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Abstract

Bentonite clay is an important part of the Swedish KBS-3 design for final disposal of spent nuclear fuel. The spent fuel will be placed in copper canisters positioned in deposition holes at 500 m depth in crystalline rock. The canisters are embedded in dense bentonite clay that minimize water flow and transport between canister and rock. The swelling pressure of the bentonite will keep the canister in place but at the same time the plasticity of the bentonite must be high enough in order to not transfer forces from the rock in case of any rock displacements.

The MX80 bentonite from American Colloid Co (Wyoming) has long been the reference for buffer material in the KBS-3 concept. Extending the knowledge base of alternative buffer materials will make it possible to optimize the KBS-3 concept regarding safety, availability and cost. For this reason the field experiment ABM, Alternative Buffer Material was started at Äspö Hard Rock Laboratory during 2006. Three test packages were installed. The packages included eleven different clays that were chosen to examine effects of smectite content, interlayer cations and overall iron content. The tests are performed at repository depth with access to natural water from the bedrock. The test packages consists of a central steel tube with heaters inside, ring shaped bentonite blocks that are thread onto the tube, sensors and equipment for artificial saturation. The outer diameter is 280 mm and the length of a test package is approximately three metres. The packages were installed in drilled holes with a diameter of 300 mm. Two of the test packages installed 2006 have later been terminated and investigated (2009 and 2013).

The ABM tests have been assessed to give interesting results and it was therefore decided to install three additional test packages. The new test packages were installed in November 2012 at Äspö HRL. This report describes the design, the block manufacturing, mounting of test packages and the final installation.

Sammanfattning

Bentonitlera är en viktig del av det Svenska KBS-3 konceptet för slutlig förvaring av använt kärnbränsle. Det använda bränslet kommer att placeras i kopparkapslar som i sin tur placeras i deponeringshål borrade på 500 meters djup i kristallint berg. Kopparkapslarna är inbäddade i tät bentonitlera som minimerar vattenflöde och förhindrar transporter mellan kapslar och berg. Svälltrycket hos leran kommer att hålla kapslarna på plats men samtidigt måste plasticiteten hos leran vara tillräcklig för att förhindra att eventuella krafter från berget inte överförs till kapseln vid till exempel en jordbävning.

MX-80 bentonit från American Colloid Co i Wyoming, USA har under lång tid varit referensmaterial för bufferten i KBS-3 konceptet. En ökning av kunskapsbasen för alternativa material kommer att göra det möjligt att optimera KBS-3 konceptet när det gäller säkerhet, tillgänglighet och kostnad. Av denna anledning startades ett nytt projekt, Alternativa Buffert Material, ABM, på Äspö HRL under 2006. Tre testpaket med totalt elva olika bentoniter som valdes ut för att undersöka effekten av olika smektitinnehåll, katjoner och järninnehåll, installerades i berget. Testerna genomförs på förvarsdjup och med tillgång till formationsvatten från det omgivande berget. Testpaketen består av ett centralt stålrör med elektriska värmare på insidan, ringformade bentonitblock som är trädda över röret, givare samt utrustning för konstgjord bevätning. Testpaketens ytterdiameter är cirka 280 mm och längden cirka 3 meter. Testpaketen installerades i borrhål med diametern 300 mm. Två av de tre testpaket som installerades 2006 har brutits och undersökts (2009 och 2013).

Den aktuella försökstypen har bedömts ge intressanta resultat och därför bestämdes det att installera ytterligare tre paket. De nya testpaketen installerades i November 2012 i Äspö HRL. Denna rapport beskriver designen, blocktillverkningen, monteringen av testpaketen samt installationen av dessa.

Contents

1 Background

Bentonite clay is part of the Swedish KBS-3 design for final repositories of spent nuclear fuel. A basic requirement for the buffer is that it has high swelling and sealing properties. Montmorillonite with sodium as the dominant cation has very high swelling potential and is available in sufficient quantities and is therefore a realistic buffer alternative. The MX80 bentonite from American Colloid Co (Wyoming) has long been the reference for buffer material in the KBS-3 concept. Extending the knowledge base of alternative buffer materials will make it possible to optimise regarding safety, availability and cost. For this reason the field experiment Alternative Buffer Material was started at Äspö Hard Rock Laboratory. Three test packages were installed at Äspö HRL in the end of 2006 (Eng et al. 2007). Two of these test packages have been terminated; test package 1 was terminated in May 2009 (Svensson et al. 2011) and test package 2 was terminated in April 2013. The results from the first tests were found to be of high interest and therefore it was decided to install three additional test packages. This report describes the test design, materials, preparatory work, block compaction, site preparations and the installation of the three new test packages at Äspö HRL. The installation was made in the beginning of November 2012.

One of the main purposes with the experiment is to study the stability and long-term behaviour of different bentonite materials. Examples on parameters to study are e.g. swelling behavior, movement of dissolvable minerals and the stability of both smectite minerals and accessory minerals. The three test packages installed in 2006 included eleven different clays with difference in the amount of swelling minerals, smectite counter ions, total amount of iron and various accessory minerals.

The use of a central steel heater makes it possible to look at the interaction of metallic iron with the buffer. The amount of instruments has been kept at a minimum in order to minimize disturbance of the experiments. This means that the main results of the test will be captured after termination of the tests.

Alternative Buffer Material (ABM) experiment is a SKB project with several international partners, collaborating in the part of laboratory experiments and analysis. There is no strict procedure for how the different organizations contribute or how the analyses are done. It is possible for one organization to analyze all materials or only the ones that they find most interesting.

2 Experiment design

2.1 General

The experiment layout is similar to the Swedish KBS-3 concept with a copper canister surrounded by clay situated in crystalline bedrock at approximately 500 m depth. The differences are mainly the scale and that the simulated canister is made of steel instead of copper.

The installation and design of the first three test packages within the ABM experiment that were installed during 2006 are described in a report (Eng et al. 2007). The new test series, described in this report, was installed during 2012 and includes also three test packages with a very similar design. The main differences are the material configuration and some extra tests where copper and titanium samples have been embedded into some of the blocks.

2.2 Test principal

The experiment consists of three test-packages placed in three separate vertical bore holes drilled in granitic rock. Each test package consists of a central steel tube including heaters on the inside, ring shaped bentonite blocks and some instruments (Figure 2-1). The bentonite will during test time be exposed to conditions fairly similar to the KBS-3 concept except for the temperature which will be higher, 130 °C compared to 90 °C. The higher temperature is expected to accelerate alteration processes such as mineral dissolution and neo-formations.

All three test packages were prepared in order to use an artificial water saturation system. The outermost slot between bentonite blocks and rock was filled with sand in which titanium pipes, perforated with drilled holes at different levels, are placed. The pipes are connected to a water tank which can be pressurized.

