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Installation of buffer, heaters and instruments in the deposition hole

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Abstract

During 2003 the Temperature Buffer Test was installed in Äspö Hard Rock Laboratory. Temperature, water pressure, relative humidity, total pressure and displacements etc. are measured in numerous points in the test. Most of the cables from the transducers are led in the deposition hole through slots in the rock surface of the deposition hole in watertight tubes to the data collection system in a container placed in the tunnel close to the deposition hole.

This report describes the work with the installations of the buffer, heaters, and instruments and yields a description of the final location of all instruments. The report also contains a description of the materials that were installed and the densities yielded after placement.

Sammanfattning

Under år 2003 installerades försöket *Temperature Buffer Test* i Äspö Hard Rock Laboratory. Temperatur, vattentryck, relativa fuktigheten, totaltryck och förskjutningar mm mäts i flera punkter. De flesta kablarna från givarna leds från bufferten i slitsar längs deponeringshålets väggar upp till tunneln i vattentäta rör fram till datainsamlingssytemen som är placerade i en container nära deponeringshålet.

Rapporten beskriver installationsarbetet med installation av buffert, värmare, och instrumentering och ger en beskrivning av de slutliga lägena för alla instrument. Rapporten innehåller också en beskrivning av de installerade materialen och de densiteter som uppnåddes efter inplacering.

Contents

1 Introduction

The Temperature Buffer Test, TBT, is a full-scale experiment that ANDRA and SKB carry out at the SKB Äspö Hard Rock Laboratory (Figure 1-1). In addition ENRESA supports TBT with THM modelling and DBE has installed a number of optic pressure sensors. The test aims at understanding and modelling the thermo-hydro-mechanical behaviour of buffers made of swelling clay submitted to high temperatures (over 100°C) during the water saturation process. No other full scales tests have been carried out with buffer temperatures exceeding 100°C so far.

An important part of the work is to measure the thermal, hydraulic and mechanical processes in the bentonite during saturation and afterwards. Several transducers have been installed in the heaters, in the buffer and in the rock mass close to the deposition hole. The temperature, the degree of saturation, the total pressure and the water pressure are measured during the saturation of the buffer. Most of the cables from the transducers are led up from the deposition holes in slots at the rock wall in watertight tubes to the data collection systems placed in a container close to the deposition hole. The installation work was finished, by casting the plug at the beginning of March 2003.

This report describes the installation of the buffer with its transducers, the deposition of the heaters and the sand and pellets filling of the gaps.

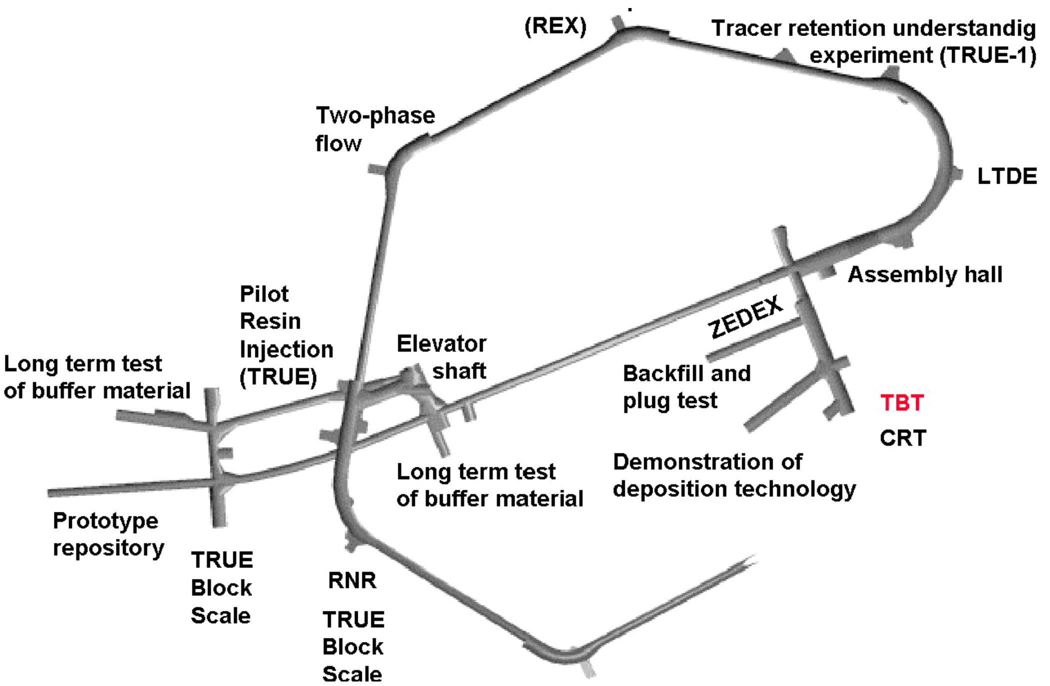


Figure 1-1. *Schematic view showing the experimental sites at Äspö HRL. The TBT experiment is placed just outside the CRT-test.*

2 Layout of the test

2.1 General

A brief overall description of the test layout is given below. The different components and instrumentations are explained and references to detailed descriptions in subsequent sections are given. This report focuses on the construction, the materials and the instrumentation. External components, such as the deposition hole, the data acquisition system and the artificial saturation system, are mentioned briefly.

2.2 Deposition hole

The *deposition hole* (DD0086G01) was core drilled in 1999. The average diameter of the hole is 1,757 mm (Andersson and Johansson 2002). A characterization of this hole has been given by Hardenby (2002) and no further information is therefore given in this report.

2.3 Heaters

Two *heaters*, made of carbon steel, are used in the test. Each heater has a diameter of 0.61 m and a height of 3.00 m. The lower heater is denoted Heater 1 and the upper is denoted Heater 2. Heater 1 was placed in the bentonite buffer with a annular gap between the heater and the blocks of about 10 mm. Heater 2 is surrounded by a sand filling (the shield) with a width of about 230 mm. A detailed description of these heaters is given in Appendix 4. The installation of the heaters is described in Section 8.2.7

2.4 Buffer, sand and pellets

The heaters are surrounded by a *bentonite buffer*. This was installed as 12 rings and 4 cylinders. The test is supplied with water through a *sand filter* located in the outer annular gap between the buffer and the rock wall. There is also a *sand shield* between the upper heater and the bentonite buffer. The uppermost part of the gap between the buffer and the rock wall is filled with bentonite *pellets* in order to seal off the sand filter from the tunnel.

A description of the manufacturing of the bentonite blocks is given in Section 3 together with a description of the sand and pellets. The installation of these materials is described in Section 8.

2.5 Instruments

The different sections with *sensors* installed in the buffer are shown in Figure 2-1. The test is instrumented for measurement of temperature (T), total pressure (P), pore pressure (U) and relative humidity (W). A number of additional installations enable different types of monitoring and fluid sampling through filter tips (F) and vessels (V): temperature measurements in and on the heater; load cells for measurements of cable forces; and sensors for measurements of lid displacements.

The selection and location of instruments is described in Section 4 and 5, respectively. The leading of cables from the instruments up through the deposition hole is described in Section 6.

