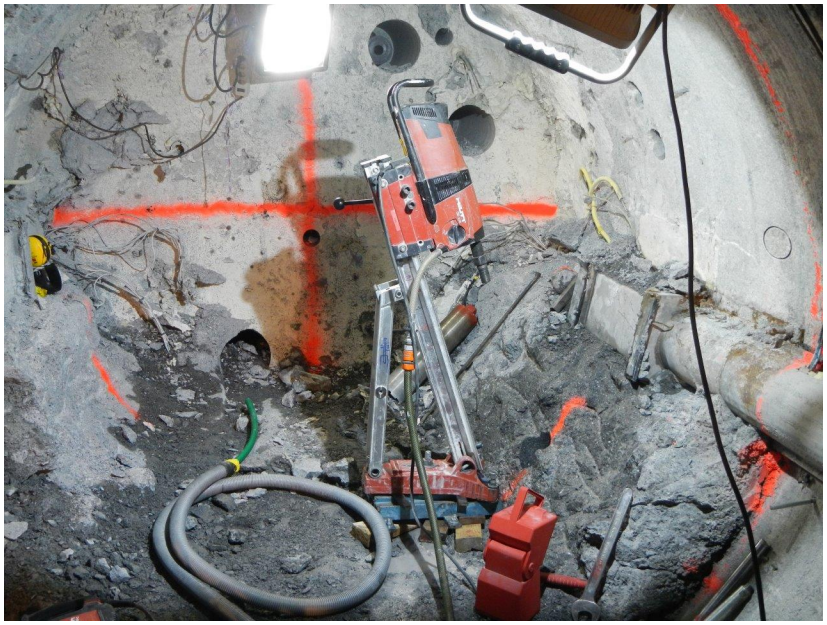
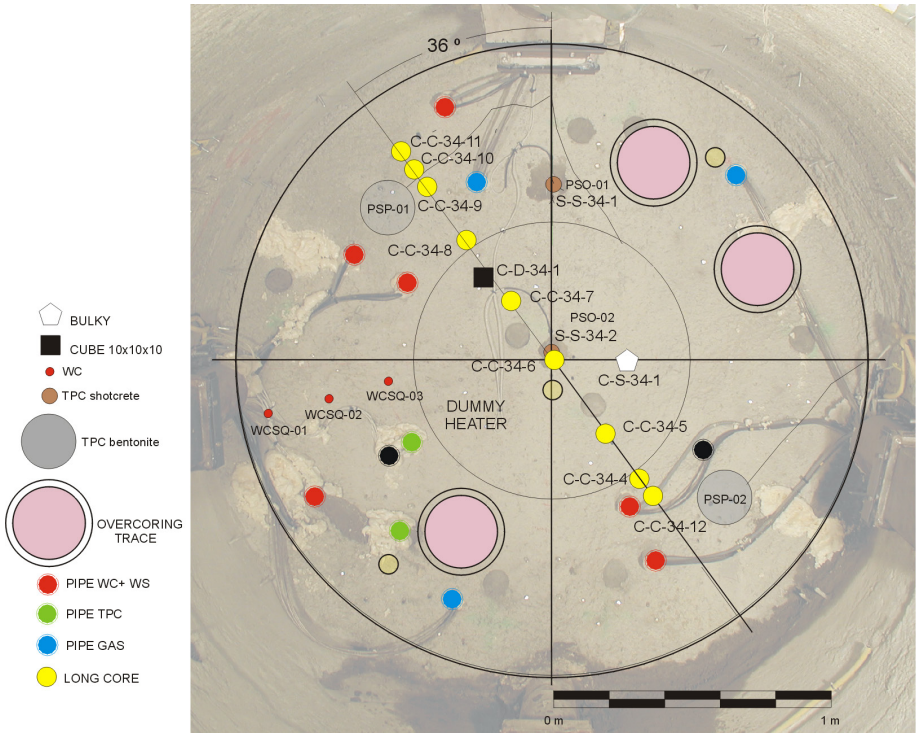


SAMPLING SECTION 34	LOCATION		
	"Actual" x coordinate: aprox. 7.882 m	Instrumented section: O	Bentonite slice: plug-bentonite slice interface
SAMPLES			
Code	Nº of samples	Type	Destination
C-C-34-4 to 12	9	Shotcrete	CIEU
C-S-34-1	1	Shotcrete	CIEMAT
C-D-34-1	1	Shotcrete	ETHN

C-C-34-1 to 3 were not taken
New sample: C-C-34-12

DISMANTLING FIGURE

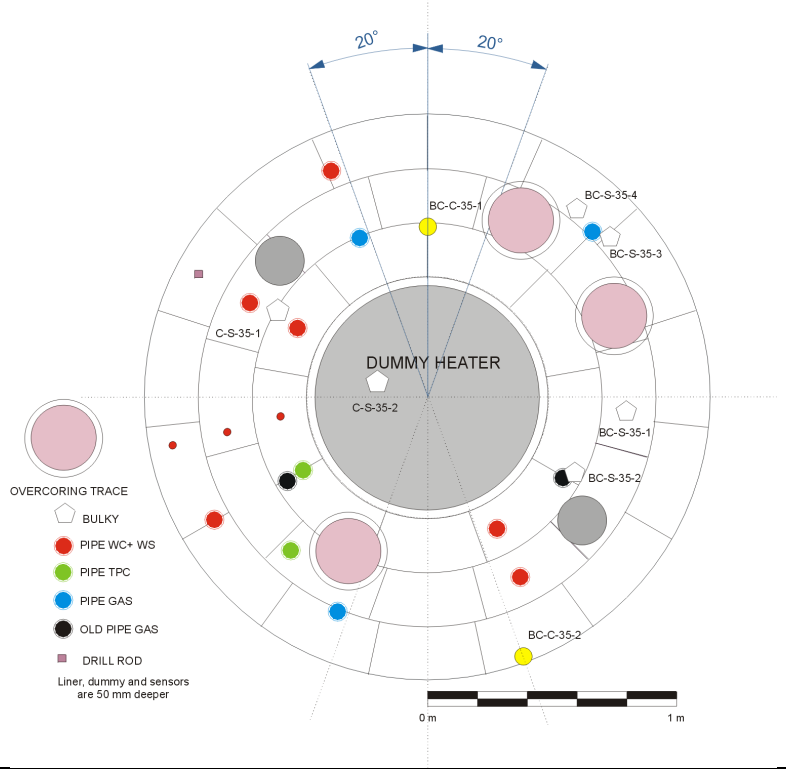


DISMANTLING PHOTO

SAMPLING SECTION 35	LOCATION		
	"Actual" x coordinate: 7.882 m	Instrumented section: NA	Bentonite slice: 74
SAMPLES			
Code	Nº of samples	Type	Destination
BC-S-35-1	1	Bentonite /Shortcrete	BGR
BC-S-35-2 to 6	5	Bentonite/shotcrete	CIEMAT
C-S-35-1 & 2	2	Shotcrete	CIEMAT
BC-C-35-1 & 2	2	Bentonite /Shortcrete	CIEMAT
M-S-35-1 and BM-C-35-1	2	Metal	OBAY

New samples: C-S-35-2
New samples BC-S_35-2 to 7
Not taken GC-C-35-1, CL-C-35-1

DISMANTLING FIGURE

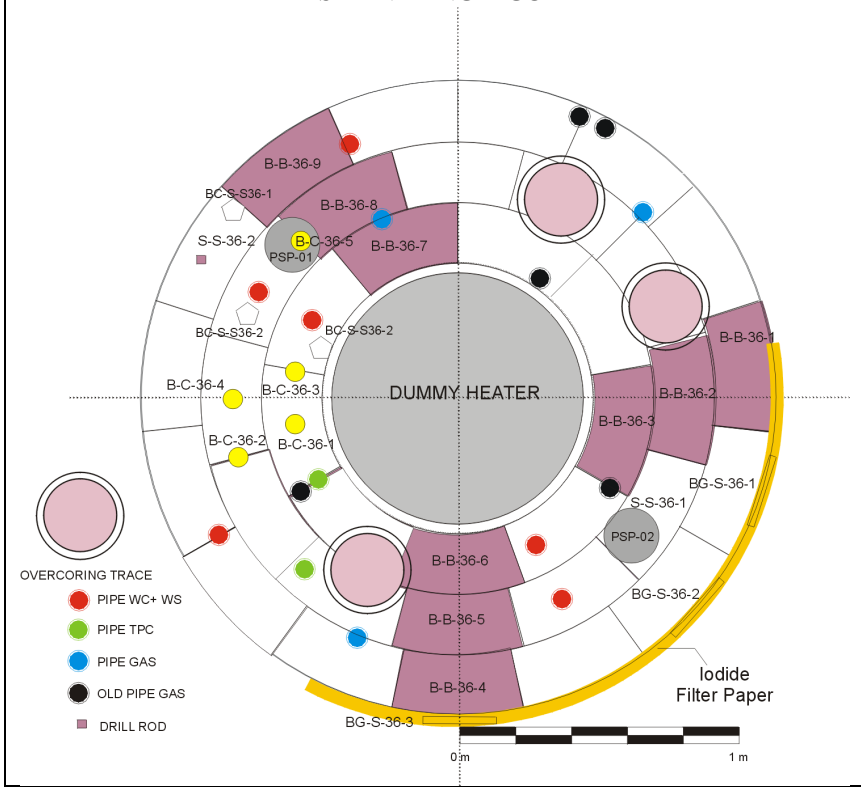


DISMANTLING PHOTO

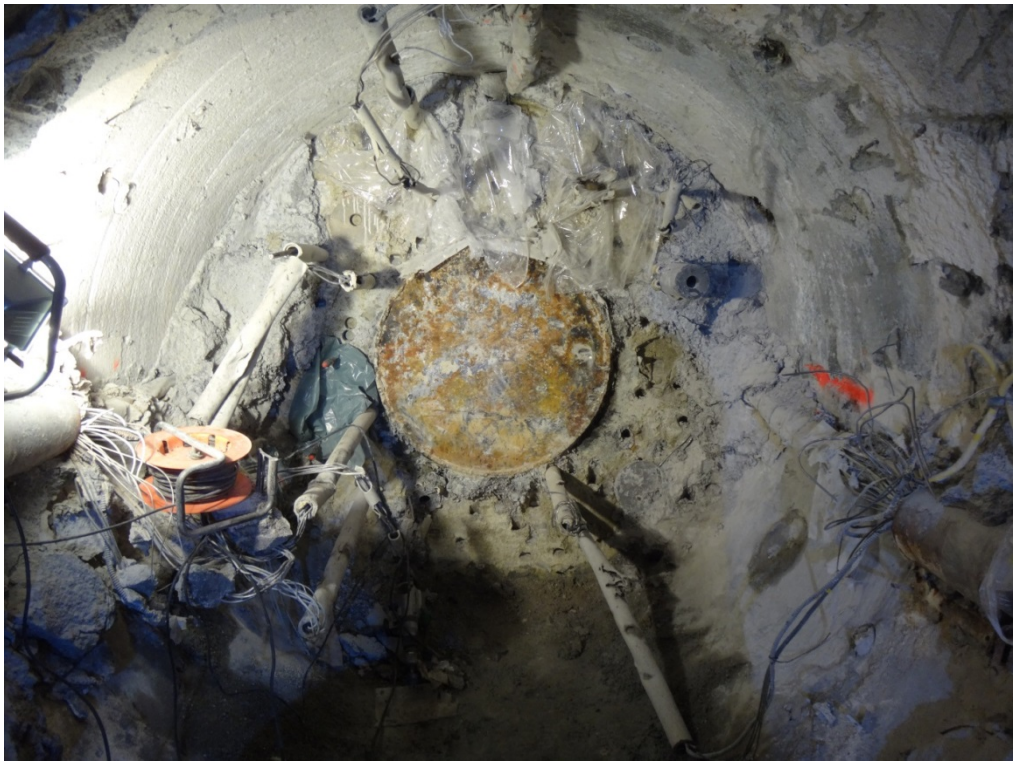
SAMPLING SECTION 36	LOCATION		
	"Actual" x coordinate:7.900 m	Instrumented section: P	Bentonite slice: 74
SAMPLES			
Code	Nº of samples	Type	Destination
BG-S-36-1 to 3	3	Filter paper	CIEMAT
B-B-36-1 to B-B-36-9	9	Bentonite	CIEMAT
B-C-36-1 to 5	5	Bentonite	CIEMAT
BC-S-36-1 to 3	3	Bent/Conc	BGR