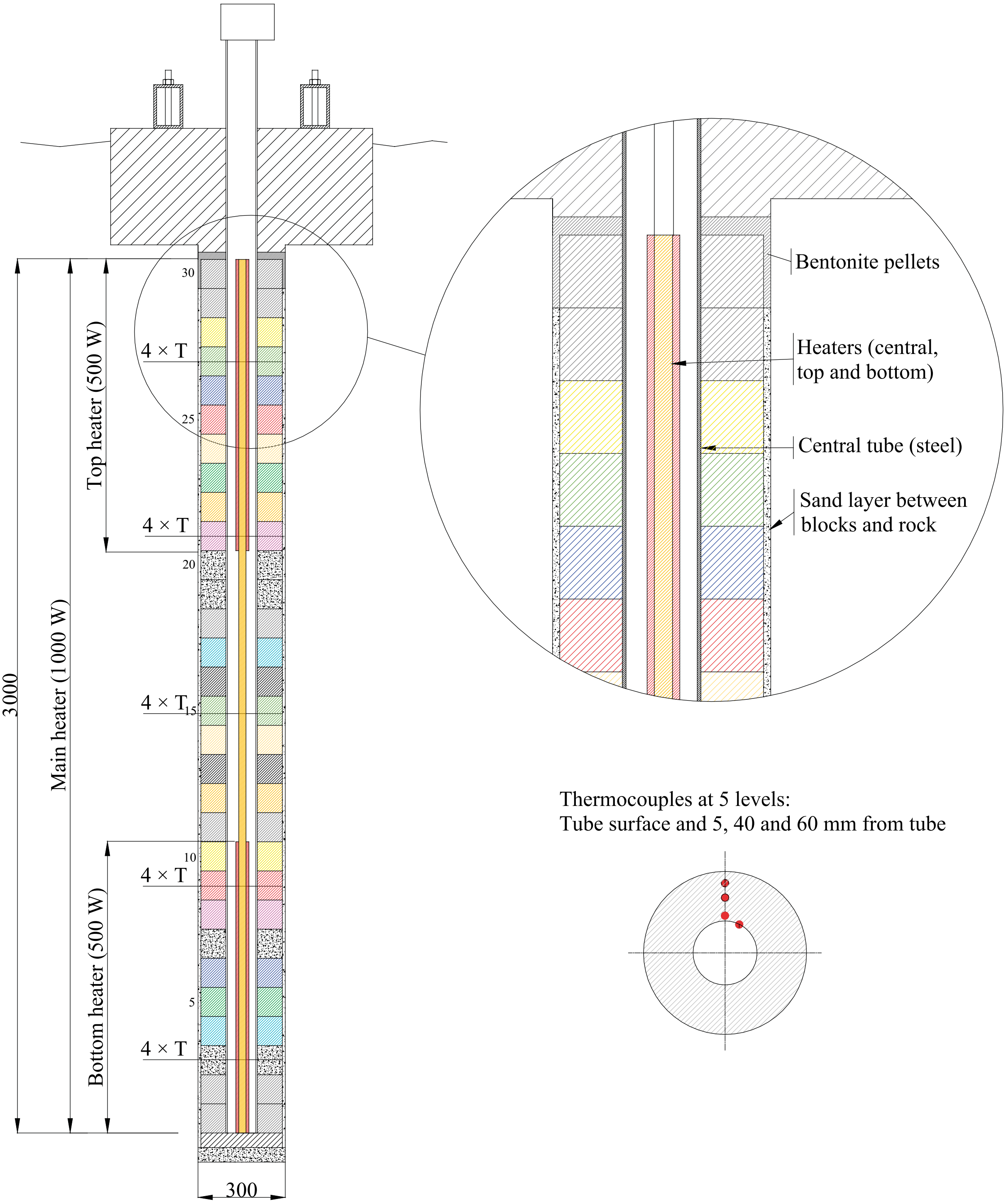


Figure 2-1. *Schematic drawing showing the principal design of the new ABM test packages. On top is a concrete block situated to keep the swelling bentonite blocks in place, reinforced with steel bars on top. The numbers at the blocks indicate block numbers (#).*

3 Test site

3.1 Location

The three new test packages were installed in a tunnel at Äspö HRL named TASD. The tunnel is located at a depth of −420 m. The main requirements for the site selection were that the depth should be similar to a repository and that the site was reasonable dry.

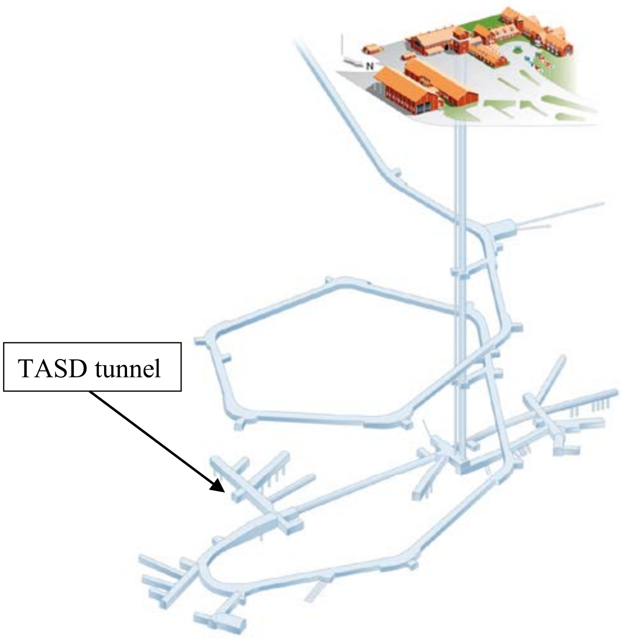
3.2 Deposit holes

Three deposit holes were drilled in the TASD tunnel, see detailed drawing provided in Appendix 1. The holes are denominated KD0096G01, KD0098G01 and KD0099G01. The drilling was made in two steps i.e. it started with drilling of a pilot hole, d = 76 mm, and continued later with a hole with a diameter of 300 mm. After drilling of the three pilot holes, the water inflow rate to each test hole was measured. All three holes were found to be very dry. After having increased the diameter to 300 mm, the inflow increased in one of the holes, KD0098G01, to approximately 8.5 liters/24 hours. All inflow seemed to come from one fracture located 0.8 metre down from the floor.

The floor in the test niche has a casted concrete sole with a thickness between 200 and 600 mm. The test holes were drilled with the requirement to have 3 metres fresh rock in the bottom. The total depth, the length of the fresh rock and the thickness of the concrete sole is provided in Table 3-1 for each of the bore holes.

Table 3-1. Data regarding depth, length of the fresh rock and the thickness of the concrete sole.

Bore hole, no	Total depth, mm	Length of fresh rock, mm	Thickness of concrete sole, mm
KD0096G01	3600	3150	450
KD0098G01	3600	3380	220
KD0099G01	3700	3130	570



Figur 3-1. *Schematic showing the Äspö HRL tunnel system and the TASD tunnel position.*

4 Buffer materials

4.1 General

The first three ABM test packages (1–3) were installed in 2006 (Eng et al. 2007). The new ABM test packages (4,5 and 6) includes twelve different materials which have been compacted to blocks, installed in the field tests and exposed to high temperature and saturated by formation water (natural water) from the rock and/or from the water saturation system. Most of the materials were also present in the first three test packages but there have been some changes:

Materials removed: Callovo Oxfordian, Friedland, MX-80 granulate and MX-80 granulates with quarz.

New materials: Asha-NW BFL-L, Geohellas saponite and GMZ.

This chapter gives a short description of the materials regarding country of origin, the main content of clay minerals and also the commercial name and abbreviations, see also (Svensson et al. 2011).

4.2 Description of the different materials

Most of the materials here are described in more detail by Karnland et al. (2006) and by Svensson et al. (2011).

- **Asha 505** produced by Ashapura Minechem Co.is the commercial name of natural Na-bentonite that is quarried in the Kutch area, 60–80 km from the ports of Kandla and Mandvi on the north-west-coast of India. The bentonite is associated with the basaltic Deccan Trap rocks of Tertiary age and formed through hydrothermal alteration of volcanic ash in saline water (Shah 1997). The bentonite occurs in scattered pockets or layers within the basaltic rocks, with thicknesses ranging from a few metres up to 30 metres. Due to the high content of secondary iron oxides the color is normally dark reddish brown but there are also light colored variants low in iron.
- **Calcigel** is the commercial name of a natural Ca-bentonite produced from selected Bavarian bentonites by Süd-Chemie AG. The bentonites are quarried in the triangle between Mainburg, Moosburg and Landshut in southern Germany, where the most important commercial deposits in Germany are located. Most of the Bavarian bentonite deposits occur as scattered, rather thin (≤ 3 m) lenses or layers in sedimentary sequences of late Miocene marls and tuffaceous sands, and are believed to have formed by in situ alteration of acid vitreous tuff, originating from the volcanic activity in the Carpathian Mountains (Süd-Chemie AG). The bentonite quality varies from relatively pure montmorillonite (up to 70 %) to material with rather much kaolinite, mica and quartz.
- IBECO **Deponit CA-N** is the commercial name of a natural calcium bentonite mined by S&B Industrial Minerals S.A. The bentonite is quarried in the north-eastern part of the island of Milos, Greece, where some of the economically most important bentonite deposits in Europe are concentrated. The island of Milos is located in the central part of the South Aegean active volcanic arc. Pyroclastic tuffs and lavas of andesitic to rhyolitic compositon are the main parent rocks of the bentonite, which forms irregular bodies within the pyroclastics (Kelepertsis 1989). The volcanic rocks have yielded K-Ar ages in the range 3.5–0.09 m.y. Based on isotope data, Decher et al. (1996) conclude that the bentonite formation is a result of hydrothermal reactions between the permeable volcanic rocks and percolating groundwater heated during volcanic activity, although there is some disagreement about the genesis (e.g. Christidis et al. 1995).
- The **FEBEX** bentonite is a Mg-Ca bentonite extracted from the Cortijo de Archidona deposit in the southern part of Serrata de Nijar in Almería, Spain. The deposit has been exploited by the major Spanish bentonite producer, Minas de Gádor S.A. Conditioning of the bentonite at the quarry/factory has been strictly mechanical. According to Caballero et al. (2005), the bentonites in Cortijo de Archidona are alteration products of rhyodacitic glasses and ignimbrites. Radiometric dating of the volcanic events indicates ages of 15 to 7 Ma. The FEBEX bentonite (also called S-2 or Serrata clay) had been chosen as reference bentonite by ENRESA before the start of the FEBEX project (Full-scale Engineered Barriers Experiment), among others because of the homogenous nature and very high montmorillonite content (ENRESA 1998). The subordinate amount of accessory minerals includes quartz, cristobalite, plagioclase and calcite.