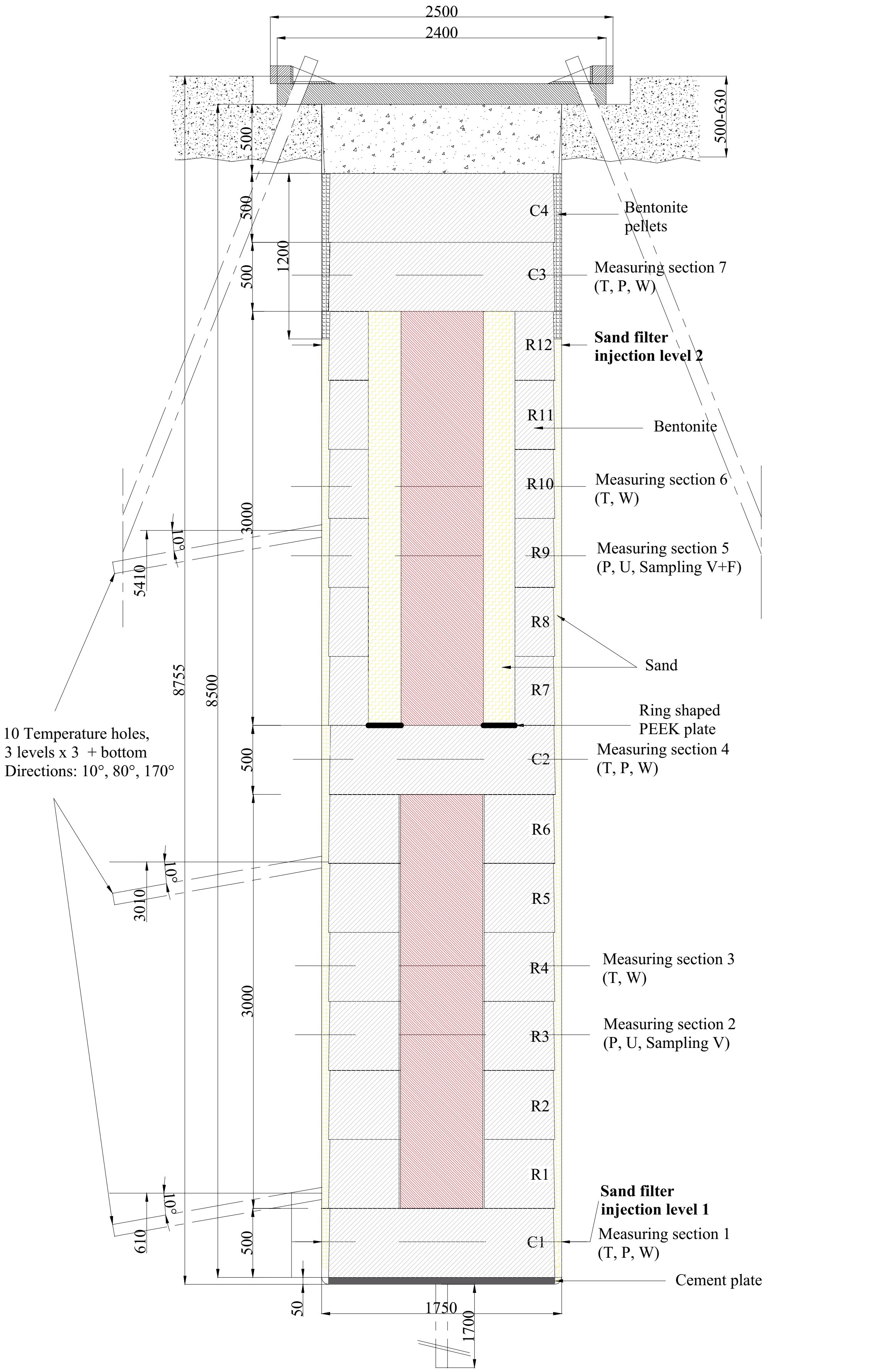


Figure 2-1. *Schematic view showing the experiment layout (T = temperature; P = total pressure; U = pore pressure; W = relative humidity; V = vessel; F = filter tip).*

2.6 Retaining construction

The lower part of the buffer is placed on a *concrete foundation*. The upper part is retained by a *concrete plug*. This is in turn kept in place by a *steel lid*, which is anchored to the rock with nine *anchor cables.* A description of the installation of this retaining construction is given in Section 9.

2.7 Data acquisition

The data acquisition is managed through three computers: one for measurements of the DBE fiber-optic pressure sensors; one for the Aitemin heaters; and one for all remaining sensors. The computer for the heaters manages the power control as well as the temperature measurements in and on the heaters.

A schematic outline of the different cabinets and instrumentation adjacent to the test is shown in Figure 2-2. The abovementioned computers are located in a nearby container. It is beyond the scope of the report to give any further information about the data acquisition system.

2.8 Artificial saturation

The test is supplied with water through the sand filter and is fed through 8 *injection points*, four in the lower part and four in the upper part. The dimensions of these filter tips are: outer diameter 9.5 mm, inner diameter 6.4 mm, and length 19.1 mm. The pore size is 40 µm. In addition, to enable the supply of water to the upper part of the buffer, a *filter mat* is located between the two uppermost blocks. This mat is fed through two injection points. A *system for artificial saturation* by which the injection points can be pressurized is located in the gallery. The levels of the injection points in the sand filter are shown in Figure 2-1. The installation of the filter mat is described in Section 8.2.11.

A flow scheme of the artificial saturation system is shown in Figure 2-3. This consists of a pressurized water tank equipped with a differential pressure sensor used for monitoring of the water level in the tank. The water pressure is monitored downstream in the main tube as well as in each tube leading to the filter tips in the sand filter. The latter sensors were installed 562 days after the test was launched. These sensors enable monitoring of the pressure in the sand filter if the ports are closed.

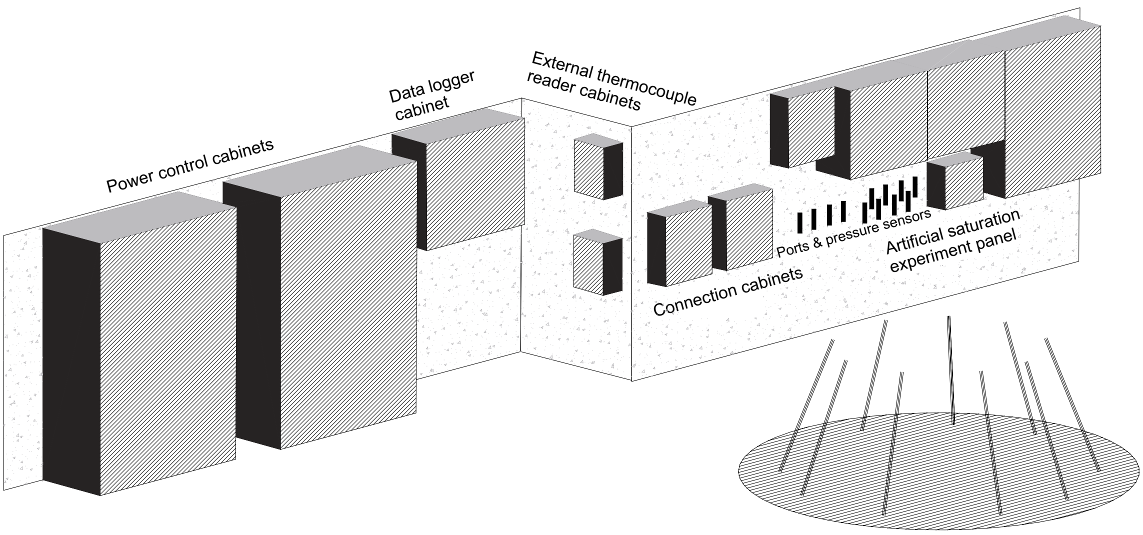


Figure 2-2. *Schematic layout of data acquisition system.*

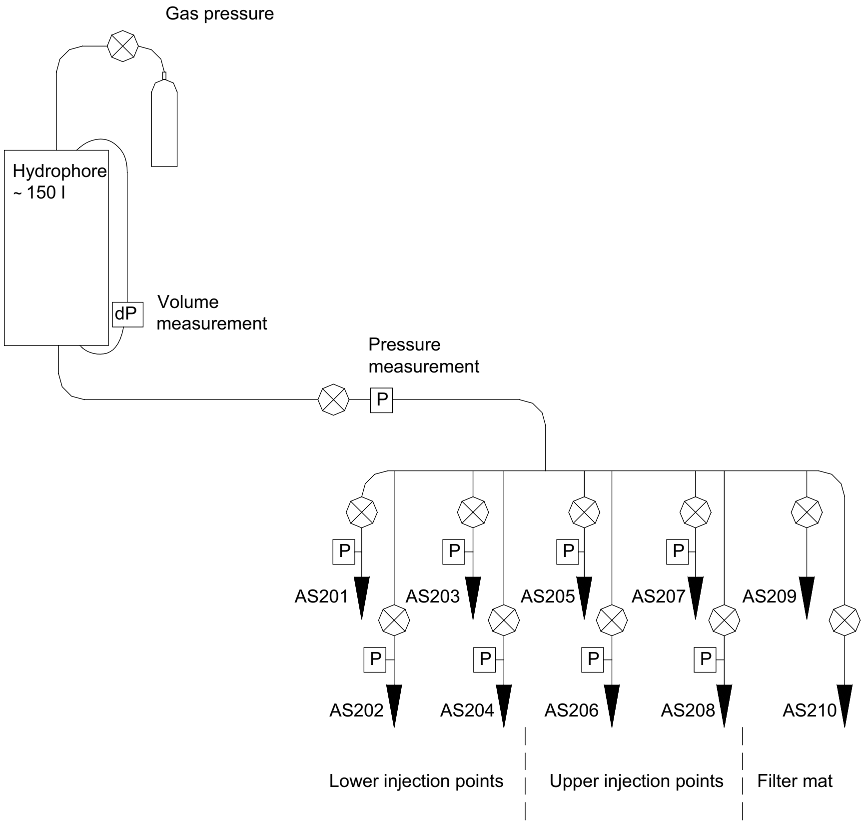


Figure 2-3. Flow scheme of artificial saturation system.

3 Buffer, sand and pellets

3.1 Manufacturing of the buffer

The blocks used for buffer material in the *Temperature Buffer Test* were made of Na-bentonite MX-80 mixed with tap water and were compacted to two different shapes; ring shaped blocks, which are placed around the upper heater and massive cylindrical blocks, which were placed above and under the heaters. The blocks were uniaxially compacted in a rigid form to an outer diameter of about 1,650 mm and a height of about 500 mm. The inner diameter of the ring shaped blocks is about 1,070 mm. The solid blocks were also used around the lower heater after machining of a hole with a diameter of about 630 mm in the central part of the block In order to have similar average density everywhere (including the gaps), the two types of blocks were compacted to different densities. The initial average weight, water content (i.e. the water-solid mass-ratio), density and void ratio of the two types of block are listed in Table 3-1. The table shows also the compaction pressure used at the compaction. The compaction of the blocks was made by Hydroweld AB in Ystad, Sweden in a press with a maximum capacity of 30,000 tons (see Figure 3-1). The technique for compacting the blocks is described in detail in Johannesson (1999).

Some blocks of brick size were installed on top of the first installed heater. The blocks had a water content of about 15.1 % and a bulk density of about 2,030 kg/m^3.

Table 3-1. Basic properties for blocks used in TBT.