New sample: B-C-36-5
New sample: B-S-36-2 and 3

DISMANTLING FIGURE



DISMANTLING PHOTO

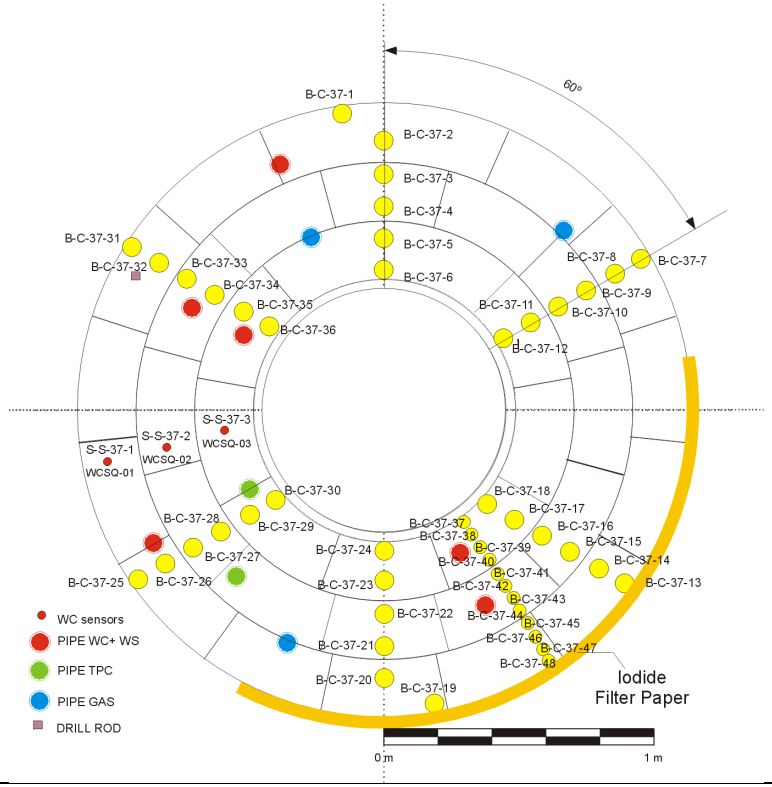


SAMPLING SECTION 37	LOCATION		
	"Actual" x coordinate: 8.410 m	Instrumented section: Q	Bentonite slice: 70 (69)

SAMPLES			
Code	Nº of samples	Type	Destination
B-C-37-1 to B-C-37-36	36	Bentonite	AITEMIN
B-C-37-37 to 48	12	Bentonite	CIEMAT

BG-S-37-1 to 3 not taken
B-B-37-1 to 3 were replaced by B-C-37-37 to 48 and they were taken from bentonite layer 69

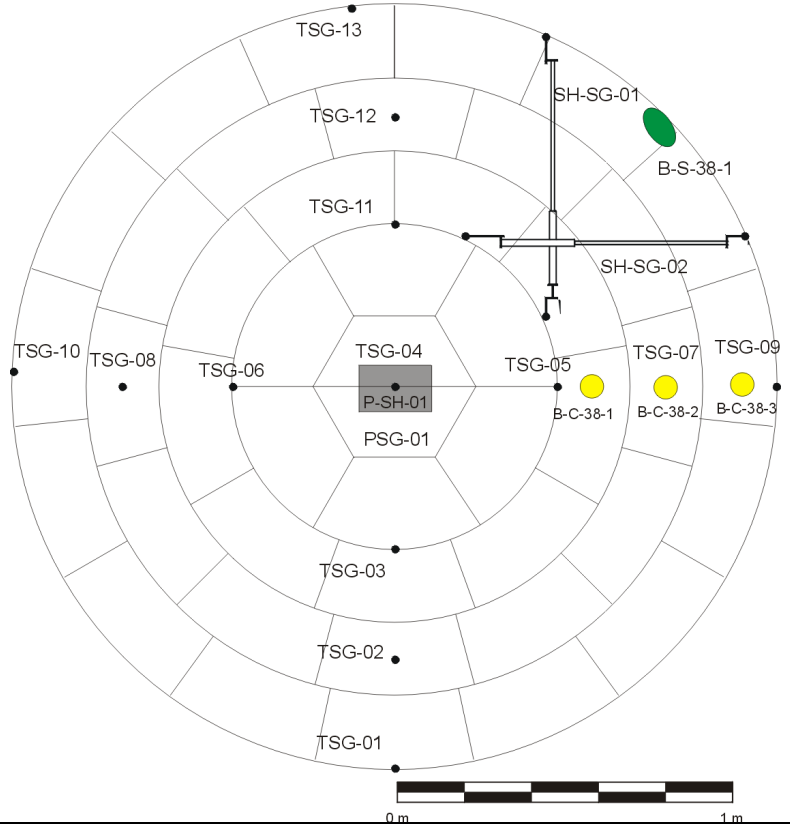
DISMANTLING FIGURE



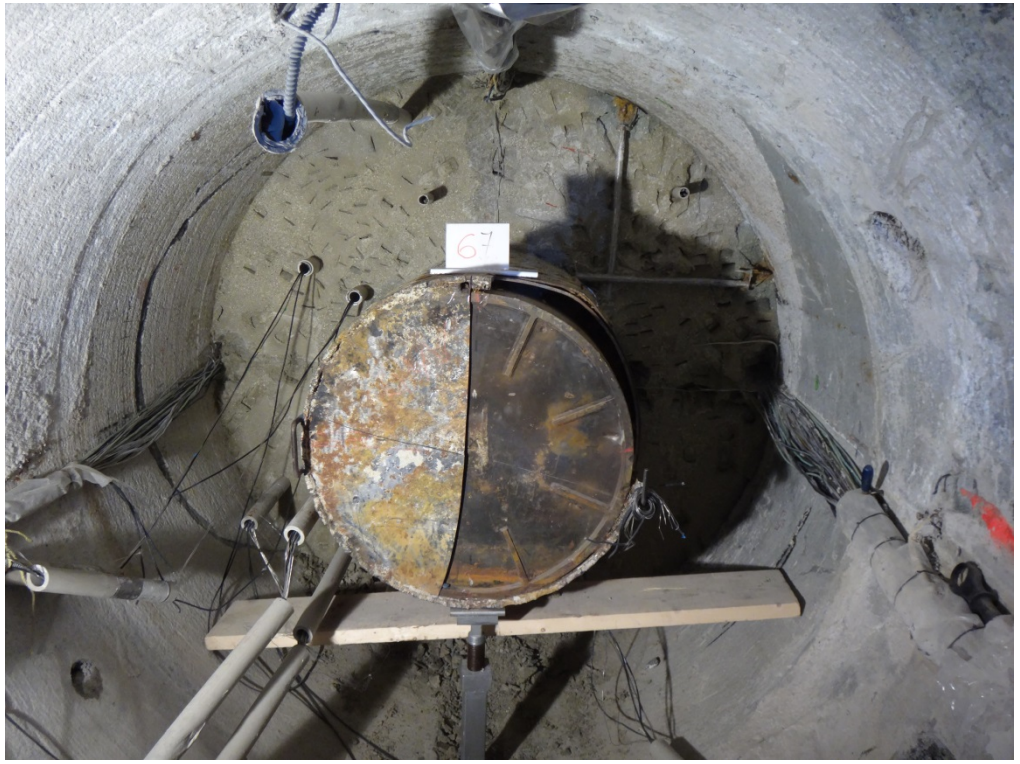
DISMANTLING PHOTO

SAMPLING SECTION 38	LOCATION		
	"Actual" x coordinate:8.815 m	Instrumented section: G	Bentonite slice: 67
SAMPLES			New samples: B-C-38-1 to 3 where shifted from Section 40 to Section 38 New samples: B-S-38-1
Code	Nº of samples	Type	Destination
B-C-38-1 to 3	3	Bentonite	AITEMIN
B-S-38-1	1	Bentonite	CIEMAT

DISMANTLING FIGURE



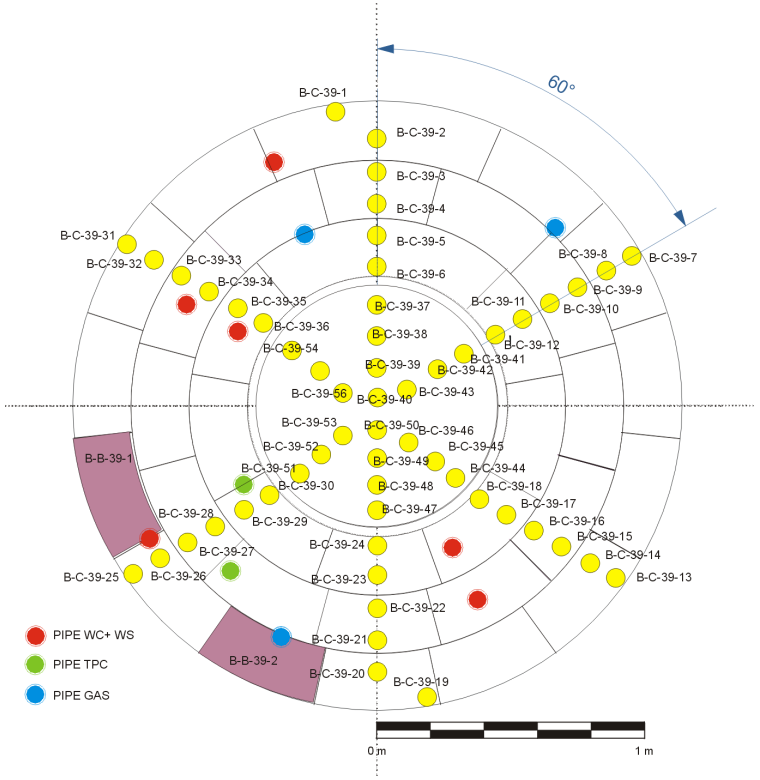
DISMANTLING PHOTO



SAMPLING SECTION 39	LOCATION		
	"Actual" x coordinate:9.186 m	Instrumented section: NA	Bentonite slice: 64 (65)

SAMPLES				
Code	Nº of samples	Type	Destination	New samples: B-C-39-37 to 56 New samples: B-B-39-1 and 2 taken in bentonite layer 65
B-C-39-1 to B-C-39-56	56	Bentonite	AITEMIN	
B-B-39-1 and 2	2	Bentonite	TECNALIA	