- **Ikosorb Ca White** (actual commercial name: IBECO RWC White) is a Ca, Mg, Na bentonite, characterized by an high Montmorillonite content (> 80 %), a low sulphur content (< 0,1 %) and an off-white color which is related to a low content of iron in the smectite clay minerals. The subordinate amount of accessory minerals includes quartz, mica, ct-opal and feldspar. The bentonite is mined in Morocco in the Mount Tidienit area, where rhyolithic pyroclastic rocks related to a rhyodacitic intrusive body of Pliocene/Pre-Pliocene age have been altered to bentonite (Martin Vivaldi 1962).
- **Ibeco Seal M-90** (actual commercial name: IBECO RWN) is a natural sodium bentonite, characterized by a high Montmorillonite content (> 80 %) and a low sulphur content (< 0,1 %), produced by S&B Industrial Minerals A in the Askana region in Georgia/CIS. The subordinate amount of accessory minerals includes quartz, illite and mica. The bentonite is derived from andesite-trachyte pyroclastic rocks of Jurassic to Tertiary age. There are several theories for the formation of the bentonite ranging from weathering or hydrothermal alteration to submarine alteration as described by Grim and Güven (1978).
- **Kunigel V1** is the commercial name of a sodium bentonite produced by Kunimine Industries Co., Ltd., Japan. The bentonite is quarried in under-ground mines in the Tsukinuno district, northern part of Japan, which is the largest bentonite production area in Japan. The Tsukinuno formation consists of stratified bodies of bentonitized felsic tuff beds intercalated in sedimentary hard shale and mudstone of Miocene age (Takagi 2005). There are more than 30 bentonite layers in the mining area, ranging in thickness from centimetres to several metres. The Tsukinuno bentonite is composed of Na smectite with subordinate quartz, feldspars, illite, calcite, and zeolite.
- The Wyoming bentonite **MX-80**, produced by American Colloid Co., is a blend of several natural sodium dominated bentonite horizons, dried and milled to millimetre-sized grains. The Wyoming bentonite occurs as layers in marine shales, and is widespread and extensively mined, not only in Wyoming but also in parts of Montana and South Dakota. The bentonite formed through alteration of rhyolitic tephra deposited in ancient Mowry Sea basin during the Createceous, more than 65 million years ago (Slaughter and Earley 1965). There are strong evidence that the tephra altered in contact with the Mowry seawater (Elzea and Murray 1989, 1990), but palaeosalinity and palaeoredox conditions within the semi-restricted basin varied spatially and through time, which explains that the smectite composition varies both stratigraphically and laterally.
- The **Rokle** deposit within the north Bohemian volcanic areas NW of Prague, is one of the economically most important deposits in the Czech Republic. The deposit is part of a series of argillised volcanoclastic accumulations of Tertiary age, formed in shallow lacustrine basins within the stratovolcano complex of Doupovské Mountains (Konta 1986). The lens-shaped bentonite body has a maximum thickness of c. 40 m. The volcanic glass is completely altered to smectite, but flakes of biotite, which is a primary constituent of the basaltic magma, are relatively frequent. The bentonite is highly variable in colour, ranging from olive-gray to yellow/red due to the admixture of secondary iron and manganese oxides.
- **Asha NW BFL-L (new)** is produced by Ashapura Minechem Co, see Asha 505 for more data. This material is less refined and is planned to be used as a backfill material. The material has been investigated within another project (Sandén et al. 2014).
- **Geohellas saponite (new).** Saponite is also a smectite as montmorillonite, but another mineral that is trioctrahedal, it has a somewhat different structure than montmorillonite and also somewhat different properties. From Greece.
- The **GMZ-bentonite (new)** deposit has been selected as the most potential buffer/backfill material supplier for China’s HLW repository. The GMZ-bentonite deposit is a large-scale one, located in the northern China´s Inner Mongolia Autonomous Region, 300 km northwest of Beijing. The deposit, with bedded ores, was formed in late Jurassic. The ore minerals include montmorillonite, quartz, feldspar, cristobalite etc.

5 Block manufacturing

5.1 General

The blocks were compacted uni-axial in a special mould with a pressure of between 50 and 100 MPa. The mould was the same as have been used for the production of blocks to the earlier ABM tests. The block manufacturing was performed at the Technical University of Lund (Figure 5-1).

5.2 Manufacturing technique

The blocks are ring shaped and the outer periphery is somewhat conical in order to facilitate the expulsion after compaction. The edges between mantle surface and end sides are chamfered to avoid stress induced cracks. Small amounts of molybdenum sulphide containing grease were used on all steel surfaces in contact with the bentonite in order to lubricate to decrease friction. The grease was removed mechanically from the block surfaces before mounting of the blocks in the test packages, see also Section 10.3.

The blocks have an average outer diameter of approximately 277.3 mm (D = 281 mm, d = 276 mm), an inner diameter of approximately 110 mm and a height of 100 mm. A compaction pressure of 100 MPa corresponds to a load of 5089 kN.

Most of the materials were used as-delivered when compacted to blocks. For some materials it was necessary to increase the water content and also to decrease the compaction pressure in order to produce blocks with high quality. The compaction properties of most materials were known since the earlier production but for the new materials it was necessary to perform some small scale laboratory compaction tests.

Figur 5-1. *Photo showing the mould positioned in the press.*

The block manufacturing included the following work steps:

- Material weighing. In order to achieve right height of the block the right amount of material must be poured into the mould.
- A thin layer of molybdenum sulphide containing grease (lubricant) was applied on all steel surfaces in contact with the bentonite powder.
- After having poured the bentonite into the mould the upper piston is lifted in place.
- The bentonite powder is evacuated from air by use of a vacuum pump connected to steel filters placed in the bottom plate of the mould.
- The powder is compacted to a block with a rate of approximately 0.5 mm/sec.
- The block is visually inspected, weighed and measured.

5.3 Results

The results from the block compaction including data from every individual block are provided in Appendix 2. A compilation of the block data is provided in Table 5-1. In total 110 blocks were manufactured. The fourteen blocks manufactured with material from old batches (Febex and Ibeco Seal M-90), see Table 5-1, were not used in the installation. When compacting the Kunigel bentonite the blocks produced at higher pressures got fractures and broke, and it was possible to make blocks only at the lower compaction pressure, causing the density to get also lower. This was possibly an effect of the lower water content of the Kunigel bentonite.

Table 5-1. Compilation of block manufacturing data.

Material	Number of blocks	Water content %	Compaction pressure MPa	Average bulk density kg/m³	Average dry density kg/m³
MX-80 2012	20	10.6	100	2140	1935
ASHA 505 2011	7	13.1	50	2084	1842
ASHA NWL-L	7	17.2	100	2108	1799
IBECO Seal M-90 2011	7	24.2	50	2017	1624
Deponit CA-N	7	18.9	100	2075	1745
Febex 2012	7	14.3	100	2056	1799
IKOSORB 2011	6	11.8	100	2084	1864
Rokle 2012	7	17.2	100	2107	1798
Kunigel	7	8	50	1931	1787
GMZ 2011	7	16.5	100	2078	1784
Saponite 2012	7	10.8	100	1779	1606
Calcigel 2012	7	16.8	50	1992	1705
Febex (old batch)	7	14.4	100	2061	1802
IBECO Seal M-90 (old batch)	7	14.7	100	2115	1844

6 Heater system

6.1 General

Electrical heaters are used in order to simulate the residual heat from the spent fuel.

6.2 Design

The bentonite blocks in the ABM experiment are shaped as rings and are piled around a central tube. Electrical heaters are placed inside the tube. The tube is made of steel, P235TR1. A technical drawing showing the dimensions of the tube and the bottom plate which is welded to the tube are provided in Appendix 3. The uppermost half metre of the tube, which will be exposed to the tunnel conditions, was painted in order to prevent corrosion.

6.3 Heaters

The heaters were delivered by Backer BHV AB. In each of the three test packages, three heaters are installed. A main heater runs along the entire test length and two additional heaters are positioned at the bottom and the top respectively (Figure 2-1). The heaters have an effect of 1 000 W each.

The design with extra heaters at top and bottom makes it possible to control the temperature along the whole test package. The goal is to have similar temperature conditions regardless of the block position.

7 Artificial water saturation system

All three test packages were prepared in order to use an artificial water saturation system. The outermost slot between bentonite blocks and rock was filled with gravel in which titanium tubes, d = 6 mm, were placed. The gravel will serve as a filter and distribute water around the outer mantle surface. Four titanium tubes were installed in each of the test packages. They were connected two and two underneath the bottom buffer block, which makes it possible to flush the system if needed (Figure 7-1). Holes were drilled in the titanium tubes every metre. In order to avoid gravel to enter or clog the small holes, a perforated plastic "sock" was pulled over the pipes. The pipes are connected to a water tank which can be pressurized.