No at comp.	No at installation	Comp.pressure (MPa)	Weight (kg)	Water content (%)	Bulk density (kg/m^3)	Degree of saturation	Void ratio
TBTB1	R11	75	1,254	17.5	2,077	0.850	0.572
TBTB2	Reserve	75	1,268	17.4	2,079	0.849	0.570
TBTB3	R10	75	1,250	17.7	2,080	0.857	0.573
TBTB4	R9	75	1,266	17.3	2,081	0.848	0.567
TBTB5	R8	75	1,266	17.6	2,075	0.849	0.575
TBTB6	R7	75	1,256	17.5	2,066	0.838	0.581
TBTB7	R12	75	1,258	17.6	2,075	0.849	0.575
TBTA1	C1	40	2,104	17.5	2,015	0.784	0.622
TBTA2	C2	40	2,112	17.5	2,008	0.776	0.627
TBTA3	C3	40	2,142	17.5	2,010	0.778	0.625
TBTA4	C4	40	2,084	17.6	1,997	0.768	0.637
TBTC1	R1	40	2,116	17.5	2,008	0.776	0.626
TBTC2	R2	40	2,122	17.5	2,007	0.775	0.628
TBTC3	Reserve	40	2,144	17.7	2,005	0.778	0.632
TBTC4	R5	40	2,130	17.4	2,005	0.772	0.629
TBTC5	R6	40	2,108	17.4	2,009	0.774	0.625
TBTC6	R3	40	2,124	17.7	2,004	0.778	0.632
TBTC7	R4	40	2,108	17.7	2,006	0.779	0.631

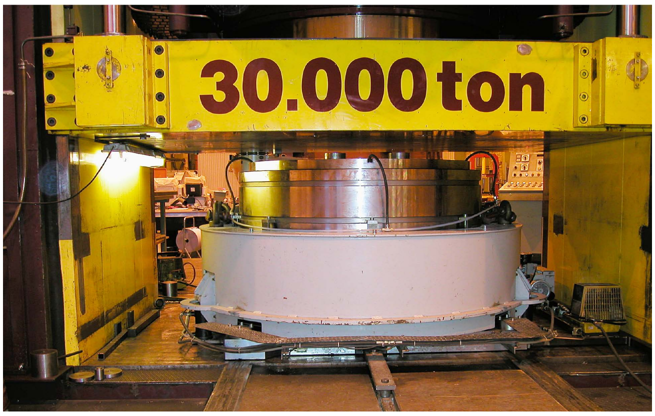


Figure 3-1. *The mould placed in the press at Hydroweld AB in Ystad, Sweden.*

3.2 The sand used in the test

The bentonite buffer around the two heaters in the *Temperature Buffer Test* consists of highly compacted bentonite blocks with an initial water content of about 17.5%. Water is added to the bentonite during the saturation phase so the water content of the buffer at fully saturation will be about 26 %. The gap between the compacted bentonite blocks and the rock surface of the deposition hole is filled with sand for artificial hydration. Furthermore the volume between the upper heater and the bentonite blocks is filled with sand (see Figure 2-1). At the uppermost part of the deposition hole (1.25 m) the outer gap is filled with pellets of bentonite.

The demands on the sand were the following:

- Since the temperature close to heater will be high (more than 170°C) it is of importance that the sand between the heater and the buffer is chemical stable and inert at high temperature during the time period at conditions that prevail in the experiment.
- The sand must be possible to compact into the gap in layers at low water content in order to minimize the risk of water to be taken up by the buffer during the installation.
- The sand, compacted in the outer gap, must withstand the swelling pressure of the buffer with an average compression of about 30% while the sand at the heater should have a compression of about 10%.
- The sand in the outer gap acts as a filter for the artificial saturation of the buffer. The sand filling must have a sufficient high hydraulic conductivity during the whole saturation phase of the buffer.

Due to the high temperature and the limited time the TBT test is planned to run, it is expected that the sand in the shield will be kept dry unless this volume of sand is also pressurized from the outside. A sand with quartz, was judged to be suitable for the test. Three types of sands were tested in the laboratory. One sand was a natural well graded sand (Ilstorp sand) one sand was sewed to a grain size between 0.25 and 1 mm (Bunker sand) and one was a sand of crushed rock (Dalby sand). The sands were loosely filled in an oedometer and the compressibility was tested up to a stress of 10 MPa. The results from the test are shown in Figure 3-2. Furthermore the density at loose filling and the density after proctor compaction together with the hydraulic conductivity of two of the materials were determined. The results from these tests are shown in Table 3-2.

It was expected that all three of the sands could be used as filling both in the outer and inner gap for the experiment. The Dalby sand was used in the experiment both for the outer and inner gap. The sand was dried to a water content close to zero before the installation. After the Dalby sand was selected for the experiment a second compaction test was performed. The result from this is shown in Figure 3-3. It is recommended that this second data set is used for modeling purposes. A grain size distribution is shown in Figure 3-4.

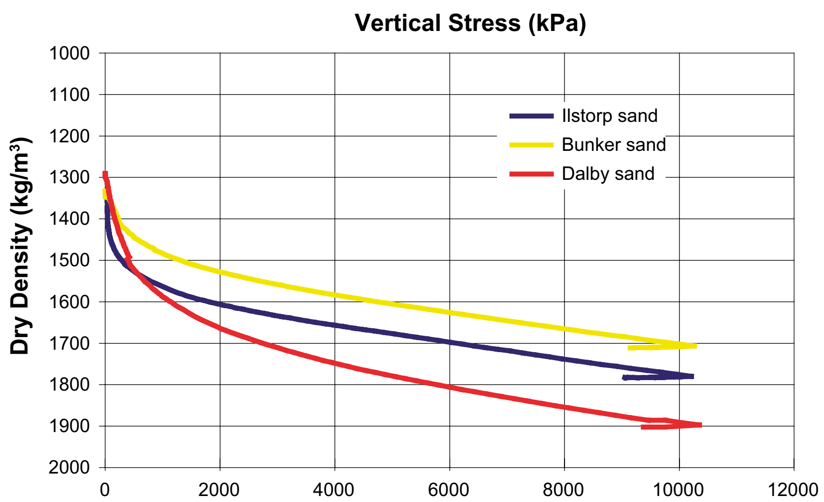


***Figure 3-2.** Initial oedometer tests performed on three types of sands.*

Table 3-2. Density and water ratio for three types of sands.

Type	Water content (%)	Loose dry density (kg/m³)	Dry density after proctor (kg/m³)	Hydraulic conductivity (m/s)
Dalby	2.4	1,170	2,020	5.8 E–7
Ilstorp	2.5	1,270	1,840	–
Bunker	2.2	1,260	1,690	4.4 E–6

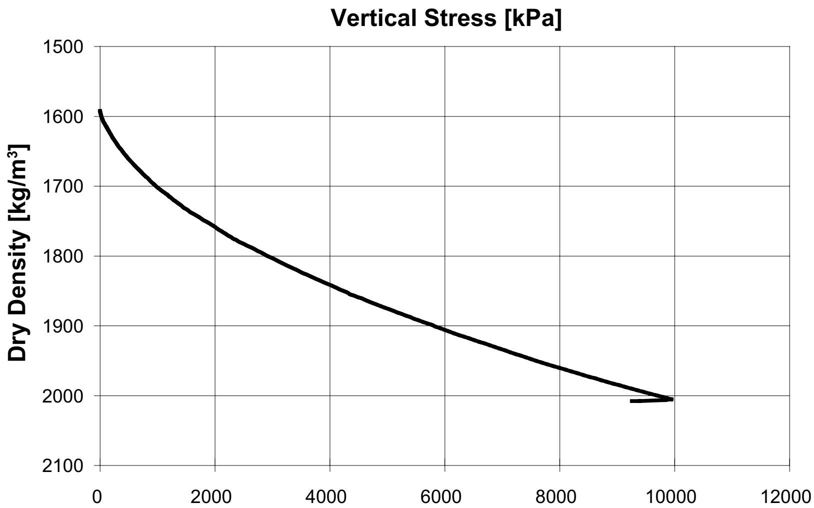


Figure 3-3. Second oedometer test performed on Dalby sand.

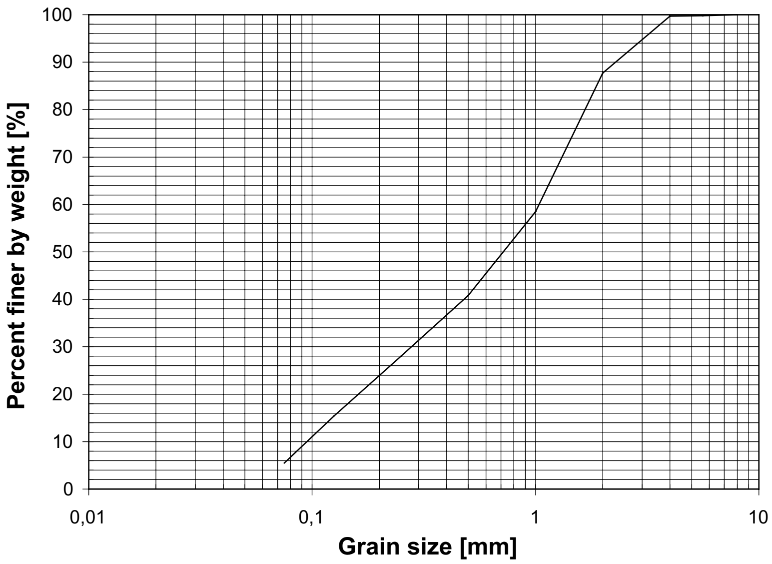


Figure 3-4. Grain size distribution of Dalby sand.

3.3 Pellets

The upper part of the gap between the bentonite and the rock wall was filled with pellets of bentonite (MX-80) in order to seal off the sand filling below, (see Figure 2-1).

The bentonite pellets had an initial water content of about 15.9%. The width and the length of each pellets was about 16.3 mm and the maximum thickness was about 8.3 mm. The bulk density of the separate pellets varied between 1,970 and 2,110 kg/m³. The expected bulk density of the filling of pellets was between 1,100 and 1,300 kg/m³.