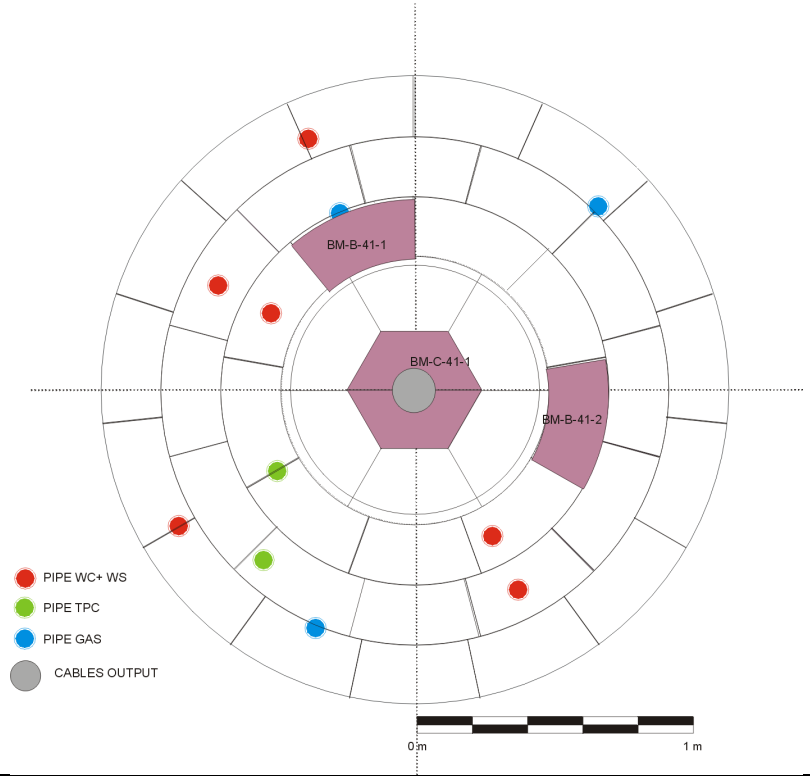
DISMANTLING FIGURE



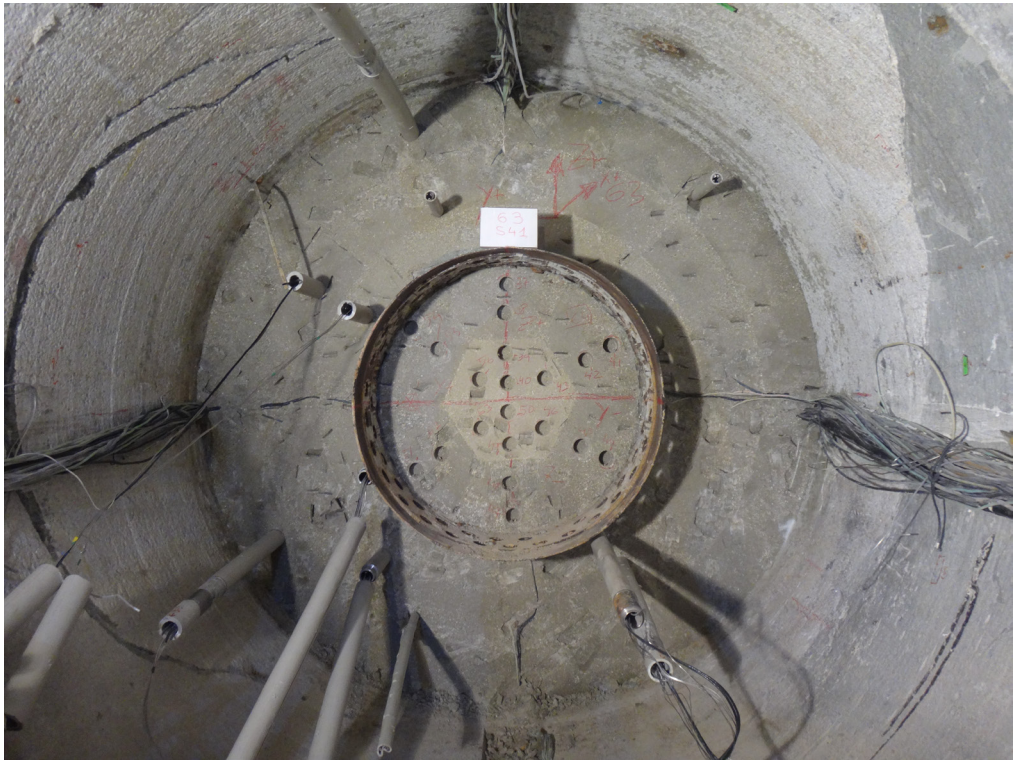
DISMANTLING PHOTO

SAMPLING SECTION 41	LOCATION			
	"Actual" x coordinate: 9.312 m		Instrumented section: H	Bentonite slice: 63 (62)
SAMPLES				Not possible to take BM-C-41-1, so two blocks were taken instead New samples: BM-B-41-1 and 2, but taken in bentonite slice 62
Code	Nº of samples	Type	Destination	
BM-C-41-1	1	Bentonite/metal	Obayashi	
BM-B-41-1 & 2	2	Bentonite	Bern. Univ.	

DISMANTLING FIGURE



DISMANTLING PHOTO

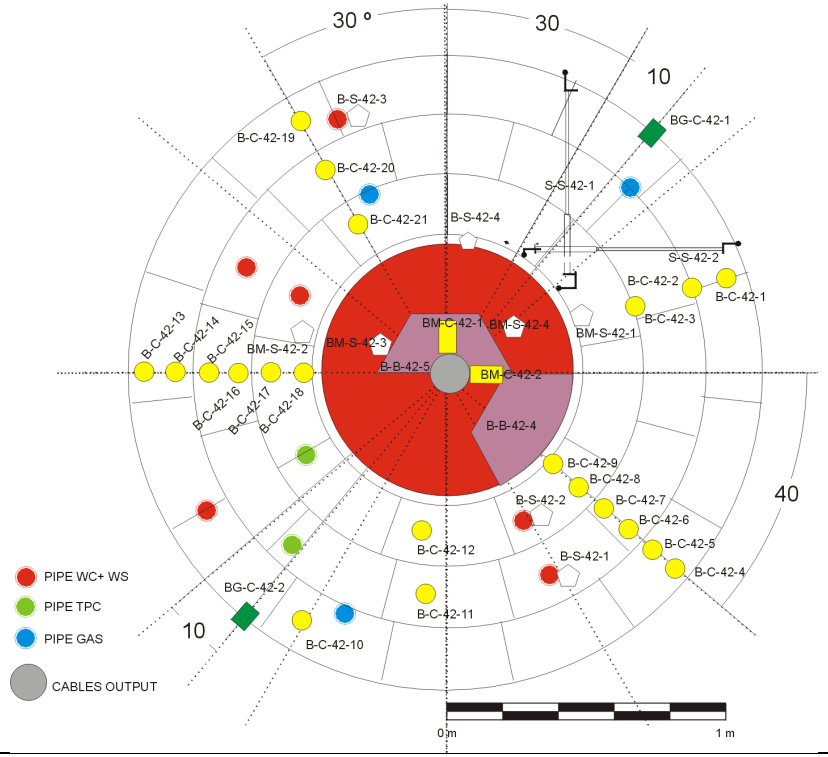


SAMPLING SECTION 42	LOCATION

	"Actual" x coordinate: 9.831 m	Instrumented section: I	Bentonite slice: 59
SAMPLES			
Code	Nº of samples	Type	Destination
BM-C-42-1 & 2	2	Bentonite/Metal	CIEMAT
B-C-42-4 to 9 B-C-42-13 to 18	12	Bentonite	MIND
B-C-42-1 to 3, 10 to 12, 19 to 21	9	Bentonite	COMI
BG-C-42-1 & 2	2	Bentonite/rock	COMI
BM-S-42-1 & 2	2	Bentonite	BGR
B-B-42-4 & 5	2	Bentonite	CIEMAT
BM-S-42-3 &4	2	Bentonite	SKBC
B-S-42-1 to 4	4	Bentonite	CIEMAT

New sample: BM-S-42-4
New sample: B-S-42-4
New sample: B-B-42-4 and 5
New sample: BM-S-42-Pxx (not represented in the figure: protrusions of bentonite inside the liner holes):

DISMANTLING FIGURE

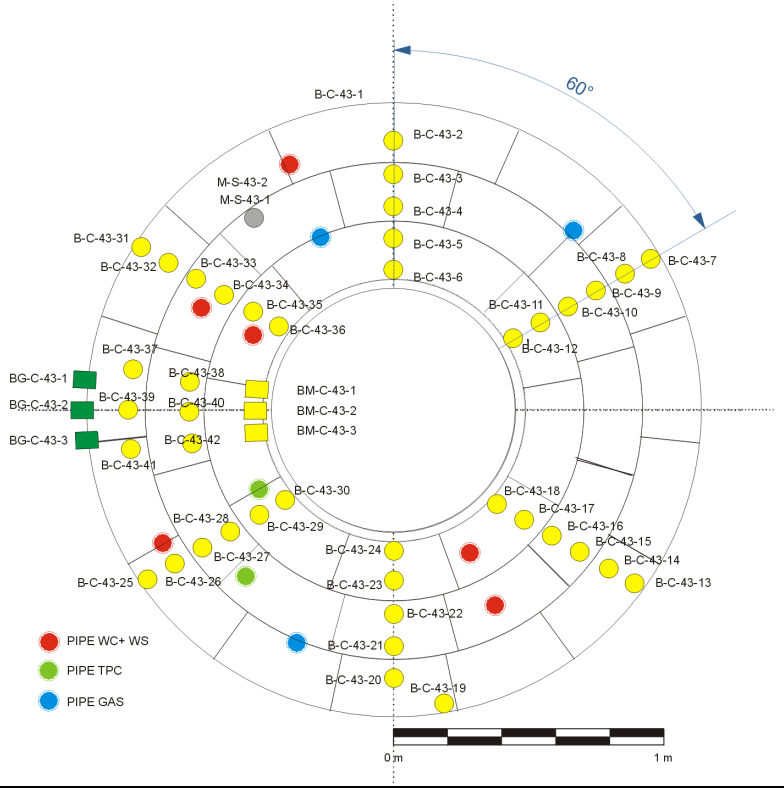


DISMANTLING PHOTO

SAMPLING SECTION 43	LOCATION		
	"Actual" x coordinate: 10.090 m	Instrumented section: NA	Bentonite slice: 57 (55)
SAMPLES			
Code	Nº of samples	Type	Destination
B-C-43-1 to B-C-43-36	36	Bentonite	AITEMIN
BM-C-43-1 to 3	3	Bentonite/Metal	UDOE
B-C-43-37 to42	6	Bentonite	UDOE
BG-C-43-1 to 3	3	Bentonite/Granite	UDOE
M-S-43-1 and 2	2	Metal	CIEMAT

New samples: M-S-43-1 in bentonite slice 57
M-S-43-2 in bentonite slice 55

DISMANTLING FIGURE

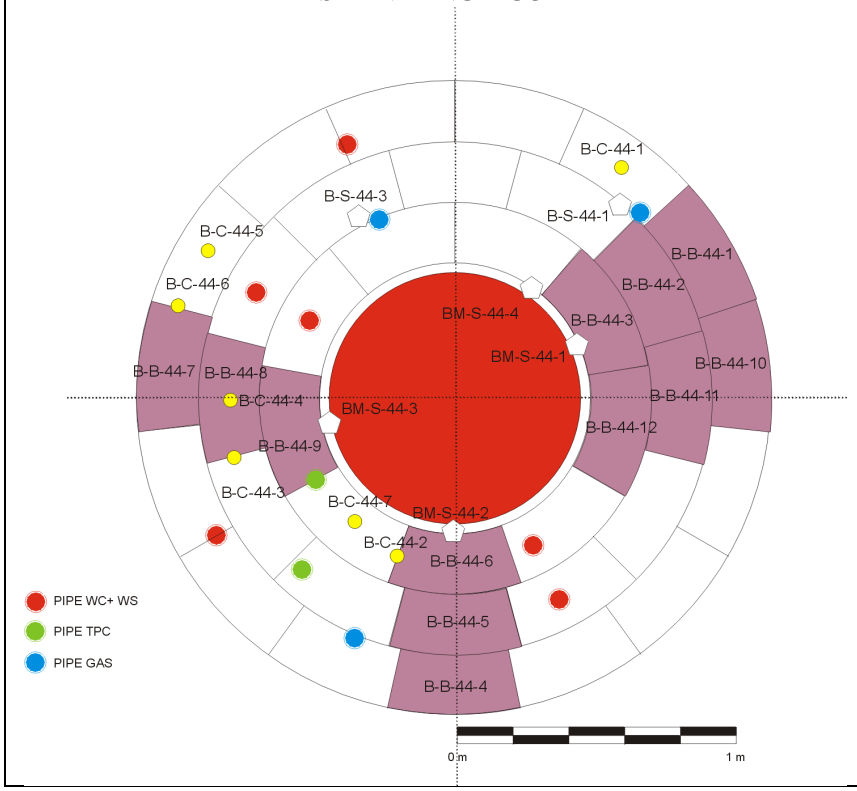


DISMANTLING PHOTO

SAMPLING SECTION 44	LOCATION		
	"Actual" x coordinate:10.607 m	Instrumented section: NA	Bentonite slice: 53
SAMPLES			
Code	Nº of samples	Type	Destination
B-B-44-1 to 9	9	Bentonite	CIEMAT
B-B-44-10 to 12	3	Bentonite	SKBC
B-C-44-1 to 7	7	Bentonite	CIEMAT
BM-S-44-1 to 4	4	Bent./liner	CIEMAT
B-S-44-1 and 3	2	Bentonite	CIEMAT

New sample B-B-44-8b
New sample: B-C-44-7
New sample BM-S-44-4
B-S-44-2 not taken