Figure 7-1. *Photo showing the titanium tubes used for the artificial wetting and how they are connected to each other beneath the lowest block.*

8 Instruments

8.1 General

The three ABM test packages are sparsely instrumented. The main objectives with the test series are to expose the different bentonite materials to conditions fairly similar to a repository and to adverse conditions with respect to temperature. This means that measurements of the temperature distribution in the test packages are important.

8.2 Thermocouples

Twenty thermocouples were installed in each of the test packages. The thermocouples are of type K (chromel–alumel type; the most common general-purpose thermocouple) and the shield of the sensors is made of cupronickel in order to withstand the tough conditions in the test holes. The thermocouples have an outer diameter of 4.5 mm. The thermocouples are positioned in block number 3, 9, 15, 21 and 27 (Figure 2-1). Four thermocouples are positioned at each level, one on the steel tube surface and three in the buffer. The thermocouples in the buffer are positioned at different radial distance from the heater, 5, 40 and 60 mm, Figure 8-1.

The thermocouples were installed in pre-drilled holes in the bentonite blocks (Figure 8-1). They are led out to the block periphery where they are bent and led upwards on the outside of the test package.

A complete list of all thermocouples showing ID and position is provided in Appendix 4 and 5.

Figure 8-1. *Photo showing the installation principle of thermocouples.*

9 Copper and titanium samples

9.1 Background

At the excavation of the outer section in the Prototype experiment in 2011 (Olsson et al. 2013) elevated Fe (II) / Fe (III) ratios was identified in the bentonite in innermost ~ 10 mm from the copper canister. Several potential explanations exist, the most discussed are: (i) interaction with the copper canister, (ii) interaction with the lubricant in bentonite blocks; (iii) an effect of the thermal gradient in the experiment or (iv) an effect due to the redox potential of the experiment, potentially linked to electrical wiring. To possibly get more information about this process copper inserts were embedded in selected blocks in the ABM45 experiment. The copper inserts are in contact with the bentonite without any lubricant (containing MoS_2, organics etc) present. The copper inserts are placed in a standard bentonite (MX-80) and an iron-rich bentonite (Asha 505) to study whether any copper-bentonite interaction is linked to the total iron content of the bentonite. The strategy is to study the Fe (II) / Fe (III) ratio in the bentonite profiles around the copper inserts after the experiment to see if there are any differences compared to the reference material. The Fe (II) / Fe (III) ratio can be studied using XANES (K Fe), Mössbauer spectroscopy or by wet chemical method.

9.2 Copper samples

Twenty copper specimens have been manufactured, Figure 9-1. Sixteen of them were installed in the test packages and four were saved as references. The specimens were manufactured of copper delivered from the Canister Laboratory in Oskarshamn. The copper quality is SKB's canister material Cu-OFP (oxygen-free phosphorous doped) and the tube from which the material was taken is denoted T58. The copper specimens have a diameter of 10 mm and a height of 25 mm. A compilation of data for all specimens and their actual position is provided in Table 9-1. The specimens were after manufacturing numbered, photo documented and washed in dilute hydrochloric acid followed by de-ionized water.

The specimens were installed in the bentonite blocks in pre-drilled holes followed by a small bentonite cylinder, Figure 9-2. The specimens were before installation washed and handled with gloves. The copper specimens were positioned at a distance of 3 cm from the heater in four directions (0°, 90°, 180° and 270°) in the actual blocks, Figure 11-1. Anaerobic sampling of the copper inserts is not expected to be possible, hence some oxidation may occur during excavation and sampling.

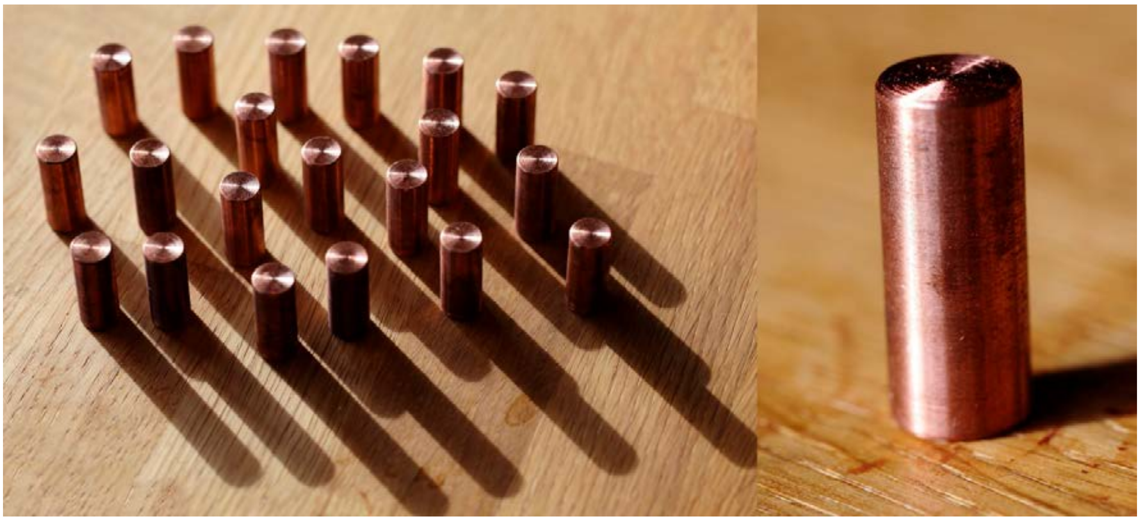


Figure 9-1. *Left: Twenty copper specimens were prepared. Right: Close up of a copper specimen.*

Figure 9-2. Left: installation of copper specimen in a pre-drilled hole Right: The hole is sealed with a cylinder manufactured of the same bentonite as the block.

Table 9-1. Compilation of copper specimen data.

Copper sample no.	Weight g	Height mm	Diameter mm	Position package, block, direction
1	17.57	25.15	10.00	4, 14, North
2	17.60	25.12	10.00	4, 14, East
3	17.53	25.10	10.02	4, 14, West
4	17.57	25.18	10.00	4, 14, South
5	17.53	25.17	9.98	4, 18, North
6	17.54	25.09	10.00	4, 18, East
7	17.61	25.17	10.02	4, 18, West
8	17.61	25.19	10.01	4, 18, South
9	17.56	25.18	10.00	5, 16, North
10	17.48	25.06	9.99	5, 16, East
11	17.55	25.13	9.99	5, 16, West
12	17.60	25.15	9.99	5, 16, South
13	17.48	25.06	10.01	5, 20, North
14	17.46	25.15	10.01	5, 20, East
15	17.65	25.21	10.02	5, 20, West
16	17.50	25.02	10.01	5, 20, South
17	17.56	25.26	10.00	Reference
18	17.38	24.92	10.00	Reference
19	17.48	25.08	10.00	Reference
20	17.47	25.00	10.00	Reference

9.3 Titanium samples

In total 24 titanium specimens were installed in six different bentonite blocks, two from each test package. The titanium specimens were cut out from a tube (D = 6 mm and d = 4 mm). Four specimens were installed in each of the six chosen blocks, see compilation in Figure 11-1. Holes were drilled in mid-height of the block periphery and the specimens were then pressed into the holes. The specimens were installed in four directions (0°, 90°, 180° and 270°) in the actual blocks, see details in Section 11. Titanium is a possible replacement material for steel in the KBS-3H concept, and hence these samples were included to enable titanium-bentonite interaction studies.

Figure 9-3. *Installation of titanium specimens.*

10 Installation

10.1 General

The test packages were assembled at the test site just above the test-holes. This section describes the preparatory work, test package assembly and the installation in the rock.

10.2 Preparation at test site

The test packages will be kept in place by concrete plugs casted above the test holes. A square shaped recess was cut out from the concrete sole above each of the test holes, Figure 10-1. A mould was build in advance and the reinforcement positioned so that everything was prepared for the casting of the plug directly after installation of the test package. The eight vertical steel rods will be used for mounting of two steel beams which will secure the concrete plug and prevent it from moving upwards, see also Figure 2-1. Observe that there is no reinforcement in the concrete close to the test package which will facilitate future termination of the test if the method to seam drill holes around the test package will be used.