4 Selection of instruments

The different instruments that are used in the experiment are described in this section. The instruments were chosen on basis of experiences from the instrumentation of the Prototype Repository and other projects ongoing at the the Hard Rock Laboratory in Äspö. The higher temperature of this experiment has been considered. A summary of sensor model numbers and measuring ranges are given in Table 4-1.

4.1 Temperature

Only one type of sensor is used for the temperature measurements, since the experiences of this type of sensors and the supplier are outstanding. In addition, temperature gauges are built into the capacitive relative humidity sensors as well as in the pressure gauges of vibrating wire type. Temperature is also measured with the psychrometers.

The temperature sensors are thermocouples type K, class 1 from **Pentronic**. These are of sheath type (made of CuNi) and are protected all the way from the measuring point up to the data collecting equipment. The outer diameter of the thermocouples is 4.0 mm. The thermocouples were calibrated at 0°C and at 100°C before the delivery and a function control were made before installation.

89 thermocouples were placed in the buffer and 40 thermocouples were placed in the rock.

4.2 Moisture content

Moisture content is measured with the following methods:

- Capacitive sensors
- Soil psychrometers

These devices measure the relative humidity (RH) in the pore system of the buffer material. RH can be converted to a suction value, and indirectly to a water content and a degree of water saturation. The psychrometers are complementing the capacitive sensors since the measuring range is different.

The relative humidity is measured in totally 35 points in the buffer.

Table 4-1. Sensor model numbers and measuring ranges.

Sensor	Model number	Measuring range (accuracy)
Rotronic (Cap. RH)	HygroClip IM-1/10; HTS11X/9	0–100% (± 1%RH)
Vaisala (Cap. RH)	HMP237 (specification for 237: Leak proof small size probe for pressures up to 10 bar)	0–100% (0–50%: ± 1.1%RH; 50–100%: ± 1.4%RH)
Wescor (Psych.RH)	PST-55	0.5–6 MPa, i.e. 95–100%
Geokon (Pressure)	Pore pressure 4500TIX-5MPa Total pressure 4800-1X-15MPa	0–5 MPa 0–15 MPa
Druck (Pressure)	Injection pressure PTX610 Differential pressure STX2100	0–25 bar 0–320 mbar

4.2.1 Rotronic

This sensor is measuring the RH with the capacitive method. The measurement ranges of the sensors are 0–100% RH and –50°C–200°C. The sensor body is made of stainless steel. The bodies are filled with resin in order to prevent water leakage. The sensor body and the cable are encapsulated in titanium. The sensors have after encapsulation a 22 mm outer diameter and a 135 mm length. The sensors were delivered calibrated. No additional calibration was done. A function control was done at the installation.

12 Rotronic relative humidity sensors were positioned in the buffer.

4.2.2 Vaisala

This sensor is measuring the RH with the capacitive method. The measurement ranges for the sensors are 0–100% RH and –40°C–180°C. The sensor body is made of stainless steel. The bodies are filled with resin in order to prevent water leakage. The sensor body and the cable are encapsulated in titanium and they have after encapsulation a 22 mm outer diameter and a 63 mm length. The sensors are delivered calibrated. An additional calibration was made before the installation due to the fact that a minor soldering work was made when leading the sensor cable in the protection tube. A function control was done at installation.

11 Vaisala relative humidity sensors were positioned in the buffer.

4.2.3 Wescor

The measurement range for the sensors is 95–100% RH. The temperature range is unknown but the sensors have been used in the CRT-test up to 70°C. These sensors are not placed in the hottest part of the buffer. The sensors were built into titanium cases, consisting of houses for the sensor bodies and titanium tubes for the cables. The titanium tubes were welded to the sensor houses. On top of the sensor houses, titanium filters were positioned. In order to prevent water leakage through the sensor after saturation of the bentonite, the bottom of the sensor houses was filled with resin. Before installation, the cable was split, exposing the leaders. Epoxy was then injected, sealing the leaders and the volume in the tube. Laboratory tests have shown that the sealing can withstand a water pressure of 5 MPa. The sensors had after encapsulation a 22 mm outer diameter and a 70 mm length. The sensors were delivered calibrated. A function control was done before installation.

12 Wescor relative humidity sensors were positioned in the buffer.

4.3 Total pressure

Total pressure is the sum of the effective stress and the pore water pressure. In this experiment is the total pressure measured with sensors from Geokon. This type of sensor is using the vibrating wire technique and was previously used both in the Prototype Repository Test and in the Canister Retrieval Test with good results. The pressure cells are specially designed and are made of titanium. The cells have an outer diameter of 76 mm and a thickness of 16 mm. The sensors are dimensioned for a pressure range of 0–15 MPa and a working temperature of 70–170°C. The cables from the sensors are led in titanium tubes.

Total pressure is measured in totally 29 points in the buffer.

4.4 Pore pressure

The water pressure is measured with Geokon sensors which are using the vibrating wire technique. On the sensors a ceramic or metallic filter assembled outside the diaphragm of the valve. The sensors are shaped as a cylindrical tube with a 25 mm outer diameter and a 127 mm length. The sensors are dimensioned for a pressure range of 0–5 MPa and a working temperature of 70–170°C. The cables from the sensors are led in titanium tubes.

Pore pressure is measured in totally 8 points in the buffer.

4.5 Additional measurements

4.5.1 Temperature measurements on heater

6 thermocouples are installed inside the heater. Additional 11 thermocouples are placed on the heater surface. The installation of these thermocouples was made by AITEMIN.

4.5.2 Gas pressure/sampling in sand

In the sand surrounding the upper heater, two titanium tubes with filter tips were placed. This arrangement gives a possibility to measure the gas pressure in the sand and also to take in situ samples of the gas/fluid in the sand. The tubes have three way valves connected in their ends, where one way is connected to a pressure transducer and the other will be used when taking samples. The pressure is measured with Druck pressure transducers.

4.5.3 Gas/fluid sampling in bentonite

Two sample collectors were installed. A sample collector consists of a titanium cup with a titanium filter placed on the top. Pore gas/fluid from the bentonite will flow through the filter and into the cup. A tube made of PEEK is connected to the bottom of the cup. This makes it possible to take in situ samples during the test period. The tubes have three way valves connected in their ends, where one way is connected to a pressure transducer and the other will be used when taking samples. The pressure is measured by Druck pressure transducers.

4.5.4 Gas tests in the bentonite

Two titanium tubes with filter tips are placed in the bentonite surrounding the upper heater. At full water saturation one of the filters will be used as gas inlet and the other as gas outlet. The exact test procedure will be decided later. The tubes have three way valves connected in their ends, where one way is connected to a pressure transducer and the other will enable access to the filter tips. The pressure is measured by Druck pressure transducers.

4.5.5 Artificial water saturation

An artificial water pressure will be applied in the outer gap filled with sand. Titanium tubes equipped with filter tips are placed in the sand on two levels, 250 mm and 6,750 mm from bottom, four at each level.

4.5.6 Hydraulic load cells for the anchor system

Three of the anchors are equipped with hydraulic cells in order to measure the force in the anchors during the saturation of the buffer. The cells are made by Glötzl.

4.5.7 Displacement of plug

Three sensors are placed on the top of the deposition hole in order to measure the displacement of the plug during the saturation.

5 Location of instruments

5.1 Strategy for describing the position of each device

Measurements are done in 7 measuring sections placed on different levels (see Figure 2-1). On each level, sensors are placed in eight main directions A, AB, B, BC, C, CD, D and DA according to Figure 5-1. Direction A and C are placed in the tunnels axial direction with A headed against the end of the tunnel i.e. almost to the South (see Figure 2-1, 5-1 and 5-2).

The bentonite blocks are called cylinders and rings. The cylinders are numbered C1–C4 and the rings R1–R12 respectively (see Figure 2-1).

Every instrument is named with a unique name consisting of one letter describing the type of measurement, (T-Temperature, P-Total Pressure, U-Pore Pressure, W-Relative Humidity, C-Chemical sampling, D-Displacement and A-Artificial water), one letter describing where the measurement takes place (B-Buffer, H-Heater, S-Sand, R-Rock and P-plug), one figure denoting the deposition hole (1 is used for the CRT test and 2 is used for this experiment), and two figures specifying the position in the buffer according to a separate list (see Appendix 2). Every instrument position is described with three coordinates according to Figure 5-2. The r-coordinate is the horizontal distance from the center of the hole and the z-coordinate is the height from the bottom of the hole (the block height is set to 500mm). The α-coordinate is the angle from the vertical direction A (almost South).