DISMANTLING FIGURE

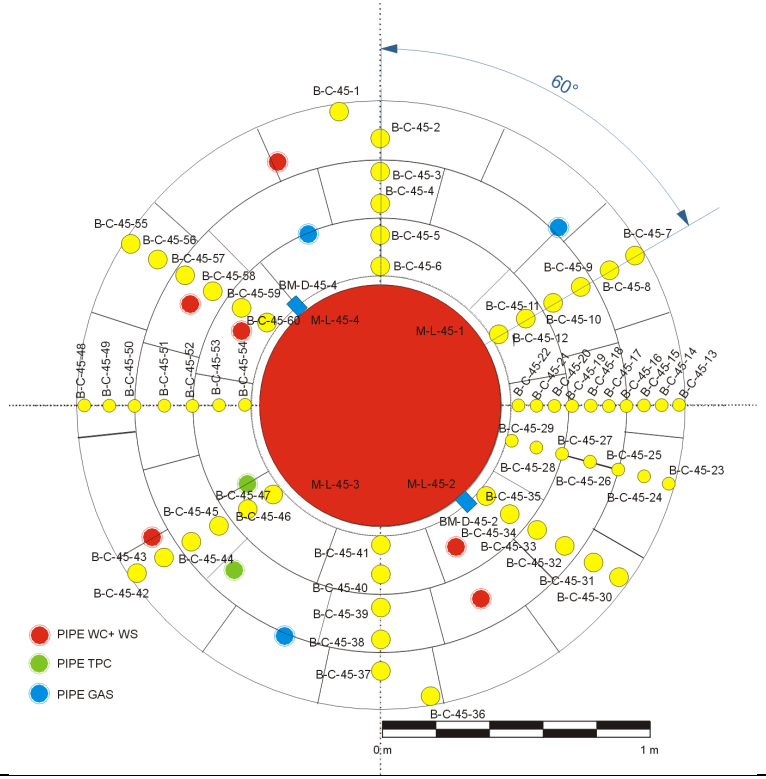


DISMANTLING PHOTO

SAMPLING SECTION 45	LOCATION		
	"Actual" x coordinate: 11.100 m	Instrumented section: NA	Bentonite slice: 49

SAMPLES				
Code	Nº of samples	Type	Destination	
B-C-45-1 to 12, B-C-45-30 to 47 & B-C-45-55 to 60	36	Bentonite	AITEMIN	M-H-45-1 to 4 not taken BM-D45-2 and 3 not taken
M-L-45-1 to 4	4	Liner	TECNALIA	
BM-D-45-1 & 4	2	Bentonite/liner	CIEMAT	
B-C-45-13 to 22	10	Bentonite	CIEU	
B-S-45-23 to 29 B-S-45-48 to 54	14	Bentonite	BGR	

DISMANTLING FIGURE

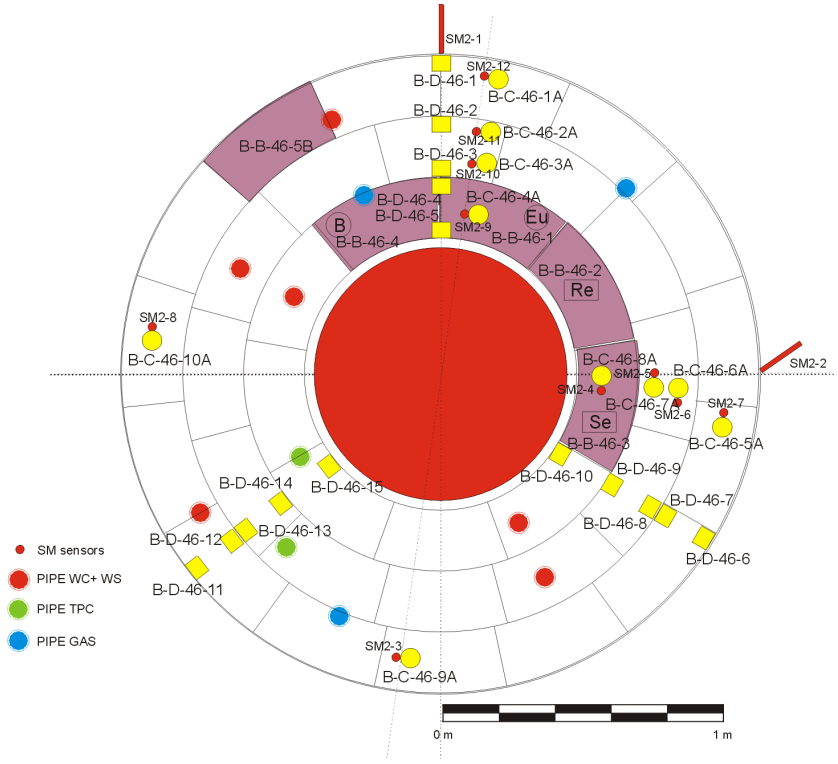


DISMANTLING PHOTO

SAMPLING SECTION 46	LOCATION		
	"Actual" x coordinate:11.490 m (11.620 m)	Instrumented section: M2	Bentonite slice: 46 (45)
SAMPLES			
Code	Nº of samples	Type	Destination
B-B-46-1 to 4	4	Bentonite	CIEMAT
B-B-46-5B	1	Bentonite	¿?
B-C-46-1A to 10A	10	Bentonite	ETHN
B-D-46-1 to 15	15	Bentonite	ETHN

B-B-46-5B taken from bentonite layer 45
B-B-46-1A to 10A taken from bentonite layer 45

DISMANTLING FIGURE

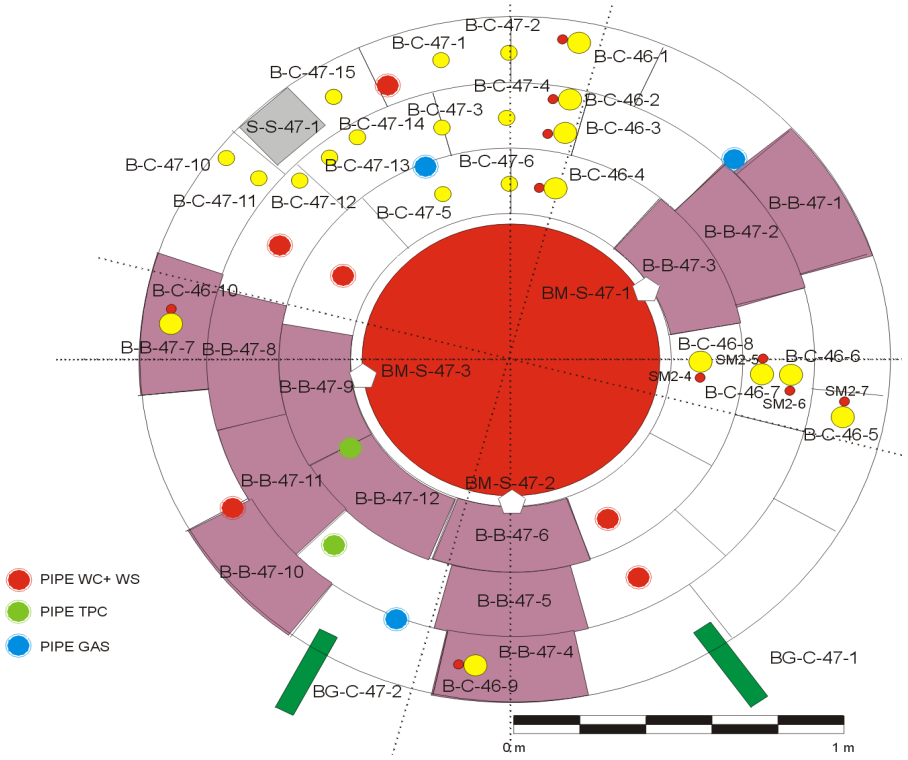


DISMANTLING PHOTO

SAMPLING SECTION 47	LOCATION		
	"Actual" x coordinate: 11.735 m	Instrumented section: NA	Bentonite slice: 44 (43)

SAMPLES				
Code	Nº of samples	Type	Destination	
B-B-47-1 to 9	9	Bentonite	CIEMAT	New Sample: B-C-47-10 to 15 around fisurometer BG-C-47-1 and2 were taken in bentonite layer 43 New samples B-C-46-1B to 10B: samples continuing of B-C-46-1A to 10 A
B-C-47-1 to 6	6	Bentonite	CIEMAT	
BG-C-47-1 to 2	2	Bentonite /Rock	Obayashi	
B-B-47-10 to 12	3	Bentonite	SKBC	
BM-S-47-1 to 3	3	Bentonite	CIEMAT	
B-C-47-10 to 15	5	Bentonite	CIEMAT, U.BERN, SKB	
B-C-46-1B to 10B	10	Bentonite	ETHN	

DISMANTLING FIGURE



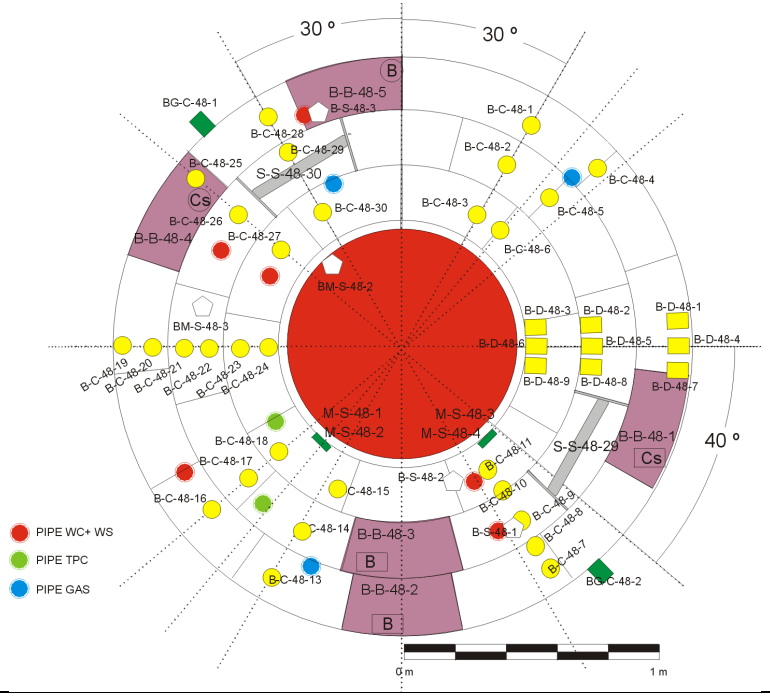
DISMANTLING PHOTO

SAMPLING SECTION 48	LOCATION		
	"Actual" x coordinate: 12.001 m	Instrumented section: F2	Bentonite slice: 42

SAMPLES			
Code	Nº of samples	Type	Destination
B-B-48-1 to 5	5	Bentonite	CIEMAT
B-D-48-1 to 9	9	Bentonite	UDOE
B-C-48-7 to 11 and 19 to 24	11	Bentonite	MIND
B-C-48-4 to 6, 13 to 15 and 25 to 27	9	Bentonite	COMI
B-C-48-1 to 3, 16 to 18 and 28 to 30	9	Bentonite	UNIM
M-S-48-1 to 4	2	Metal	Univ. Berna
B-S-48-1 to 3	3	Bentonite	CIEMAT
BG-C-48-1 and 2	2	Bentonite/Rock	COMI
BM-S-48-2 to 3	2	Bentonite/Metal	BGR