Figure 10-1. *Preparatory work at test site.*

10.3 Test package assembly

The test packages were mounted together just above the test-holes in order to minimize lifting and handling of the completed packages. The work was performed according to the following:

1. A special platform was placed above the test holes and the bottom plate of the central tube was fastened here by bolts, Figure 10-2 and 10-3.
2. The bottom block of each test package included titanium tubes that should be used for the artificial saturation system was mounted, see also description in Section 7.
3. The bentonite blocks were threaded onto the central steel tube (heater) one block at the time. Special efforts were made to remove lubricant on the inner part of every block before mounting. This was made by a rotating tool grinding of the bentonite block surface.
4. The thermocouples were positioned in five chosen blocks in each of the test packages according to the description in Section 8.
5. Copper and titanium inserts were installed in some blocks to further investigate metal-bentonite interactions, see description in Section 9 and 11.
6. The exposure of the bentonite blocks to the moist conditions in the tunnel was minimized during the work. The blocks were kept in plastic bags until just before mounting and after they have been threaded onto the steel tube they were wrapped in plastic.

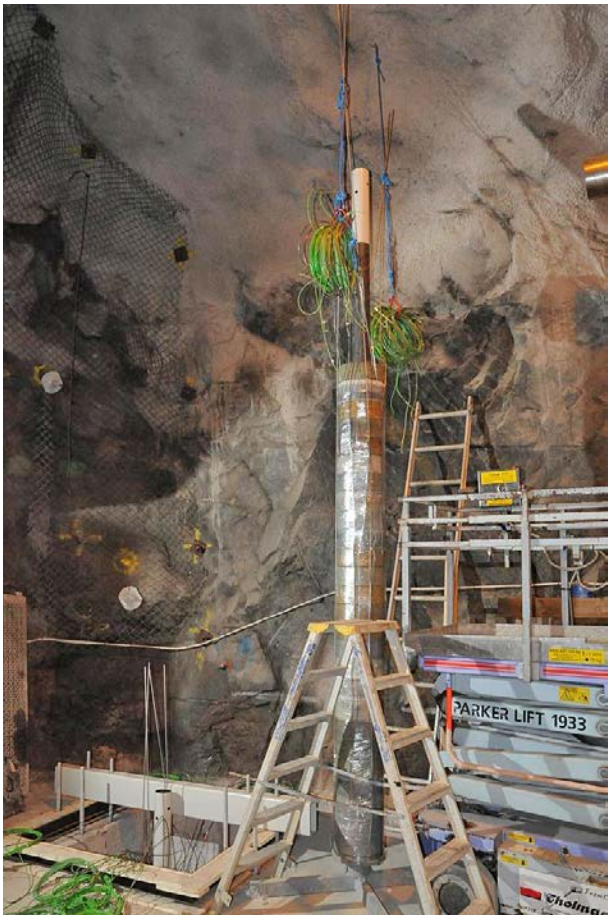


Figure 10-2. *The central steel tube is mounted on a platform above the test-hole and the mounting of blocks and sensors have started.*

Figure 10-3. *The blocks were threaded onto the steel tube one by one.*

10.4 Installation

The bottom surface of the test holes were evened out by pouring a small amount of sand down into the holes. The test packages were lowered down very carefully in order to avoid damages on the blocks and cables, Figure 10-4. During the lowering, the protection plastic was removed in steps.

After installation of the test package in the test hole, the gap between blocks and rock was filled with gravel up to the lower surface of the uppermost block. The rest of the gap and approximately 3 to 4 additional cm above the block were filled with bentonite pellets, Figure 10-6. This will serve as a sealing and prevent concrete from flowing down in the sand filter.

Figure 10-4. *The test packages were lowered down into the holes very carefully.*

Figure 10-5. The plastic wrapped around the blocks was removed in conjunction with the installation.

Figure 10-6. The gap between the uppermost block and the rock together with some additional centimetres above the block was filled with bentonite pellets.

10.5 Gravel

The filter around the bentonite blocks consists of gravel 2–8 mm. The gravel is made of crushed rock, Figure 10-7. The gravel was air-dried in room temperature before installation in order to facilitate the installation and avoid that lumps were formed.

Figure 10-7. Photo showing the gravel used in the gap between block and rock.

10.6 Concrete lid

In order to keep the concrete lid in position and prevent the bentonite from swelling up from the test hole, steel beams were positioned over the concrete, Figure 10-8 and 10-9. The beams were fastened by steel rods anchored into the rock.

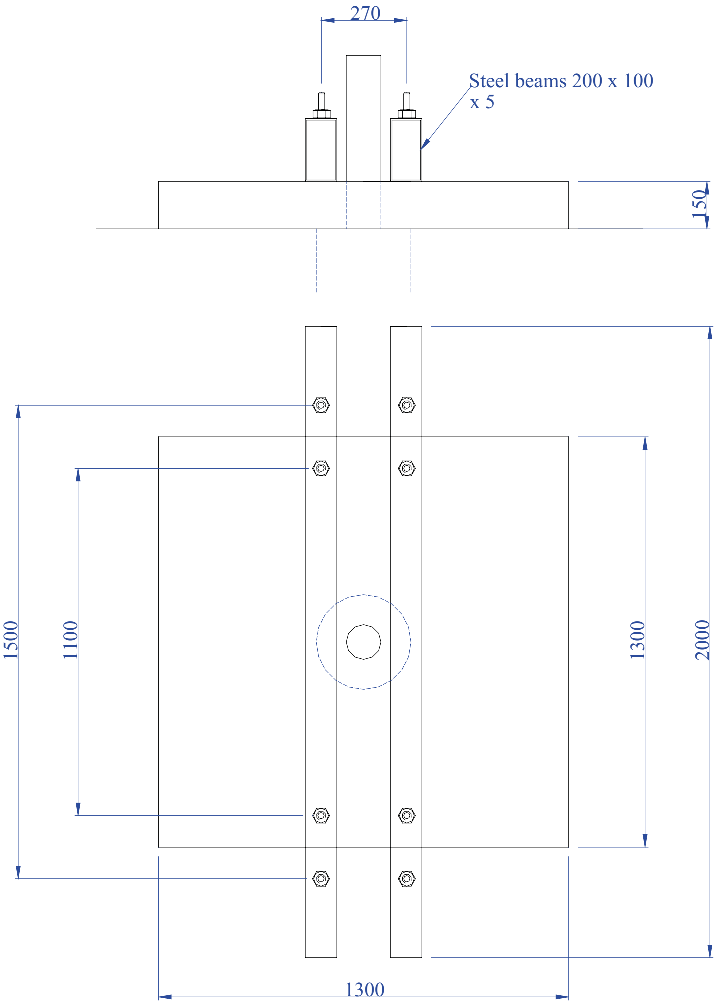


Figure 10-8. *Technical drawing showing the position of the steel beams.*

Figure 10-9. *Photo showing the three test packages after finishing the installation work.*

11 Bentonite block configuration

At least two blocks of each bentonite material was placed in each test package. Additional MX-80 blocks were positioned at top and bottom in order to secure a tight sealing. The complete block order for all three packages is provided in Table 11-1 together with information regarding in which block thermocouples, copper and titanium samples are positioned. In the last column for each of the packages the manufacturing number of the specific block is provided. A corresponding table with block manufacturing number and data for the individual block is provided in Appendix 2. The bottom block is #1 and the uppermost block is #30 (see overview Figure 2-1).

Table 11-1. Figure showing the block material configuration, manufacturing number and in which blocks thermocouples, titanium samples and copper samples are embedded.

ABM 4	**Bore hole id: KD0096G01**		
Block position	**Material**	**Remark**	**Block #**
30	MX-80		19
29	MX-80		16
28	Ikosorb		6
27	Deponit CAN	Thermocouple	7
26	Ibeco SEAL		3
25	GMZ		3
24	Asha 505		7
23	Calcigel		1
22	Asha NW BFL-L		3
21	Febex	Thermocouple	7
20	MX-80	Titanium	1
19	Saponite		4
18	MX-80	Copper (5,6,7 and 8)	20
17	Kunigel V1		6
16	Rokle		6
15	Deponit CAN	Thermocouple	3
14	Asha 505	Copper (1,2,3 and 4)	3
13	Rokle		7
12	Asha NW BFL-L		1
11	MX-80		10
10	Ikosorb		3
9	GMZ	Thermocouple	1
8	Febex		6
7	Saponite		5
6	Ibeco SEAL		4
5	Calcigel		3
4	Kunigel V1		3
3	Deponit CAN	Thermocouple + Titanium	5
2	MX-80		9
1	MX-80		2

Table 11-1. Continued.