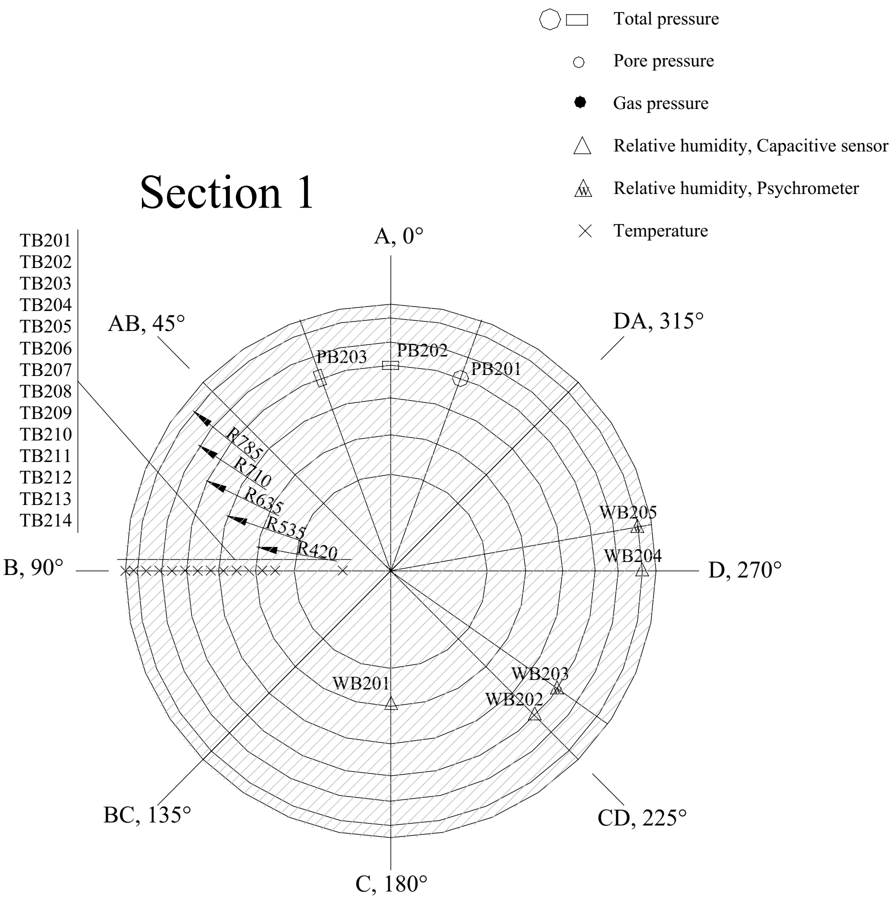


Figure 5-1. Schematic view, showing the main directions of the instrument positioning. The drawing shows the instrumentation in measuring Section 1.

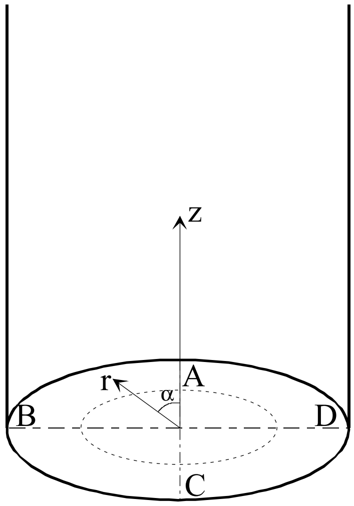


Figure 5-2. Figure describing the coordinate system used when determining the instrument positions.

5.2 Position of each instrument in the bentonite

The instruments are located in three main levels in each instrumented block, the surface of the block (only total pressure cells measuring the horizontal pressure) and 50 mm and 250 mm from the upper block surface. The thermocouples and the total pressure cells were placed at the 50 mm level by practical reasons, while most of the other sensors were placed at the 250 mm level.

The positions of each instrument for the seven measuring sections are shown in Appendix 1. These plots were used at the preparation of the blocks and at the installation of the sensors. In Appendix 2 are all the installed sensors listed with the measured coordinates after the installation, one table for each type of sensors.

5.3 Position of thermocouples in the rock

The thermocouples are located in ten bore holes in the rock, Figure 2-1. The depth of each bore hole is 1.5 m. 4 thermocouples are placed in each borehole on different distances from the rock surface. The position of each instrument is described in Appendix 2.

5.4 Hydraulic load cells on the anchors

Totally nine anchors were installed in order to keep the retaining plug in position. Three of the anchors are equipped with hydraulic load cells.

5.5 Displacement sensors for measuring the plug displacement

Totally three sensors were installed on a radius of 750 mm and with a disposition of 120°.

6 Leading sensor cables up from the deposition hole

All cables and tubes, coming out from the instruments in the bentonite blocks plus the power cables and thermocouples from the heaters, were led up along the bentonite block periphery surface. From the same levels as the top of each heater, they were led into slots made in the rock wall. The cables are also divided depending on whether they come from the lower heater and its surrounding bentonite or from the upper part. This distribution was made in order to be able to excavate the upper part of the experiment and leave the lower part for a longer period.

Since a lot of cables and tubes were led in the gap between rock and bentonite in the deposition hole (about 260 units), it was important to distribute them on the block periphery in a prescribed order. Every cable or tube had a α-coordinate, which is the angle from direction A (Figure 5-2). Each cable was led out to this position from the sensors position in pre-manufactured tracks on the blocks surface, up along the bentonite block periphery and into the slots in the rock.

6.1 Slots in the rock

Ten main slots (width 100 mm and depth 60 mm) were made on the surface of the deposition hole (see Figure 6-1 and 6-2). Five slots were used for cables coming from the lower heater and the instruments placed in the bentonite up to measuring Section 4. The other five were used for the upper part of the experiment.

The power cables from the heaters were led in separate slots in order to avoid interference with the sensors. Three of the main slots were extended with minor slots (20 × 20 mm) in order to lead up the thermocouples from the rock (see Figure 6-2).

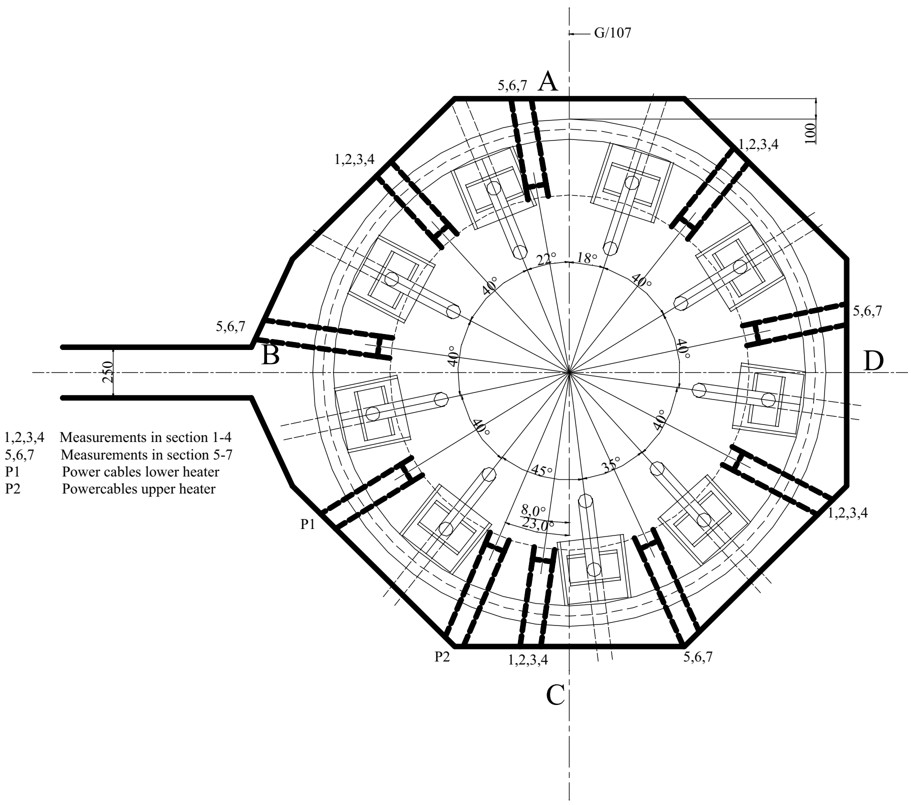


Figure 6-1. *Schematic view, showing the positions of the slots in the rock (bolded lines), the anchor cables and the wedged seats on the lid.*