B-C-48-12 not taken
BM-S-48-1 not taken

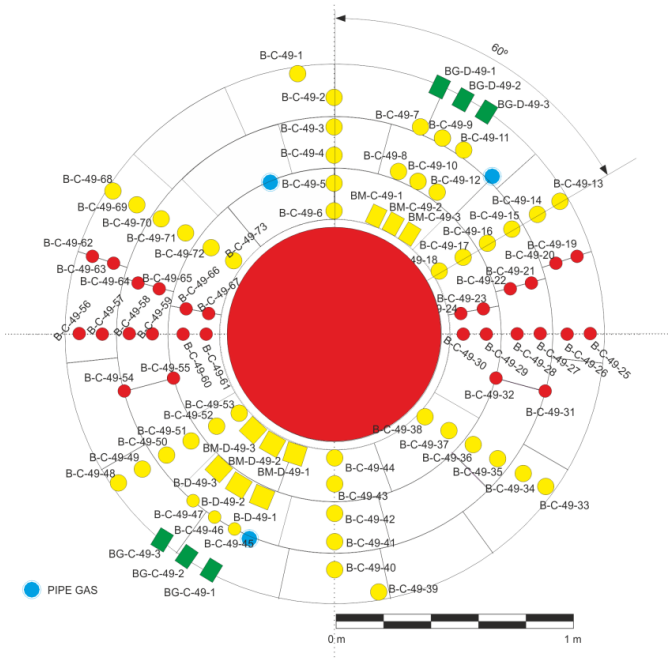
DISMANTLING FIGURE



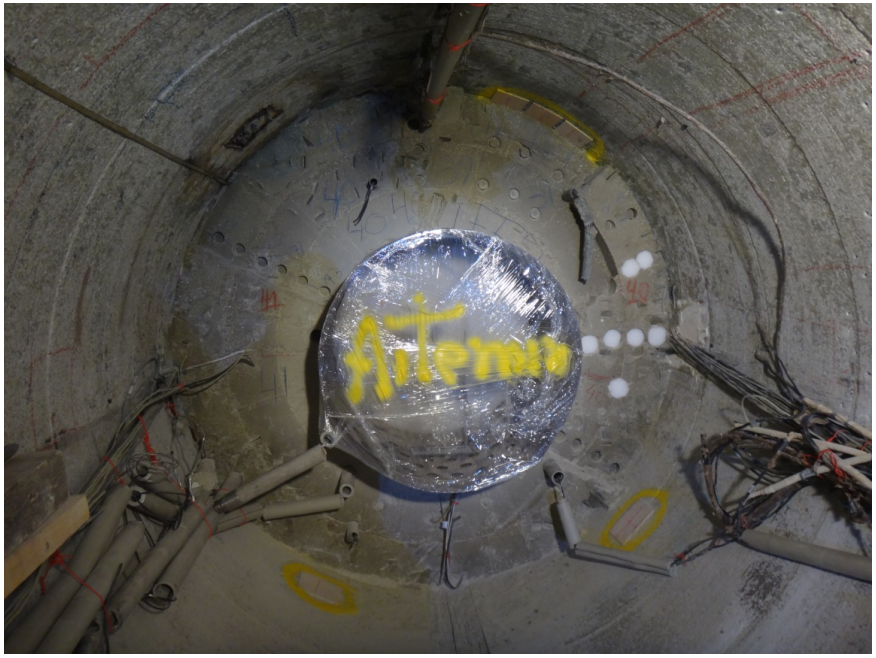
DISMANTLING PHOTO

SAMPLING SECTION 49	LOCATION			
	"Actual" x coordinate: 12.250 m		Instrumented section: NA	Bentonite slice: 40
SAMPLES				
Code	Nº of samples	Type	Destination	
B-C-49-1 to 6, 13 to 18, 33 to 44, 48 to 53&68 to 73	36	Bentonite	AITE	
BG-C-49-1 to 3	3	Bentonite/Rock	UDOE	
BM-C-49-1 to 3	3	Bentonite/Metal	UDOE	
B-C-49-7 to 12	6	Bentonite	UDOE	
BG-D-49-1 to 3	3	Bentonite/Rock	UDOE	
BM-D-49-1 to 3	3	Bentonite/Metal	UDOE	
B-D-49-1 to 3	3	Bentonite	UDOE	
B-C-49-45 to 47	3	Bentonite	UDOE	
B-C-49-19 to 32 & 54 to 67	28	Bentonite	SAIN	

DISMANTLING FIGURE



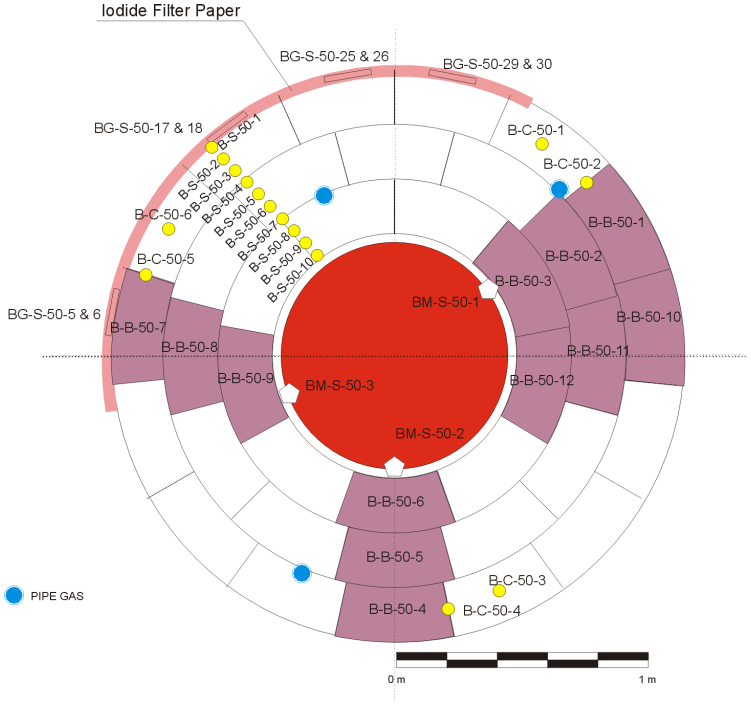
DISMANTLING PHOTO



SAMPLING SECTION 50	LOCATION		
	"Actual" x coordinate: 12.640 m	Instrumented section: NA	Bentonite slice: 37
SAMPLES			
Code	Nº of samples	Type	Destination
B-B-50-1 to 6	6	Bentonite	CIEMAT
B-B-50-7 to 9	3	Bentonite	UPC
B-C-50-1 to B-C-50-6	6	Bentonite	CIEMAT
BG-S-50-5,6,17,18,25,26,29,30	8	FP	CIEMAT
BM-S-50-1to3	3	Bent./liner	CIEMAT
B-S-50-1 to 10	10	Bentonite	BGR
B-B-50-10 to 12	3	Bentonite	SKBC

BG-S-50-5 labelled as BG-S-50-5-I
Not every planned iodide paper samples taken

DISMANTLING FIGURE

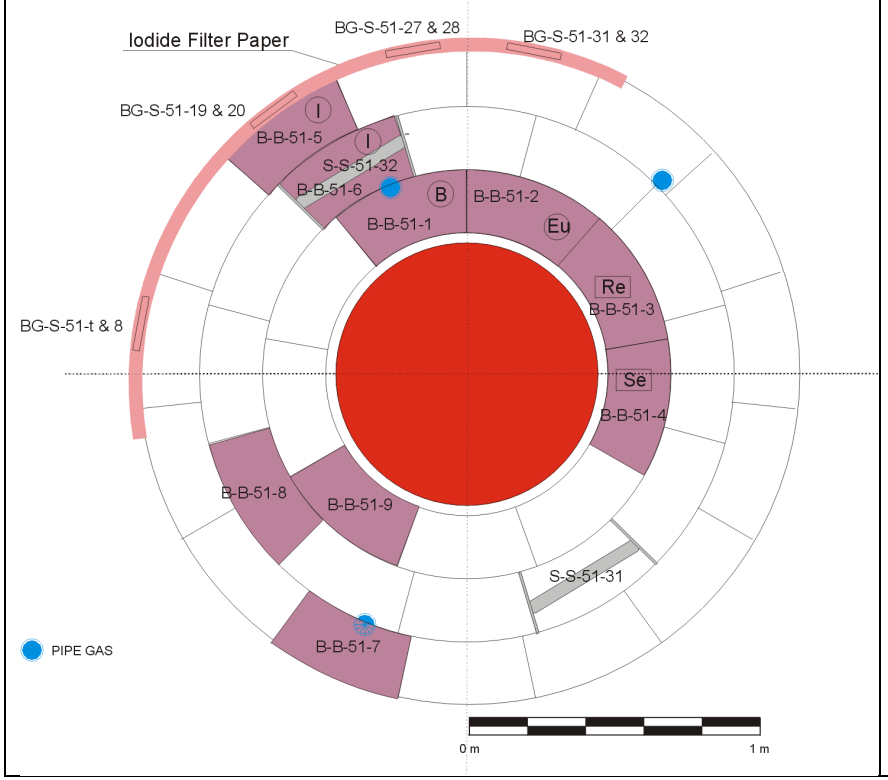


DISMANTLING PHOTO

SAMPLING SECTION 51	LOCATION		
	"Actual" x coordinate: 13.273 m	Instrumented section: E2	Bentonite slice:32
SAMPLES			
Code	Nº of samples	Type	Destination
B-B-51-1 to 6	6	Bentonite	CIEMAT
B-B-51-7 to 9	3	Bentonite	Nagra
BG-S-51-7, 8,19,20,27,28,31, 32	8	FP	CIEMAT

New samples: B-B-51-7 to 9
Not every planned iodide paper samples taken. Taken in bentonite layers 34 and 35

DISMANTLING FIGURE

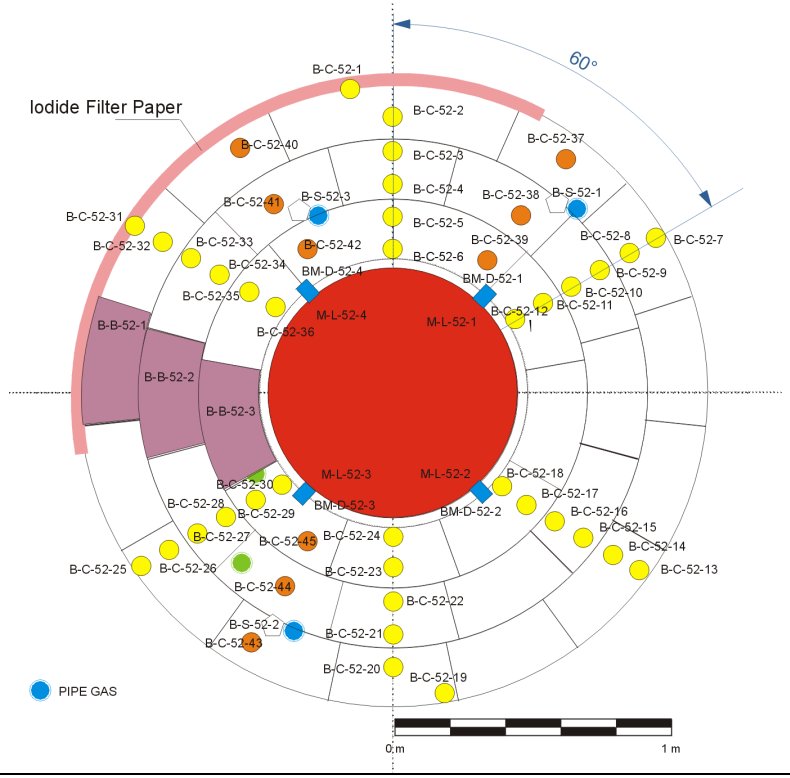


DISMANTLING PHOTO

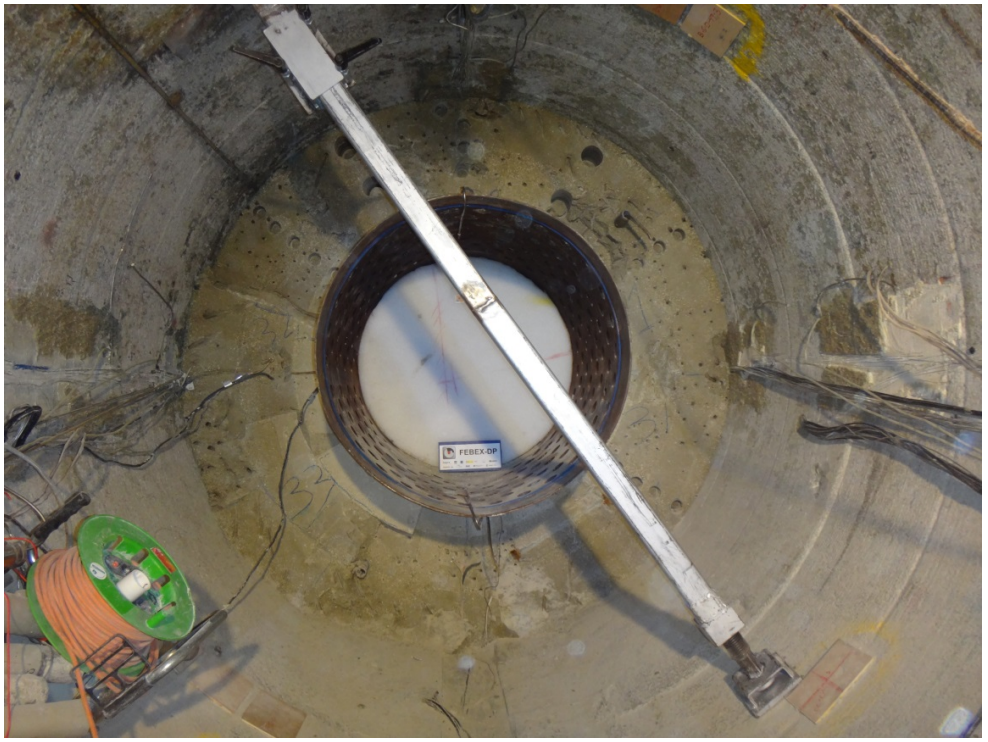
SAMPLING SECTION 52	LOCATION		
	"Actual" x coordinate: 13.379 m	Instrumented section: NA	Bentonite slice:31
SAMPLES			
Code	Nº of samples	Type	Destination
B-C-52-1 to 36	36	Bentonite	AITEMIN
M-L-52-1 to 4	4	Liner	TECNALIA
BM-D-52-1 to 4	4	Bentonite/Liner	CIEMAT
B-S-52-1 to 3	3	Bentonite	CIEMAT
B-B-52-1 to 3	3	Bentonite	EFPL
B-C-52-37 to 45	9	Bentonite	BGR