ABM 5	**Bore hole id: KD0098G01**		
Block position	**Material**	**Remark**	**Block #**
30	MX-80		13
29	MX-80		15
28	Asha 505		6
27	Calcigel	Thermocouple	4
26	Deponit CAN		6
25	Febex		1
24	GMZ		6
23	Ibeco SEAL		2
22	Ikosorb		5
21	Kunigel V1	Thermocouple	5
20	MX-80	Copper (13,14,15 and 16)	18
19	Asha NW BFL-L		5
18	Rokle		4
17	Saponite		2
16	Asha 505	Copper (9,10,11 and 12)	4
15	MX-80	Thermocouple + Titanium	17
14	Rokle		3
13	Febex		3
12	Saponite		1
11	Ibeco SEAL		6
10	Calcigel		6
9	Asha NW BFL-L	Thermocouple	6
8	MX-80		14
7	Ikosorb		2
6	GMZ		5
5	Kunigel V1		4
4	Deponit CAN		4
3	Asha NW BFL-L	Thermocouple + Titanium	4
2	MX-80		12
1	MX-80		5

Table 11-1. Continued.

ABM 6	**Bore hole id: KD0099G01**		
Block position	**Material**	**Remark**	**Block #**
30	MX-80		11
29	MX-80		3
28	Asha NW BFL-L		2
27	Deponit CAN	Thermocouple	2
26	Ibeco SEAL		5
25	Kunigel V1		2
24	Saponite		3
23	Calcigel		2
22	Ikosorb		4
21	Asha 505	Thermocouple	2
20	MX-80		6
19	Febex		2
18	Rokle		2
17	GMZ		2
16	Asha 505		5
15	Deponit CAN	Thermocouple	1
14	Saponite		7
13	MX-80	Titanium	4
12	Ibeco SEAL		7
11	Febex		4
10	Asha NW BFL-L		7
9	Calcigel	Thermocouple	5
8	Rokle		5
7	Ikosorb		1
6	GMZ		4
5	Kunigel V1		7
4	Asha 505		1
3	Calcigel	Thermocouple + Titanium	7
2	MX-80		7
1	MX-80		8

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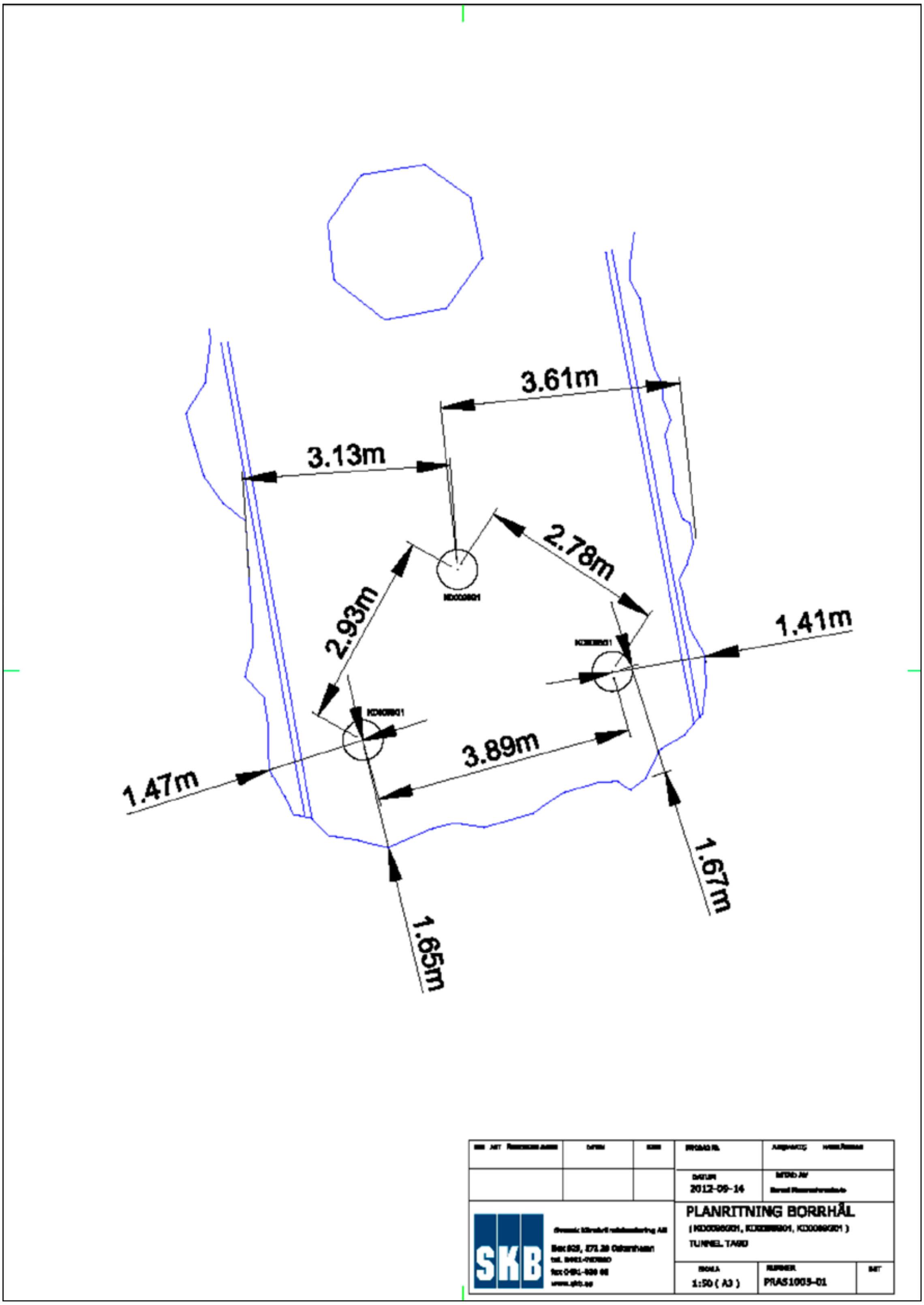
Drawing of the test site



Appendix 2

Block manufacturing data

Block	Material	Water content %	Mass g	Dy1 mm	Dy2 mm	Di mm	h mm	Volume mm³	Volume comp. mm³	Bulk density g/cm³	Dry density g/cm³
1	GMZ 2011	16.5	13 280	275.6	280.3	110.2	125.7	6 428	6 400	2.075	1.781
2	GMZ 2011	16.5	13 340	275.6	280.3	110.1	126.3	6 461	6 433	2.074	1.780
3	GMZ 2011	16.5	13 320	275.7	280.2	110.1	125.4	6 415	6 387	2.086	1.790
4	GMZ 2011	16.5	13 360	275.6	280.2	110.1	126.1	6 448	6 420	2.081	1.786
5	GMZ 2011	16.5	13 340	275.6	280.0	110.0	125.5	6 414	6 386	2.089	1.793
6	GMZ 2011	16.5	13 340	275.7	280.2	110.0	126.4	6 468	6 440	2.071	1.778
7	GMZ 2011	16.5	13 300	275.5	280.1	110.0	126.3	6 455	6 427	2.069	1.776
1	IKOSORB 2011	11.8	10 720	280.9	277.0	110.3	100.2	5 166	5 138	2.086	1.866
2	IKOSORB 2011	11.8	10 740	280.9	277.1	110.3	100.6	5 189	5 161	2.081	1.861
3	IKOSORB 2011	11.8	10 740	280.8	276.8	110.3	100.5	5 175	5 147	2.087	1.866
4	IKOSORB 2011	11.8	10 740	280.8	277.1	110.3	100.4	5 177	5 148	2.086	1.866
5	IKOSORB 2011	11.8	10 740	280.9	277.0	110.3	100.7	5 192	5 164	2.080	1.860
6	IKOSORB 2011	11.8	10 740	280.8	277.2	110.3	100.6	5 189	5 161	2.081	1.861
1	ASHA505 2011	13.1	10 820	281.7	277.6	110.7	101.2	5 242	5 214	2.075	1.835
2	ASHA505 2011	13.1	10 820	281.4	277.5	110.5	100.8	5 216	5 188	2.086	1.844
3	ASHA505 2011	13.1	10 820	281.5	277.5	110.8	102.0	5 275	5 247	2.062	1.823
4	ASHA505 2011	13.1	10 820	281.4	277.3	110.5	100.3	5 185	5 157	2.098	1.855
5	ASHA505 2011	13.1	10 820	281.4	277.4	110.6	100.7	5 207	5 178	2.089	1.847
6	ASHA505 2011	13.1	10 820	281.5	277.5	110.7	101.0	5 225	5 197	2.082	1.841
7	ASHA505 2011	13.1	10 820	281.3	277.5	110.5	100.5	5 198	5 170	2.093	1.850
1	Dep CA-N	18.9	10 580	279.7	275.7	109.9	100.5	5 134	5 106	2.072	1.743
2	Dep CA-N	18.9	10 580	279.6	275.7	109.9	100.1	5 111	5 083	2.081	1.751
3	Dep CA-N	18.9	10 580	279.7	275.7	109.9	100.4	5 129	5 100	2.074	1.745
4	Dep CA-N	18.9	10 580	279.7	275.7	109.9	100.5	5 134	5 106	2.072	1.743
5	Dep CA-N	18.9	10 580	279.7	275.7	109.9	100.5	5 134	5 106	2.072	1.743
6	Dep CA-N	18.9	10 580	279.7	275.6	109.9	100.3	5 121	5 093	2.077	1.747
7	Dep CA-N	18.9	10 580	279.7	275.7	109.9	100.5	5 134	5 106	2.072	1.743
1	Febex 2012	14.3	10 640	280.8	276.9	110.0	100.9	5 203	5 175	2.056	1.799
2	Febex 2012	14.3	10 640	280.8	276.9	110.0	100.7	5 193	5 165	2.060	1.802
3	Febex 2012	14.3	10 640	280.7	276.8	110.0	100.9	5 199	5 171	2.058	1.800
4	Febex 2012	14.3	10 620	280.7	276.8	110.1	100.8	5 192	5 164	2.057	1.799
5	Febex 2012	14.3	10 640	280.7	277.0	110.2	100.9	5 200	5 172	2.057	1.800
6	Febex 2012	14.3	10 620	280.8	276.9	110.3	100.9	5 198	5 170	2.054	1.797
7	Febex 2012	14.3	10 640	280.8	276.9	110.0	101.0	5 208	5 180	2.054	1.797
1	IBECO Seal 2011	24.2	10 420	279.8	275.9	110.0	101.2	5 174	5 146	2.025	1.630
2	IBECO Seal 2011	24.2	10 440	279.9	276.0	110.1	101.7	5 203	5 174	2.018	1.624
3	IBECO Seal 2011	24.2	10 440	279.9	275.9	110.0	101.7	5 202	5 174	2.018	1.625
4	IBECO Seal 2011	24.2	10 420	279.9	275.9	110.0	101.7	5 202	5 174	2.014	1.622
5	IBECO Seal 2011	24.2	10 400	279.9	276.0	110.1	101.5	5 192	5 164	2.014	1.621
6	IBECO Seal 2011	24.2	10 420	279.8	275.9	110.0	101.6	5 195	5 167	2.017	1.624
7	IBECO Seal 2011	24.2	10 420	279.9	276.0	110.0	101.8	5 209	5 181	2.011	1.619