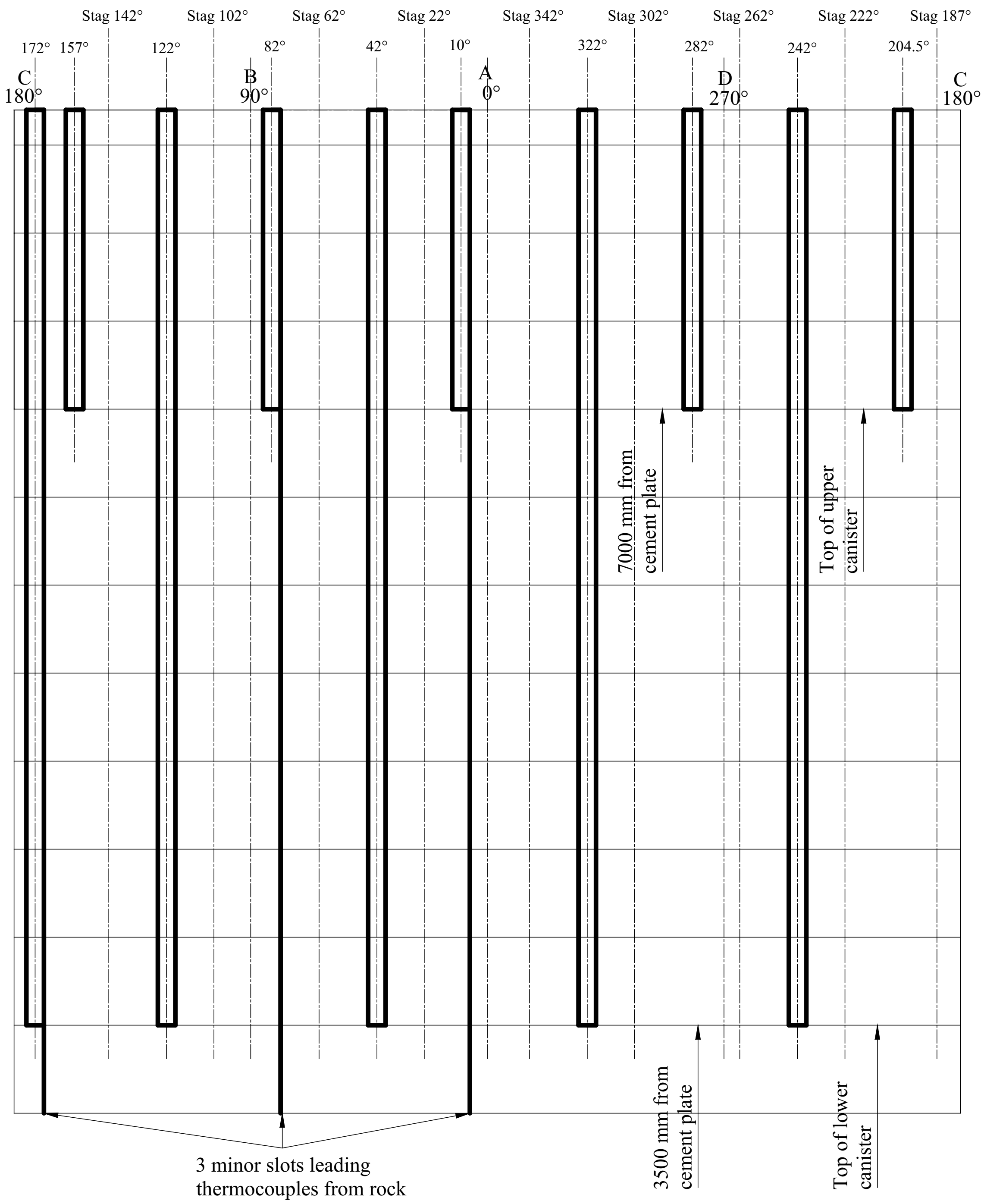


Figure 6-2. *Schematic view, showing the inner surface of the deposition hole.*

6.2 Cables and tubes from instruments in the bentonite and the rock.

All instrument cables were led in titanium tubes (Ø 8 mm or Ø 6 mm) except for the thermocouples (Ø 4 mm) which were made of cupro nickel. Tracks were made on the block surface from the instrument positions in the bentonite blocks to the decided positions on the bentonite blocks periphery, where they were bended and led axial along the bentonite blocks. When the tubes reached the entrance of a slot in the rock they were bend over and led the rest of the way up in the slot.

6.3 Cables from the heaters

The following cables were led from each heater:

- Six power cables from the electrical heaters with 4 mm outer diameter.
- Six thermocouples from the inside with 3 mm outer diameter.
- Eleven thermocouples from the surface of the heater with 3 mm outer diameter.

All cables were collected under the top lid of the heater and then distributed in different directions. From the heaters the cables were led through the bentonite in which slots had been sawed in advance in block no R6 and block no R12. The directions of the cables coming from the lower heater are shown in Figure 6-3 and corresponding plot for upper heater is shown in Figure 6-4. The cables were then led up along the bentonite blocks and into the predestined slots in the rock. Figure 6-5 shows the upper heater placed in the deposition hole. The power cables from the heater were led in tubes of copper trough the bentonite to the surface of the deposition hole. The installation of the heater and the preparation of the cables from the heaters are described in Appendix 4 .

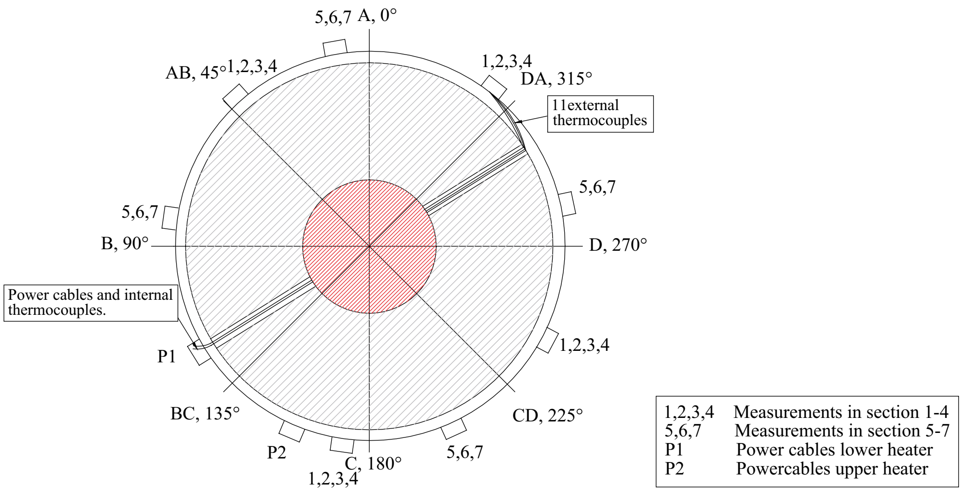


Figure 6-3. *Figure showing the directions of cables from the lower heater relative the instrument directions A, B, C and D in block R6. In this block slots were sawed in order to let the cables from the heater pass through the bentonite and out to the rock.*

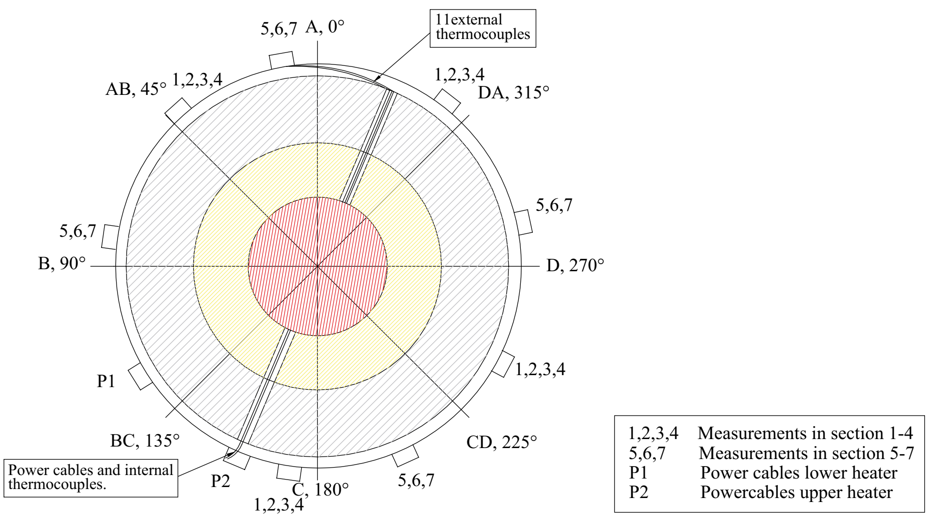


Figure 6-4. *Figure showing the directions of cables from the upper heater relative the instrument directions A, B, C and D in block R12. In this block slots were sawed in order to let the cables from the heater pass through the bentonite and out to the rock.*

***Figure 6-5.** The upper heater placed in the deposition hole before the inner gap (the shield) was filled with sand.*

7 Preparation of the bentonite blocks

7.1 Preparation for instruments

Every instrumented block (see Appendix 1) was prepared in advance at the site where the blocks were compacted that is at Hydroweld AB in Ystad, Sweden. The preparation was somewhat different depending on instrument type.

Thermocouples

- **Pentronic**. The thermocouples have an outer diameter of 4.0 mm. A hand-hold boring-machine was used at installation. **Working:** Borehole Ø 5 mm, depth 50 mm.

Total pressure

- **Geokon.** Shaped as an ice hockey puck with a diameter of 76 mm and a thickness of 16 mm. The sensors were either positioned horizontal or vertical. If horizontal, the sensors were countersunk in the bentonite block surface by use of a hand hold cutter. **Working:** Borehole Ø 76–80 mm, depth 18 mm. A vertical position means that an almost rectangular hole was needed. This was made by drilling 3 holes with a diameter of 16 mm in a row and then formed the hole with a chisel. **Working:** Borehole Ø 16mm, depth 88 mm. The shape of the rectangular hole was formed with a chisel.

Pore pressure

- **Geokon.** Shaped as a cylindrical tube with an outer diameter of 25 mm and a length of 127 mm. The holes for these gauges were bored with a drilling machine of Hilti-type fastened with a vacuum plate. **Working:** Borehole Ø 27mm, depth 250mm.

Relative humidity

- **Vaisala.** Shaped as a cylindrical tube with a 22 mm outer diameter and a 63 mm length. The holes for these gauges were bored with a drilling machine of Hilti-type fastened with a vacuum plate. **Working:** Borehole Ø 23 mm, depth 250 mm.
- **Rotronic.** Shaped as a cylindrical tube with a 22 mm outer diameter and a 135 mm length. The holes for these gauges were bored with a drilling machine of Hilti-type fastened with a vacuum plate. **Working:** Borehole Ø 23mm, depth 250 mm.
- **Wescor.** Shaped as a cylindrical tube with a 22 mm outer diameter and a 70 mm length. The holes for these gauges were bored with a drilling machine of Hilti-type fastened with a vacuum plate. **Working:** Borehole Ø 23mm, depth 250 mm.

7.2 Tracks for cables and tubes on the bentonite blocks surface

Tracks were made on the blocks surface from each instrument position, leading out the tubes to the block periphery. The tracks were made by a hand–hold cutter.

Working: All tubes from the instruments, except for the thermocouples have a track with the dimension 10 × 10 mm. The thermocouples have a track with the dimension 6 × 6 mm. When a track reached the sensor hole, the track was made deeper in order to let the tube make a smooth bend (Figure 7-1).

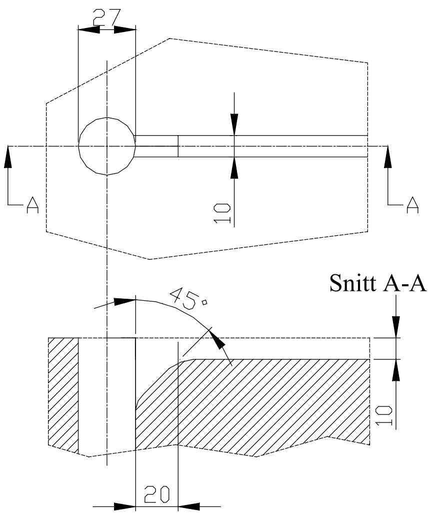


Figure 7-1. Schematic view showing how the tracks on the bentonite block surface were connected to the sensor holes. The view shows a sensor hole for a Geokon pore pressure sensor.