New samples: B-B-52-1 to 3
New sample B-C-52-37 to 45
M-H-52-1 taken at Aitemin's workshop by Tecnalia

DISMANTLING FIGURE



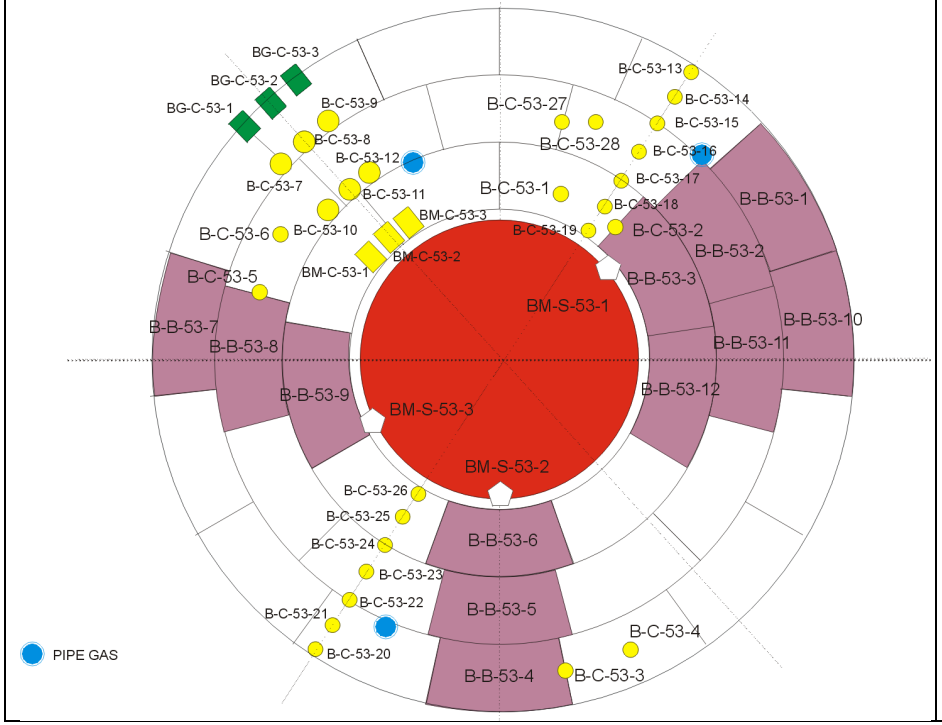
DISMANTLING PHOTO



SAMPLING SECTION 53	LOCATION		
	"Actual" x coordinate: 13.768 m	Instrumented section: NA	Bentonite slice: 28
SAMPLES			
Code	N° of samples	Type	Destination
B-B-53-1 to 9	9	Bentonite	CIEMAT
B-C-53-1 to 6	6	Bentonite	CIEMAT
BM-S-53-1 to 3	3	Bent./liner	CIEMAT
BG-C-53-1 to 3	3	Bentonite/ Rock	UDOE
BM-C-53-1 to 3	3	Bentonite /Metal	UDOE
B-C-53-7 to 12	6	Bentonite	UDOE
B-C-53-13 to 26	14	Bentonite	BGR
B-B-53-10 to 12	3	Bentonite	SKBC
B-C-53-27 to 28	2	Bentonite	Nagra

New samples: B-C-53-27 and 28

DISMANTLING FIGURE

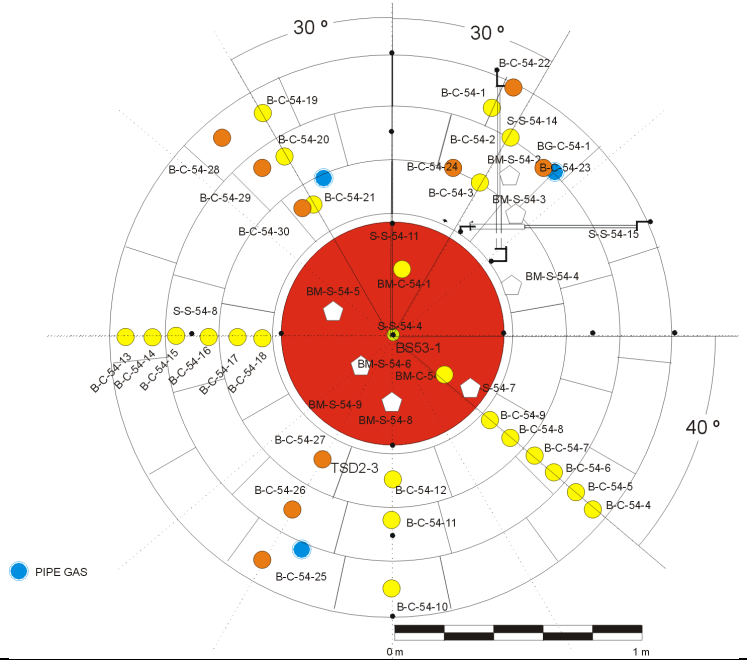


DISMANTLING PHOTO

SAMPLING SECTION 54	LOCATION		
	"Actual" x coordinate: 14.289 m	Instrumented section: D2	Bentonite slice: 24

SAMPLES				
Code	Nº of samples	Type	Destination	
BM-S-54-2,3	2	Bent./ sensor	TECNALIA	BM-C-54-1&2 from layer 23 BM-S-51-1, BG-C-54-1 & 2 not taken New samples B-C-54-22 to 30 New samples: BM-S-54- 7 to 9 taken from bentonite layer 23 New samples: BM-S-54_P1 to P17 (protrusions in liner holes – not shoed in the drawings)
BM-S-54-4	1	Bentonite/liner	CIEMAT	
BM-C-54-1 & 2	2	Bentonite/heater	CIEMAT	
B-C-54-1 to 3 & 10 to 12 & 19 to 21	9	Bentonite	COMI	
B-C-54-4 to 9 & 13 to 18	12	Bentonite	MIND	
B-C-54-22 to 30	9	Bentonite	BGR	
BM-S-54-5	1	Bentonite/Metal	BGR	
BM-S-54-7,8,9	3	Bentonite/Metal	CIEMAT	

DISMANTLING FIGURE

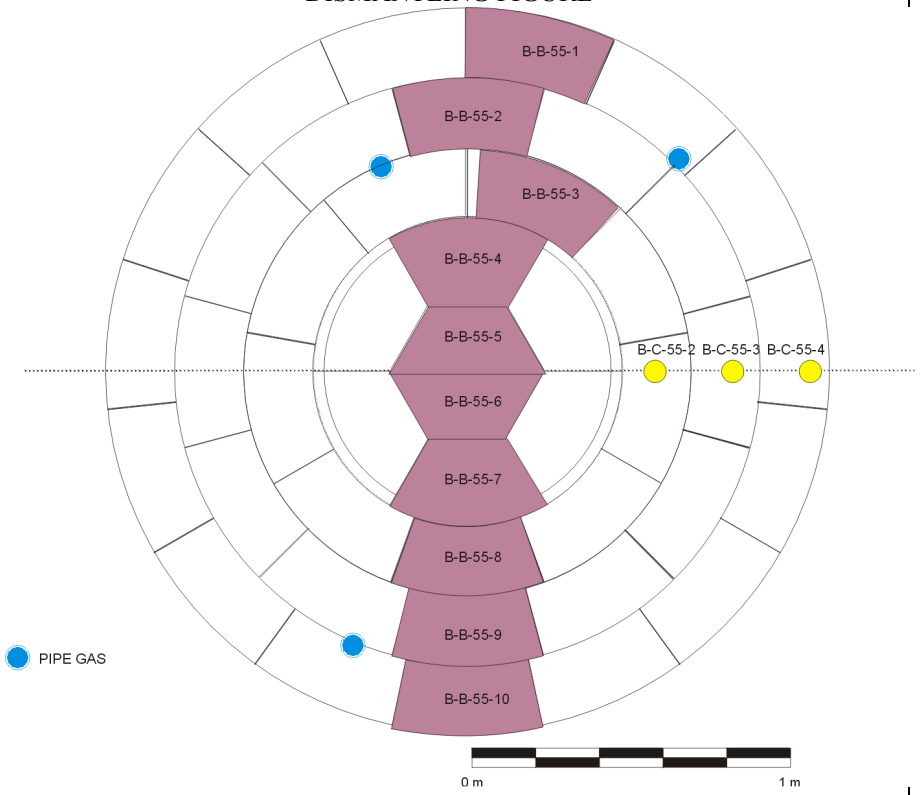


DISMANTLING PHOTO

SAMPLING SECTION 55	LOCATION		
	"Actual" x coordinate: 14.410 m	Instrumented section: NA	Bentonite slice: 23

SAMPLES				
Code	Nº of samples	Type	Destination	New samples: B-B-55-1 to 10 B-C-55-1 not taken
B-C-55-2 to 4	3	Bent.	AITEMIN	
B-B-55-1 to 10	10	Bentonite	Nagra	

DISMANTLING FIGURE

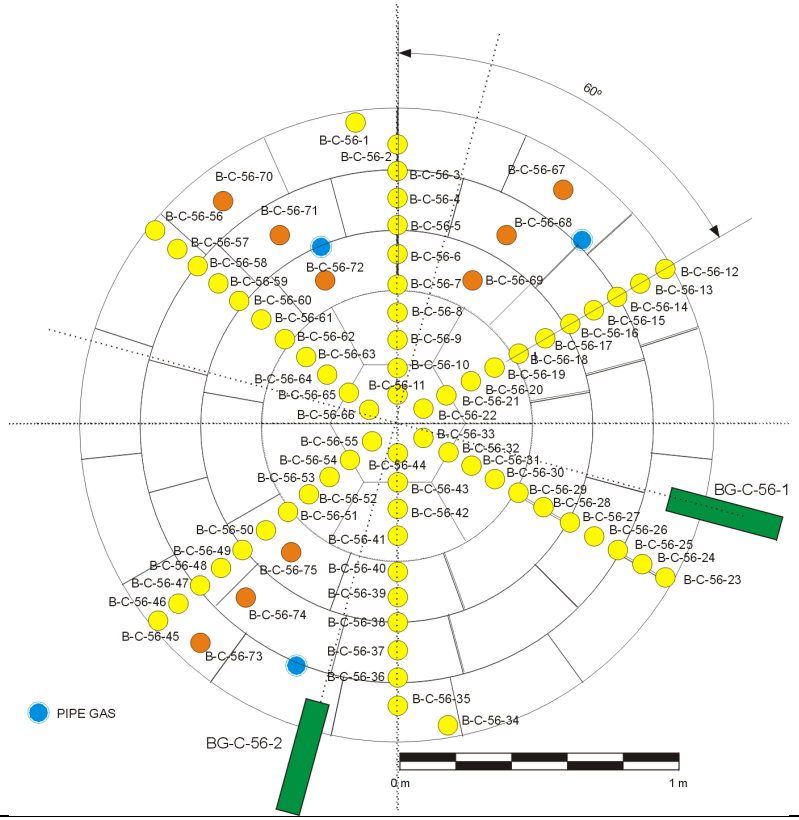


DISMANTLING PHOTO

SAMPLING SECTION 56	LOCATION		
	"Actual" x coordinate: 14.540 m	Instrumented section: NA	Bentonite slice: 22