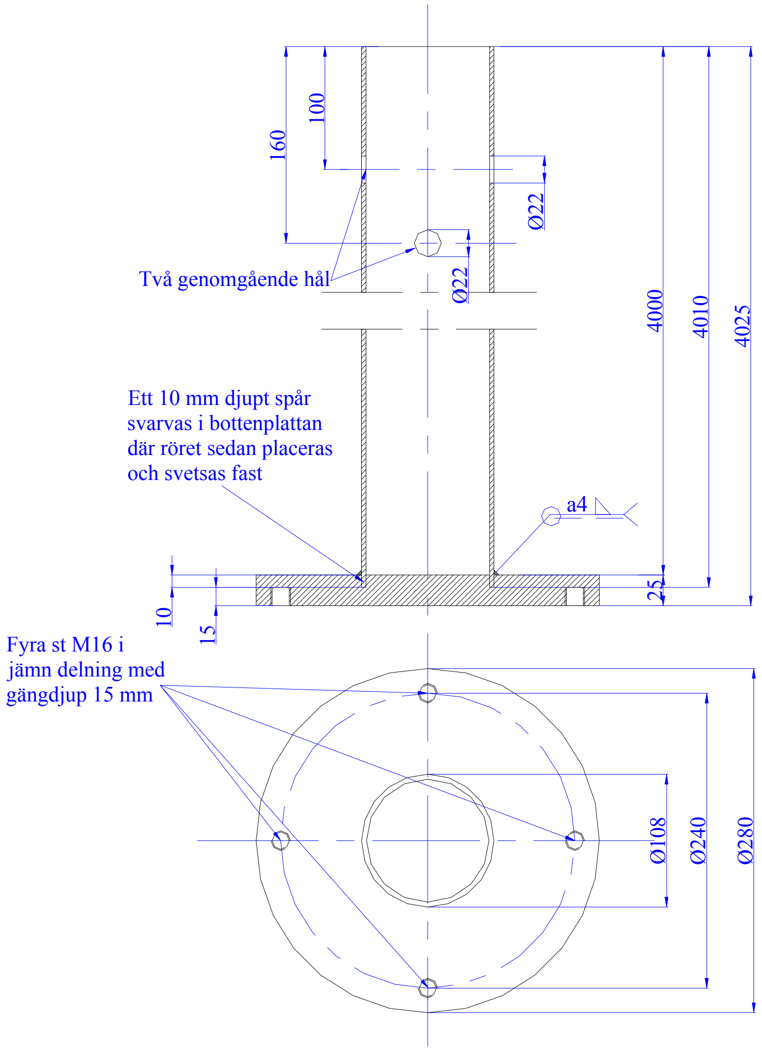
Block	**Material**	**Water content** **%**	**Mass** **g**	**Dy1** **mm**	**Dy2** **mm**	**Di** **mm**	**h** **mm**	**Volume** **mm³**	**Volume comp.** **mm³**	**Bulk density** **g/cm³**	**Dry density** **g/cm³**
1	Kunigel 2012	8.0	10 720	281.3	277.0	110.5	108.5	5 600	5 572	1.924	1.781
2	Kunigel 2012	8.0	10 720	281.4	277.1	110.6	108.9	5 623	5 595	1.916	1.774
3	Kunigel 2012	8.0	10 660	281.4	277.0	110.5	107.1	5 530	5 502	1.938	1.794
4	Kunigel 2012	8.0	10 720	281.2	277.0	110.5	107.0	5 520	5 492	1.952	1.807
5	Kunigel 2012	8.0	10 720	281.2	277.0	110.5	108.5	5 598	5 569	1.925	1.782
6	Kunigel 2012	8.0	10 720	281.2	277.0	110.5	107.3	5 536	5 507	1.946	1.802
7	Kunigel 2012	8.0	10 660	281.1	277.0	110.5	108.6	5 600	5 572	1.913	1.771
1	Calcigel2012	16.8	10 820	280.4	276.3	110.1	106.0	5 441	5 413	1.999	1.711
2	Calcigel2012	16.8	10 840	280.4	276.2	110.1	107.0	5 490	5 462	1.985	1.699
3	Calcigel2012	16.8	10 840	280.5	276.2	110.1	106.7	5 477	5 449	1.989	1.703
4	Calcigel2012	16.8	10 820	280.3	276.3	110.2	107.0	5 488	5 460	1.982	1.697
5	Calcigel2012	16.8	10 840	280.5	276.2	110.1	107.0	5 492	5 464	1.984	1.698
6	Calcigel2012	16.8	10 820	280.4	276.1	110.1	105.5	5 411	5 383	2.010	1.721
7	Calcigel2012	16.8	10 800	280.3	276.2	110.1	106.1	5 442	5 413	1.995	1.708
1	Saponit	10.8	9 870	281.7	277.4	110.6	107.1	5 545	5 516	1.789	1.615
2	Saponit	10.8	9 900	281.6	277.4	110.6	107.5	5 563	5 535	1.789	1.614
3	Saponit	10.8	9 880	281.6	277.4	110.6	107.2	5 547	5 519	1.790	1.616
4	Saponit	10.8	9 910	281.6	277.2	110.7	107.5	5 556	5 528	1.793	1.618
5	Saponit	10.8	9 890	281.6	277.4	110.6	107.6	5 568	5 540	1.785	1.611
6	Saponit	10.8	9 880	281.6	277.4	110.6	108.8	5 630	5 602	1.764	1.592
7	Saponit	10.8	9 870	281.6	277.5	110.6	109.7	5 679	5 651	1.747	1.576
1	MX-80	10.6	11 020	276.7	280.7	110.3	100.5	5 171	5 143	2.143	1.938
2	MX-80	10.6	11 040	276.8	280.7	110.3	100.6	5 178	5 150	2.144	1.938
3	MX-80	10.6	11 040	276.7	280.6	110.3	100.7	5 179	5 151	2.143	1.938
4	MX-80	10.6	11 040	276.8	280.7	110.4	100.7	5 181	5 153	2.142	1.937
5	MX-80	10.6	11 040	276.9	280.8	110.4	100.8	5 191	5 163	2.138	1.933
6	MX-80	10.6	11 040	276.8	280.8	110.4	100.8	5 189	5 161	2.139	1.934
7	MX-80	10.6	11 040	276.8	280.7	110.3	100.4	5 168	5 140	2.148	1.942
8	MX-80	10.6	11 040	276.9	280.8	110.4	100.2	5 160	5 132	2.151	1.945
9	MX-80	10.6	11 020	276.8	280.7	110.4	100.7	5 181	5 153	2.138	1.933
10	MX-80	10.6	11 040	276.8	280.8	110.3	100.8	5 191	5 162	2.139	1.934
11	MX-80	10.6	11 020	276.9	280.8	110.4	100.7	5 186	5 158	2.137	1.932
12	MX-80	10.6	11 040	277.0	280.9	110.4	100.8	5 195	5 167	2.137	1.932
13	MX-80	10.6	11 040	276.8	280.7	110.3	100.8	5 188	5 160	2.139	1.934
14	MX-80	10.6	11 040	276.9	280.8	110.4	100.8	5 191	5 163	2.138	1.933
15	MX-80	10.6	11 020	276.9	280.8	110.4	100.7	5 186	5 158	2.137	1.932
16	MX-80	10.6	11 020	277.0	280.9	110.4	100.8	5 195	5 167	2.133	1.928
17	MX-80	10.6	11 040	276.9	280.7	110.4	100.9	5 194	5 166	2.137	1.932
18	MX-80	10.6	11 040	276.8	280.7	110.3	100.7	5 183	5 155	2.142	1.936
19	MX-80	10.6	11 040	276.9	280.7	110.3	100.8	5 191	5 162	2.139	1.934
20	MX-80	10.6	11 040	276.8	280.7	110.3	100.5	5 173	5 145	2.146	1.940