7.3 Preparation for cables through block R6 and R12

The power cables from the heaters were led through the bentonite. This was done by sawing slots in the bentonite blocks in advance, see Figure 6-3 and Figure 6-4. The slots were sawed with a special alligator-saw.

7.4 Reducing the radius of the cylinders and machining of the inner radius of the blocks placed around Heater 1.

The ring-shaped blocks surrounding the lower heater were produced by machining solid blocks to get a final inner diameter of about 620 mm. The inner part was removed from the rest of the block by drilling a slot using a drill with a diameter of 40 mm. The inner parts had a weight of about 350 kg. It was lifted of the rest of the block with an overhead crane by attaching several lifting eye bolts to the central part. The surface of the inner diameter was then grinded in order to get a smooth surface.

The outer diameters of all the cylinders were also machined in order to get a homogeneous density in the different sections of the buffer after saturation. The average outer diameter for these blocks was reduced from about 1,650 mm to 1,580 mm. This work was also done by drilling holes along the outer radius of the block.

8 Installation of the buffer and the heaters

8.1 General

The buffer material and heaters were installed in the deposition hole and transducers were installed in the buffer. During preparation and installation the blocks were designated according to Figure 2-1. The activities carried out during the installation of the buffer are listed in Table 8-1. The activities are described in detail in Section 8.2.

Table 8-1. List of activities performed during the installation of the buffer the deposition hole.

ID	Activity	Description
1	Preparation of deposition hole DD0086G01.	Cleaning of the bottom of deposition hole. Surveying of the concrete slab.
2	Mounting of gantry-crane over deposition hole.	The crane used for placing of the bentonite blocks was installed over the deposition hole.
3	Deposition of bentonite block C1.	The gantry-crane was used for placing the bentonite block in the deposition hole.
4	Instrumentation of bentonite block C1.	The block was equipped with transducers.
5	Deposition of bentonite blocks R1–R3.	The gantry-crane was used for placing the bentonite blocks in the deposition hole.
6	Instrumentation of bentonite block R3.	The block was equipped with transducers.
7	Deposition of bentonite block R4.	The gantry-crane was used for placing the bentonite block in the deposition hole.
8	Instrumentation of bentonite block R4.	The block was equipped with transducers.
9	Deposition of bentonite blocks R5–R6.	The gantry-crane was used for placing the bentonite blocks in the deposition hole.
10	Transportation of Heater 1.	The heater was transported from Simpevarp to the TASD-tunnel.
11	Deposition of the heater into the deposition hole.	A bolt in the roof of the tunnel and a winch was used for emplacement of the heater in the deposition hole. This work is described in Appendix 3.
12	Deposition of bentonite block C2.	The gantry-crane was used for placing the bentonite block in the deposition hole.
13	Instrumentation of bentonite block C2.	The block was equipped with transducers.
14	Installation of a PEEK ring on top of the bentonite block C2.	In order to prevent sand from the inner gap to enter block C2 a peek ring was placed on top of the block.
15	Deposition of bentonite blocks R7–R9.	The gantry-crane was used for placing the bentonite block in the deposition hole.
16	Instrumentation of bentonite block R9.	The block was equipped with transducers.
17	Deposition of bentonite block R10.	The gantry-crane was used for placing the bentonite block in the deposition hole.
18	Instrumentation of bentonite block R10.	The block was equipped with transducers.
19	Deposition of bentonite blocks R11–R12.	The gantry-crane was used for placing the bentonite block in the deposition hole.
20	Transportation of Heater 2.	The heater was transported from Simpevarp to the TASD-tunnel.
21	Deposition of the heater into the deposition hole.	A bolt in the roof of the tunnel and a winch will be used for emplacement of the heater in the deposition hole. This work is described in Appendix 3.
22	Placing of a sand filling between the heater and the bentonite blocks R7–R12.	Dry sand was placed in the gap between the bentonite and the heater.
23	Deposition of bentonite block C3.	The gantry-crane was used for placing the bentonite block in the deposition hole.
24	Instrumentation of bentonite block C3.	The block was equipped with transducers.
25	Deposition of bentonite block C4.	The gantry-crane was used for placing the bentonite block in the deposition hole.
26	Instrumentation of bentonite block C4.	The block was equipped with transducers.
27	Filling of sand in the outer gap.	The outer gap was filled with sand.
28	Filling of bentonite pellets in the gap between bentonite blocks C3 and C4 and the wall of the deposition hole.	The gap between the two most upper bentonite blocks and the rock surface in the deposition hole was filled with bentonite pellets.

8.2 Procedures for deposition of buffer and heaters

8.2.1 Preparation of the deposition hole (ID 1)

The deposition holes were cleaned before the installation of the buffer. This work was done with a vacuum cleaner. The concrete slab was surveyed in order to check if it was horizontal before the installation of the buffer.

8.2.2 Mounting of gantry-crane (ID 2)

The mounting of the gantry-crane over the deposition hole was done in the following steps:

The gantry-crane was transported to the TASD tunnel with a front loader.

The position of the gantry-crane in the tunnel during deposition was determined (input for the calculation is the co-ordinates of the centre of the deposition hole and the dimensions of the gantry-crane).

A surveyor's assistant marked the positions of the four feet of the gantry-crane on the tunnel floor.

The gantry-crane was placed over the deposition hole with its feet placed in the marked positions.

A check was made that the gantry-crane was placed in a horizontal position (with a spirit level)

The gantry-crane was operated according to the manual for the crane.

8.2.3 Deposition of bentonite blocks.

The blocks were transported and stored in special designed cases. The cases had an air tight hood in order to minimize the risk of changes in water content of the block during transportation and storage. The deposition of the bentonite blocks was made in the following steps:

The bentonite block was transported to the gantry-crane in its case with a loader. The cap of the case was removed with the loader. The number on the case was noted and the height of the blocks measured in four positions. The diameter of the block was also measured and noted (see Appendix 3). It was examined by eye. Any observed damages on the blocks were noted.

The block was attached to the lifting equipment with four straps and moved in position and lowered in the deposition hole with a gantry-crane (see Figure 8-1 and 8-2). The block was centred in the deposition hole. The final adjustment of the position of the block was made just before the block was put in place in the deposition hole.

Figure 8-1. *A bentonite block attached to the lifting equipment with four straps.*

Figure 8-2. *The first block placed at the bottom of the deposition hole.*

After placement, the four straps were released from the block and the lifting equipment was removed from the deposition hole.

The depth from the upper part of the deposition hole to the upper surface of the block was measured with a laser in four positions and noted in a protocol. Also the radial distance from the rock surface to the outer diameter of the block was measured in four points. The results of these measurements are given in Appendix 3.

8.2.4 Instrumentation of bentonite blocks

This section describes the activities with the following ID (see Table 8-1): 4, 6, 8, 13, 16, 18, 24 and 26.

The preparation of the bentonite blocks for the instrumentation is described in Section 7 in this report. The installation of each instrument was done in the following steps:

- The transducer with the titanium tube was taken from the packages of transducers placed in the tunnel. The mark on the transducer was checked.
- The tube with the transducer was lowered in the deposition hole.
- The position of the transducer was checked with holes drilled in the block and with the drawings of the prepared blocks in Appendix 1. If the position was ok, it was noted in a protocol.
- The tube was bent to fit the holes and the grooves prepared in the block and installed. When the transducer was installed this was noted in a protocol.

8.2.5 Filling of the outer gap with sand

The filling of the outer gap with sand was made after the emplacement of each bentonite block. The sand was transported down in the deposition hole in baskets. The used sand was weighted before it was poured into the outer gap. Sand was filled up to about mid height of block R12. The total amount of sand used for filling the outer gap was about 3,984 kg. The density value for the filter is very sensitive to the diameter value for the deposition hole. For a diameter of 1,752 mm, the average density of the sand filling can be calculated to 1,805 kg/m^3. The corresponding density value for a diameter of 1,757 mm (as stated in Andersson and Johansson 2002) is 1,729 kg/m^3.

8.2.6 Transportation of the heaters

The work with ID 10 and 20 (see Table 8-1) is not further described in this report.

8.2.7 Deposition of heater

The work with ID 11 and 21 (see Table 8-1) is described in Appendix 4. See also Figure 8-3 and Figure 8-4.

Figure 8-3. *The heater just before it is placed in the deposition hole.*

Figure 8-4. *The upper heater placed in the deposition hole.*

8.2.8 Installation of small bentonite blocks on top of the lid of Heater 1.

Highly compacted ring-shaped bentonite blocks surround Heater 1. These rings have a total height that is larger than the length of the heater. The resulting volume between the top of the heater and the top of the last ring was filled with small bentonite blocks (bricks with the dimensions 233 × 114 × 65 mm^3). The height of the volume filled with small bentonite blocks was thus about 26 mm. The bricks were made of MX-80 bentonite with a water ratio of 16% at Höganäs Bjuf AB in Bjuv. The blocks had an average dry density of about 1,640 kg/m^3. See also Figure 8-5.

The blocks were lowered in a basket to the top of the heater in the deposition hole. The placement was made by hand. In order to fill the volume above the heater some of the blocks were cut in smaller pieces. This was made with a saw. The weight of all the blocks installed was noted in a protocol for the purpose of calculating of the final bulk density. The gaps between the blocks were filled with bentonite powder. The weight of the powder was also noted in a protocol.