SAMPLES				
Code	Nº of samples	Type	Destination	New samples: B-C-56-67 to 75
B-C-56-1 to 66	66	Bentonite	AITEMIN	
B-C-56-67 to 75	9	Bentonite	BGR	
BG-C-56- 1 to 2	2	Bentonite/rock	Obayashi	

DISMANTLING FIGURE

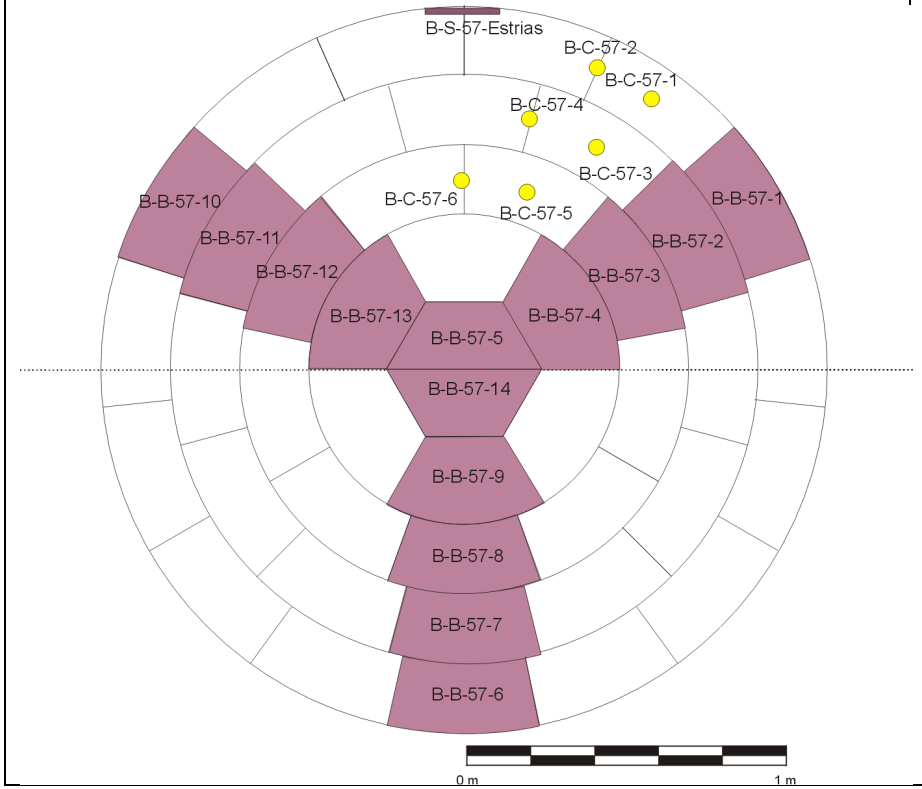


DISMANTLING PHOTO

SAMPLING SECTION 57	LOCATION		
	"Actual" x coordinate: 14.923 m	Instrumented section: NA	Bentonite slice: 19
SAMPLES			
Code	Nº of samples	Type	Destination
B-B-57-1 to 8 and B-B-57-10 to 13	9	Bentonite	CIEMAT
B-B-57-6 to 9	4	Bentonite	UPC
B-B-57-14	1	Bentonite	CIEMAT & UPC
B-C-57-1 to 6	6	Bentonite	CIEMAT

New sample in the top of the gallery B-S-57-Estrias for Ciemat

DISMANTLING FIGURE

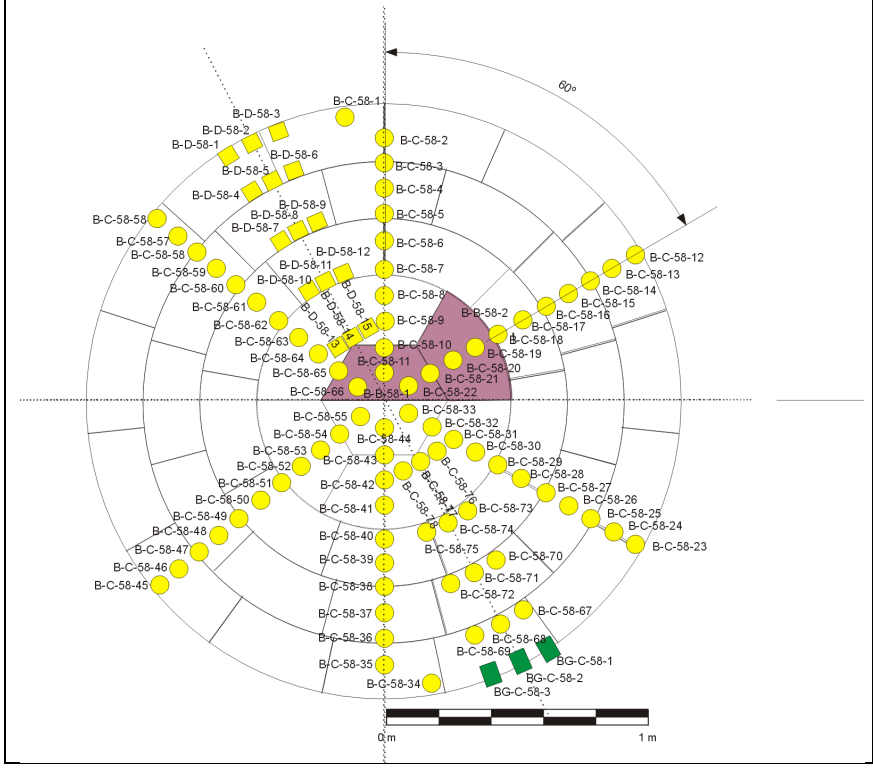


DISMANTLING PHOTO

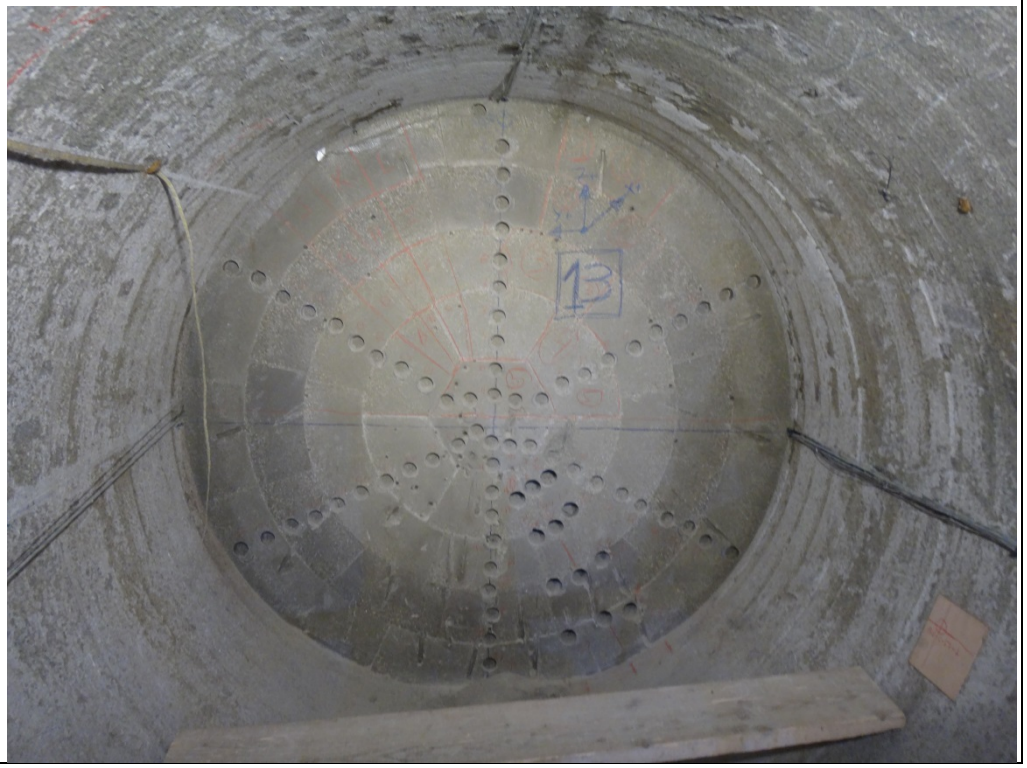
SAMPLING SECTION 58	LOCATION		
	"Actual" x coordinate: 15.700 m	Instrumented section: NA	Bentonite slice: 13
SAMPLES			
Code	Nº of samples	Type	Destination
B-C-58-1 to 66	66	Bentonite	AITEMIN
B-D-58-1 to 15	15	Bentonite	UDOE
BG-C-58-1 to 3	3	Bentonite/Granite	UDOE
B-C-58-67 to 78	12	Bentonite	UDOE
B-B-58-1 & 2	2	Bentonite	EPFL

New samples: B-B-58-1 &2

DISMANTLING FIGURE



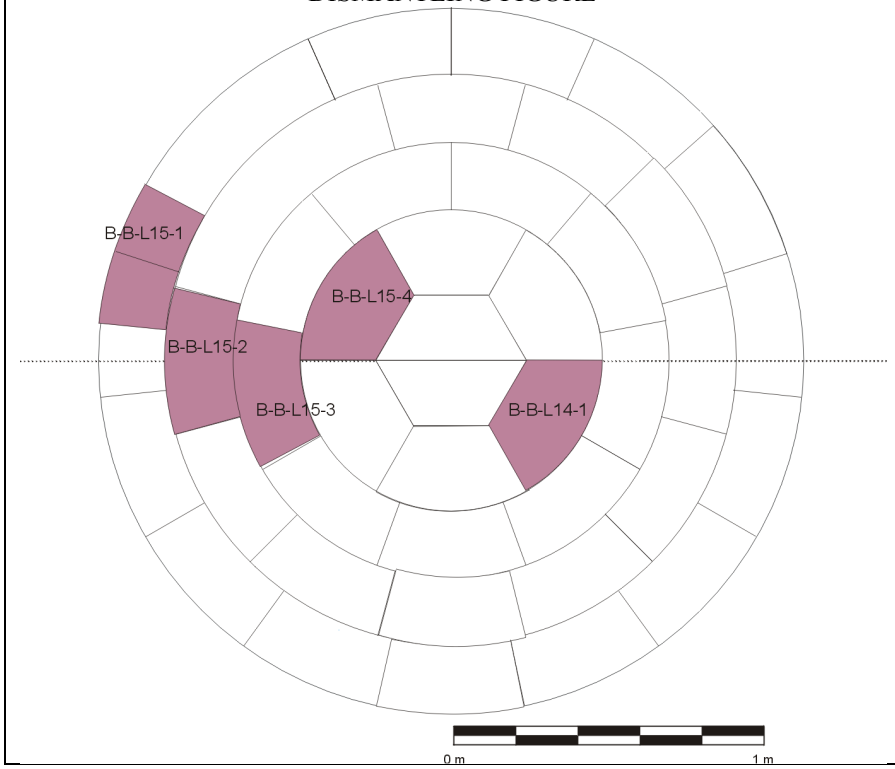
DISMANTLING PHOTO



EXTRA SAMPLING SECTION 58-59	LOCATION		
	"Actual" x coordinate:16.375 m	Instrumented section: NA	Bentonite slice: 14 and 15

SAMPLES				
Code	Nº of samples	Type	Destination	Some new samples were taken in bentonite layers 14 and 15
B-B-L15-1 to 4	4	Bentonite	EPFL	
B-B-L14-1	1	Bentonite	EPFL	