Block	Material	Water content	Mass	Dy1	Dy2	Di	h	Volume	Volume comp.	Bulk density	Dry density
		%	g	mm	mm	mm	mm	mm³	mm³	g/cm³	g/cm³
1	ASHA-NWL-L	17.2	10 740	276.8	280.7	110.4	99.4	5 115	5 086	2.112	1.802
2	ASHA-NWL-L	17.2	10 720	276.9	280.7	110.4	98.9	5 091	5 063	2.117	1.807
3	ASHA-NWL-L	17.2	10 720	277.2	280.9	110.5	99.9	5 152	5 124	2.092	1.785
4	ASHA-NWL-L	17.2	10 740	276.8	280.9	110.3	99.4	5 121	5 092	2.109	1.799
5	ASHA-NWL-L	17.2	10 720	276.7	280.7	110.4	99.5	5 118	5 089	2.106	1.797
6	ASHA-NWL-L	17.2	10 740	276.8	281.0	110.4	99.5	5 126	5 098	2.107	1.798
7	ASHA-NWL-L	17.2	10 720	276.8	280.7	110.4	99.2	5 104	5 076	2.112	1.802
1	ROKLE 2012	17.2	10 820	276.3	280.2	110.2	100.8	5 168	5 140	2.105	1.796
2	ROKLE 2012	17.2	10 820	276.4	280.2	110.1	100.8	5 172	5 144	2.103	1.795
3	ROKLE 2012	17.2	10 800	276.2	280.0	110.1	100.3	5 138	5 109	2.114	1.804
4	ROKLE 2012	17.2	10 620	276.5	280.3	110.3	99.0	5 081	5 052	2.102	1.793
5	ROKLE 2012	17.2	10 820	276.5	280.2	110.1	100.5	5 159	5 131	2.109	1.799
6	ROKLE 2012	17.2	10 820	276.4	280.3	110.1	100.7	5 169	5 141	2.105	1.796
7	ROKLE 2012	17.2	10 820	276.3	280.1	110.0	100.6	5 159	5 131	2.109	1.799
1	Febex (old batch)	14.4	10 420	280.9	276.9	110.2	98.6	5 083	5 055	2.061	1.802
2	Febex (old batch)	14.4	10 420	281.1	277.2	110.3	99.0	5 113	5 085	2.049	1.791
3	Febex (old batch)	14.4	10 440	280.9	276.9	110.3	99.1	5 107	5 079	2.055	1.797
4	Febex (old batch)	14.4	10 440	280.7	276.8	110.3	97.0	4 993	4 965	2.103	1.838
5	Febex (old batch)	14.4	10 440	280.8	277.0	110.2	99.5	5 130	5 102	2.046	1.789
6	Febex (old batch)	14.4	10 440	280.9	277.1	110.3	99.1	5 112	5 084	2.054	1.795
7	Febex (old batch)	14.4	10 440	280.8	277.1	110.3	98.8	5 094	5 066	2.061	1.801
1	IBECO Seal (old batch)	14.7	10 720	280.6	276.7	110.1	99.0	5 095	5 067	2.116	1.845
2	IBECO Seal (old batch)	14.7	10 740	280.6	276.7	110.1	99.4	5 115	5 087	2.111	1.841
3	IBECO Seal (old batch)	14.7	10 740	280.7	276.8	110.0	99.2	5 111	5 083	2.113	1.842
4	IBECO Seal (old batch)	14.7	10 740	280.6	276.7	110.0	99.3	5 112	5 084	2.113	1.842
5	IBECO Seal (old batch)	14.7	10 740	280.6	276.7	110.0	99.4	5 117	5 089	2.110	1.840
6	IBECO Seal (old batch)	14.7	10 740	280.5	276.5	110.2	98.8	5 076	5 048	2.128	1.855
7	IBECO Seal (old batch)	14.7	10 740	280.7	276.7	110.1	99.3	5 112	5 084	2.112	1.842

Appendix 3

Construction drawing of central heater tube and bottom plate

RevNo	Revision note	Date	Signnature	Checked



1. Svetsen mellan platta och rör skall täthetstestas med hjälp av helium.
2. Rostskyddsmålning av svetsen lokalt dvs ca 2 cm upp på rör samt ca 2 cm ut på platta.
3. Rostskyddsmålning av översta halvmetern på röret (längst från bottenplattan)

2	3	Bottenplatta, S355J2G3	
1	3	Centrumrör 108 x 3.6, P235TR1	
Itemref	Quantity	Title/Name, designation, material, dimension etc	Article No. / Reference

Designed by	Checked by	Approved by-date	File name	Date	Scale
TS - 120831					

Clay Technology AB
Ideon 223 70, Lund
Tel: 046-286 2570, Fax: 046-134230

ABM45, Centrumrör

Ritn.nr. 20120831-1	Edetion	Sheet

Appendix 4

Positions of thermocouples in the experiments

ID	Test package	Block no.	Distance from heater mm
PXA403:1T	4	3	0
PXA403:2T	4	3	5
PXA403:3T	4	3	40
PXA403:4T	4	3	60
PXA409:1T	4	9	0
PXA409:2T	4	9	5
PXA409:3T	4	9	40
PXA409:4T	4	9	60
PXA415:1T	4	15	0
PXA415:2T	4	15	5
PXA415:3T	4	15	40
PXA415:4T	4	15	60
PXA421:1T	4	21	0
PXA421:2T	4	21	5
PXA421:3T	4	21	40
PXA421:4T	4	21	60
PXA427:1T	4	27	0
PXA427:2T	4	27	5
PXA427:3T	4	27	40
PXA427:4T	4	27	60

ID	Test package	Block no.	Distance from heater mm
PXA503:1T	5	3	0
PXA503:2T	5	3	5
PXA503:3T	5	3	40
PXA503:4T	5	3	60
PXA509:1T	5	9	0
PXA509:2T	5	9	5
PXA509:3T	5	9	40
PXA509:4T	5	9	60
PXA515:1T	5	15	0
PXA515:2T	5	15	5
PXA515:3T	5	15	40
PXA515:4T	5	15	60
PXA521:1T	5	21	0
PXA521:2T	5	21	5
PXA521:3T	5	21	40
PXA521:4T	5	21	60
PXA527:1T	5	27	0
PXA527:2T	5	27	5
PXA527:3T	5	27	40
PXA527:4T	5	27	60

Appendix 5

Thermocouples in Test package 6

Positions of thermocouples in the experiments

ID	Test package	Block no.	Distance from heater mm
PXA603:1T	6	3	0
PXA603:2T	6	3	5
PXA603:3T	6	3	40
PXA603:4T	6	3	60
PXA609:1T	6	9	0
PXA609:2T	6	9	5
PXA609:3T	6	9	40
PXA609:4T	6	9	60
PXA615:1T	6	15	0
PXA615:2T	6	15	5
PXA615:3T	6	15	40
PXA615:4T	6	15	60
PXA621:1T	6	21	0
PXA621:2T	6	21	5
PXA621:3T	6	21	40
PXA621:4T	6	21	60
PXA627:1T	6	27	0
PXA627:2T	6	27	5
PXA627:3T	6	27	40
PXA627:4T	6	27	60

Arkitektkopia AB, Bromma, 2018

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