DISMANTLING FIGURE

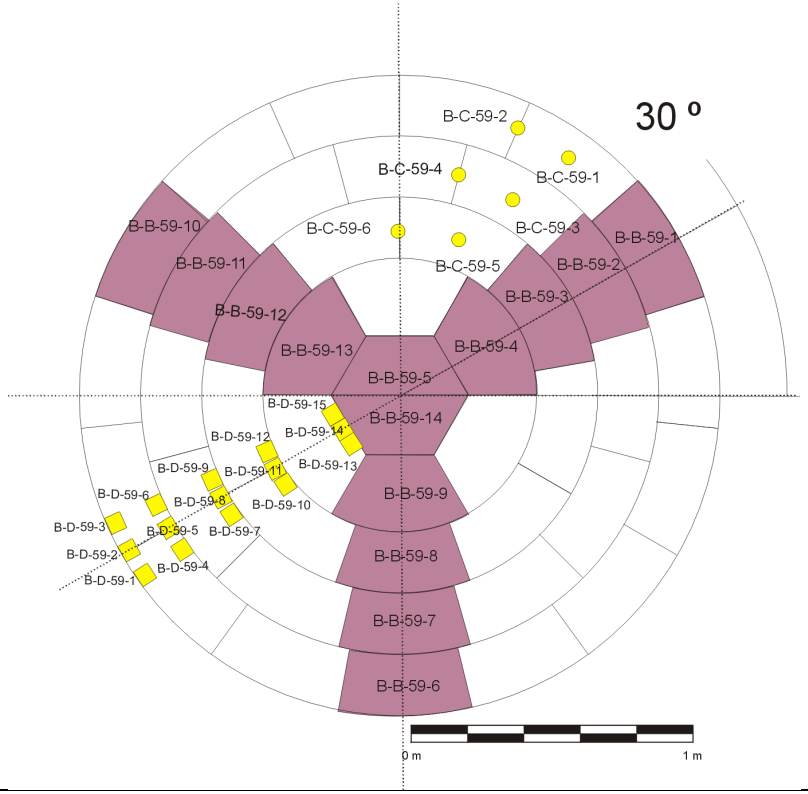


DISMANTLING PHOTO
Not taken

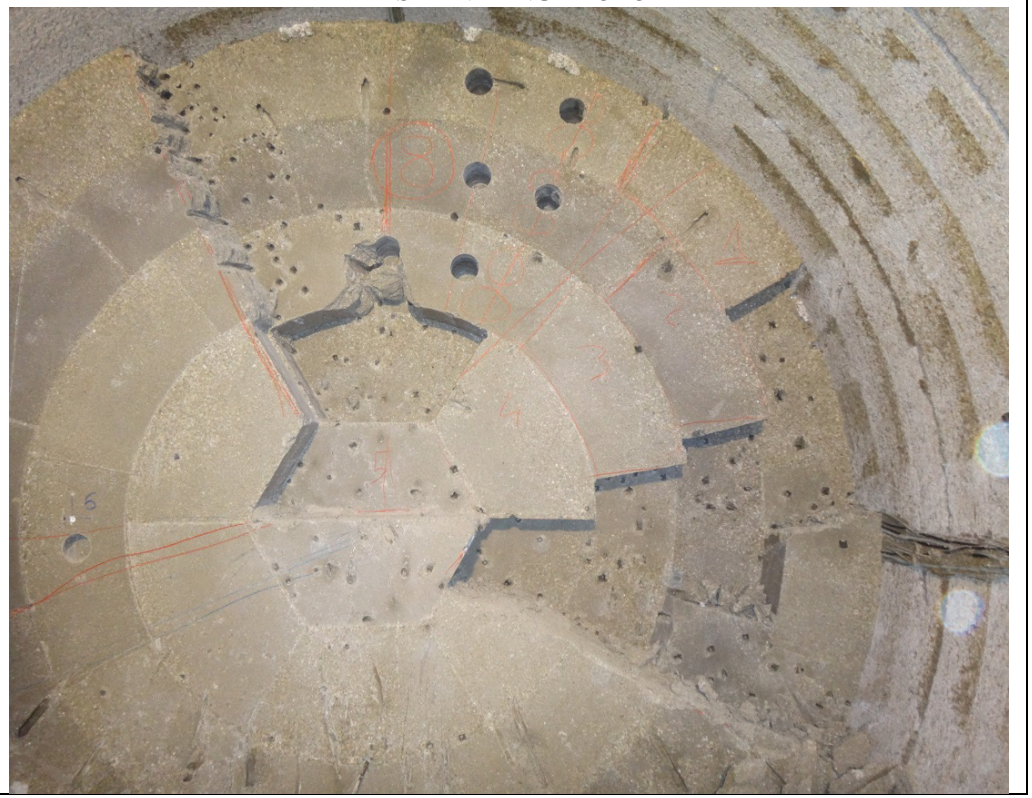
SAMPLING SECTION 59	LOCATION		
	"Actual" x coordinate:16.375 m	Instrumented section: NA	Bentonite slice: 8

SAMPLES			
Code	Nº of samples	Type	Destination
B-B-59-1 to 14	14	Bentonite	CIEMAT
B-C-59-1 to 6	6	Bentonite	CIEMAT
B-D-59-1 to 15	15	Bentonite	UDOE

DISMANTLING FIGURE



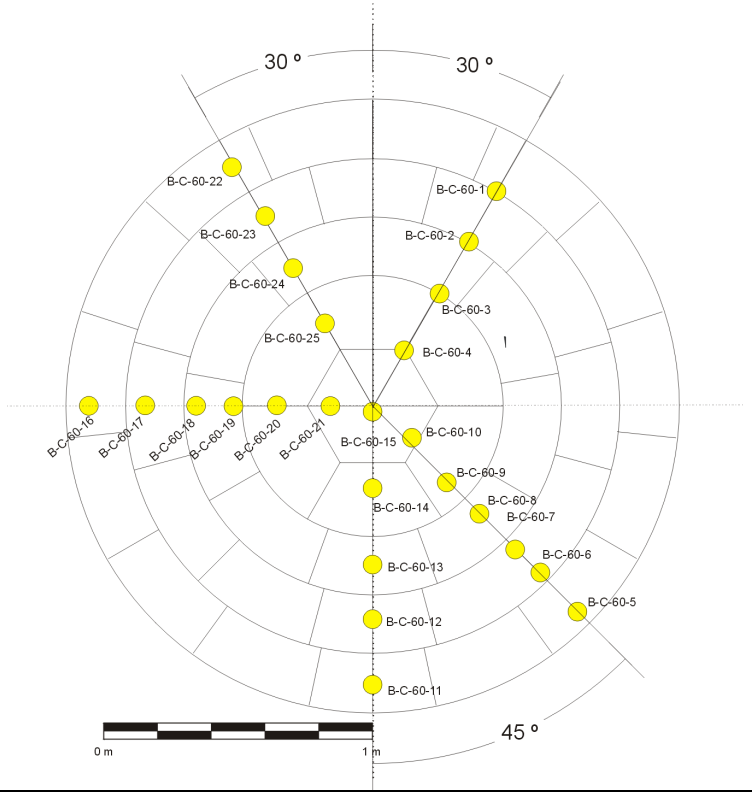
DISMANTLING PHOTO



SAMPLING SECTION 60	LOCATION		
	"Actual" x coordinate:16.720 m	Instrumented section: NA	Bentonite slice: 5
SAMPLES			
Code	Nº of samples	Type	Destination
B-C-60-1 to 4, 11 to 15 & 22 to 25	13	Bentonite	COMI
B-C-60-5 to 10 & 16 to 21	12	Bentonite	MIND
BG-C-60-1 and 2	2	Bentonite/Rock	COMI

BG-C-60-1 and 2 were not sampled

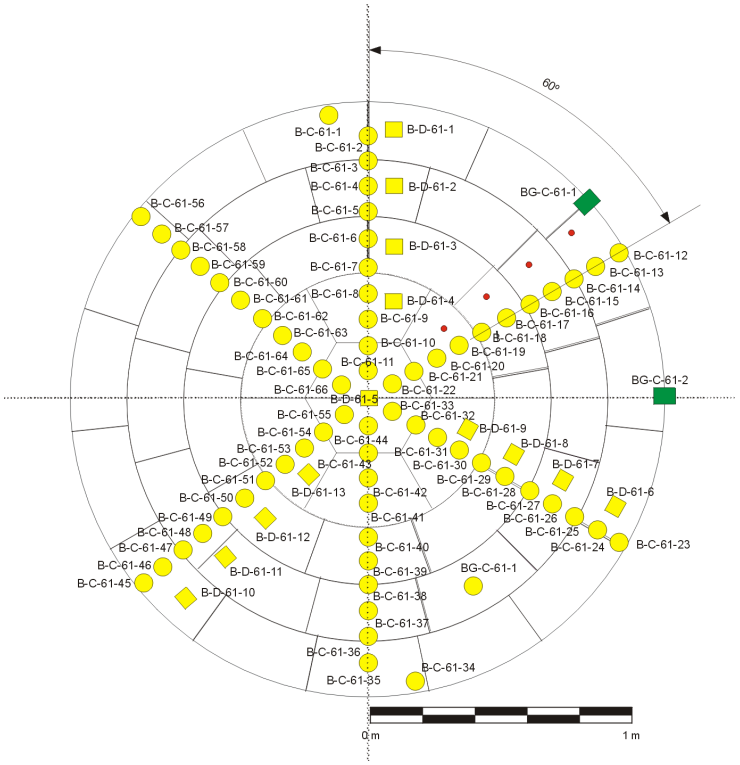
DISMANTLING FIGURE



DISMANTLING PHOTO

SAMPLING SECTION 61	LOCATION		
	"Actual" x coordinate: 16.910 m	Instrumented section: NA	Bentonite slice: 4
SAMPLES			Surface was too irregular for X-coords measurements Thermal conductivity was measured at 4 points (red dots) It was not easy to differentiate layers 4 and 3 while sampling B-D-61-X
Code	Nº of samples	Type	Destination
B-C-61-1 to 66	66	Bentonite	AITEMIN
BG-C-61-1&2	2	Bentonite	CIEMAT
B-D-61-1 to 13	13	Bentonite	ETHN

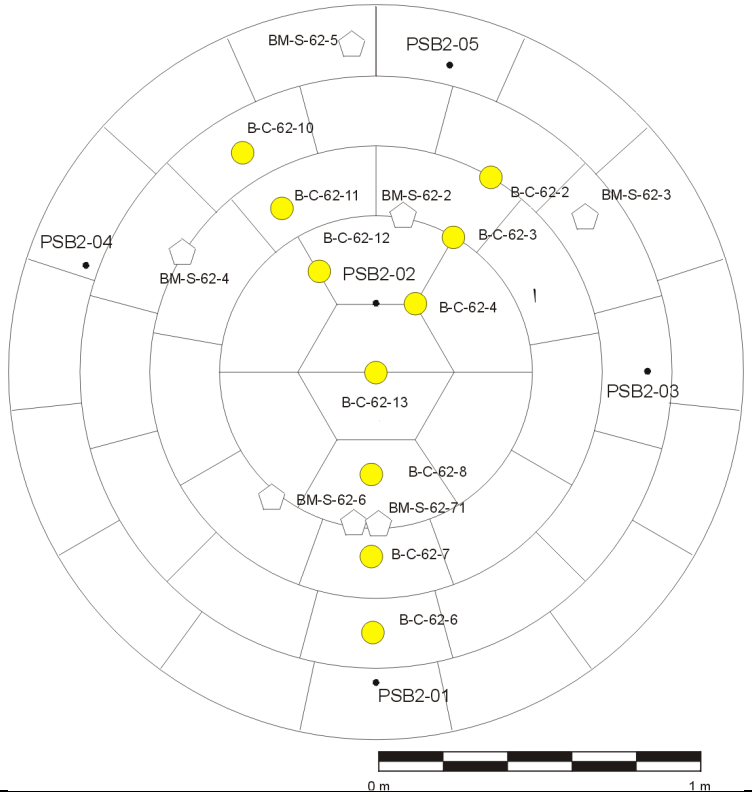
DISMANTLING FIGURE



DISMANTLING PHOTO

SAMPLING SECTION 62	LOCATION		
	"Actual" x coordinate:	Instrumented section: B2	Bentonite slice: 1 to 3
SAMPLES			New samples: B-C-62-1 to 15, but B-C-62-1, -5, -9 were impossible to take. New samples: BM-S-62-71-6&7: anchoring and iron bar of extensometer
Code	Nº of samples	Type	Destination
BM-S-62-1 to 7	7	Bent./sensor	CIEMAT
B-C-62-2 to 4, 6to 8 and 10 to 13	10	Bentonite	BGR

DISMANTLING FIGURE



DISMANTLING PHOTO