Figure 8-5. *Small bricks of bentonite are placed on top of Heater 1.*

Figure 8-6. *The PEEK ring placed on top of block C2.*

8.2.9 Installation of a ring of PEEK on top of bentonite block C2 (ID 14)

In order to prevent sand from the inner gap to enter the bentonite block C2 a ring shaped PEEK plate was placed on top of bentonite block C2 (Figure 8-6). The PEEK plate was placed in the deposition hole before bentonite block R7 was placed in the deposition hole. The ring also made it easier to place the upper heater in the centre of the deposition hole.

8.2.10 Filling of sand in the inner gap (ID 22)

When the blocks surrounding the upper heater were put in place in the deposition hole the gap between the heater and the bentonite buffer was filled with sand (Figure 8-7). The sand was transported in to the deposition hole in baskets. Each basket was weighted and the weight was noted in a protocol. The sand was compacted by hand to the decided density from the upper surface of bentonite block R12. This work was done after the heater fixed in its right position in the deposition hole. The total weight of the sand was about 3,357 kg. The average dry density of the sand filling was after the installation about 1,820 kg/m^3.

8.2.11 Placing a filter on top of block C3

A filter consisting of two layers of plastic sheets, delivered from PIAB with the model code PPM-F, with a total thickness of about 4 mm was placed on top of block C3 (Figure 8-8 and Figure 8-9). The diameter of the filter was about 1,400 mm. The filter was placed in a countersink which was machined from the top of the block. The filter have access to water from the top of the deposition hole trough two tubes which are connected to the filter with special designed plates placed underneath the filter.

8.2.12 Filling of bentonite pellets (ID 28)

The pellets were placed in the gap after all the bentonite blocks were installed (Figure 8-10). This was done just before casting of the plug.

The sequence of the filling was as follows:

- The pellets were delivered in big bags, holding about 1 ton. The bags were weighted before the filling started and the left over pellets after emplacement were also weighted.
- The pellets blowing machine was filled with pellets. From the top of the last installed bentonite block the pellets were blown into the gap through a specially designed nozzle.
- After the gap was filled with pellets a levelling of the upper surface of block C4 was made.

The total amount of pellets used was about 745 kg. The density value is very sensitive to the diameter value for the deposition hole. For a diameter of 1,752 mm, the average density of the pellets filling can be calculated to 1,300 kg/m^3. The corresponding density value for a diameter of 1,757 mm (as stated in Andersson and Johansson 2002) is 1,263 kg/m^3.

Figure 8-7. *The inner gap between the upper heater and the bentonite blocks was filled with sand.*

Figure 8-8. *The two plates used for applying the filter with water placed on the surface of block C3.*

Figure 8-9. *The filter consisting of two layers placed on top of block C3.*

Figure 8-10. *The outer gap between block C4 and the wall of the deposition hole filled with pellets of MX-80.*

8.3 Density of the installed buffer

As described in previous chapters, the buffer of bentonite consists of highly compacted large blocks, small bricks of bentonite on top of the heater lid and pellets of bentonite in the most upper part of the outer gap between the bentonite blocks and the surface of the deposition hole. Furthermore, most of the outer gap and the inner gap between the heater and the bentonite of the upper heater were filled with sand. The final density of the buffer is depending of the weight of the installed buffer material and the dimensions of the block, the deposition hole and the heaters but also on the deformation of the volumes of the sand, caused by the swelling pressure of the buffer. Calculations of the expected density of the buffer at four different sections of the deposition hole have been done and are presented in Table 8-2. These four sections correspond to:

- the most upper part of the deposition hole (section A) where the outer gap was filled with pellets,
- at the solid blocks between the two heaters and underneath the lower heater (section B) where the outer gap is filled with sand,
- around the upper heater (section C) where both the outer gap and the inner gap between the buffer and the heater is filled with sand and around the lower heater (section D) where the outer gap is filled with sand.

With the known density of the buffer it is also possible to calculate the expected swelling pressure of the buffer which also is presented in Table 8-2.The calculations are made with the following assumptions:

- No axial swelling of the buffer is occurring.
- The volume of the sand in the inner gap around the upper heater is assumed to be reduced with 20% caused by the swelling pressure of the buffer.
- The volume of the sand in the outer gap between the buffer and the wall of the deposition hole is assumed to be reduced with 10% caused by the swelling pressure of the buffer.
- The relation between the void ratio and the swelling pressure can be estimated with Eqn. 8-1 (Börgesson et al. 1995).

$$e = e_0 \times \left[\frac{p}{p_0} \right]^{\beta} \qquad (8\text{-}1)$$

where

e_0 = void ratio at the reference pressure p_0 (= 1.1)

e = void ratio at the pressure p

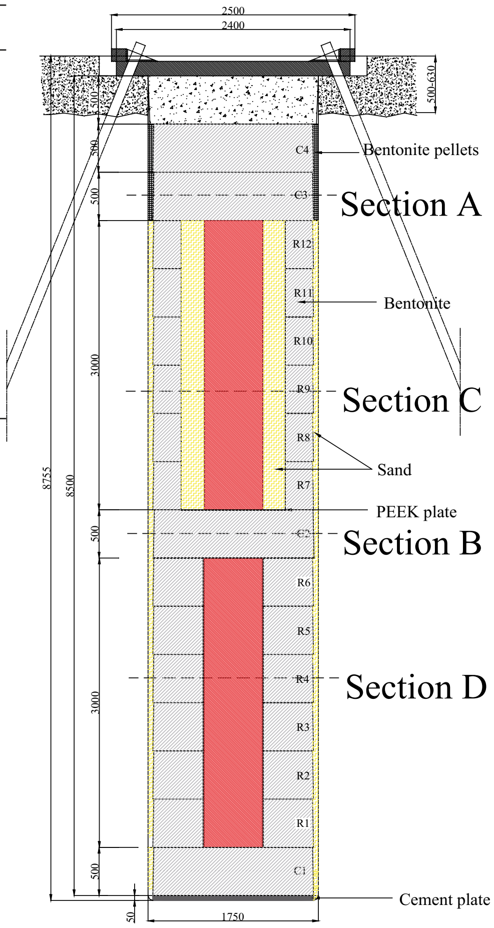
p_0 = reference pressure (= 1,000 kPa)

β = pressure exponent (= –0.19)

The calculated average density at saturation varies between 2,015 and 2,040 kg/m^3 for the different sections.

Table 8-2. Calculated density at saturation, void ratio and expected swelling pressure for different parts of the buffer in the deposition hole.

Section	A	B	C	D
Block density (kg/m^3)	1,996	1,996	2,064	1,996
Water content (%)	17.5	17.5	17.5	17.5
Outer diameter (mm)	1,580	1,580	1,640	1,640
Inner diameter (mm)	–	–	1,070	636
Average buffer density at saturation (kg/m^3)	2,015	2,040	2,020	2,030
Void ratio at saturation	0.754	0.712	0.740	0.722
Expected swelling pressure (kPa)	7,320	9,890	8,070	9,190



9 Retaining construction

9.1 Concrete foundation

A concrete foundation was cast at the bottom floor of the deposition hole. The diameter was 1,650 mm and the thickness was approx. 150 mm. A mould was temporarily mounted for this work. Concrete was used for the foundation and was reinforced with a copper net. A horizontal surface of the foundation was obtained with a 5–15 mm thick layer of a levelling compound.

9.2 Recess

In order to get the right distance of 8.5 m between the foundation in the deposition hole and the bottom of the concrete plug at the top, it was necessary to cut a recess around the deposition hole for the steel lid. The recess was cut 175 mm below the existing tunnel floor and was shaped as an octagon with a largest diameter of 2,922 mm. The bottom of the recess was made horizontal.

9.3 Plug

The mould for the concrete plug was made conical to ensure that the concrete plug can move vertically. The mould was made of stainless steel sheets. The steel sheets were screwed into the rock wall. Joints and bottom of the mould were sealed. The void between the mould and the rock wall was grouted in order to restrain the pressure from the concrete during casting.

The concrete plug was cast in situ. The height of the plug is 0.5 m. Concrete of quality K 40 was used. A 5 mm waterproof rubber mat was placed on top of the upper bentonite block to prevent swelling during the casting. The concrete layer covering the reinforcement (B500B) was 50 mm thick. The inside of the mould was covered with mould oil in order to make sure that the concrete cone can move vertically.

9.4 Lid

The lid was made of steel with a thickness of 150 mm and a diameter of 2,400 mm. The lid was designed to prevent the bentonite buffer from swelling. There are nine cut-outs in the lid for the anchor cables. The anchor cables are attached to the lid via wedged seats on a machined surface for good load distribution. A steel ring was mounted on the outside of the wedge seats to prevent them from sliding.

The lid was designed to retain a total load of 9 MPa from beneath. The weight of the lid is 5,325 kg, the supporting ring 1,325 kg and nine piece wedge seats 360 kg, make the total installation weight 7,010 kg.

In order to achieve a good contact between the lid and the concrete in the recess, a thin layer prepared by a mixture of cement and water ("sluring" in Swedish) was applied on the recess surface.

9.5 Anchor cables

Nine holes were percussion drilled to a depth of 10 m. The outward angel of the holes was 21.8° from the deposition hole. The drill hole diameter was 120 mm. The upper part of the holes through the concrete floor was core drilled (Ø 140 mm) in order to ensure not to drill in reinforcements with the main equipment.

The anchor cables were installed in nine 10 m long drilled holes. The total length of each cable is 11 m. The cables were of type VSL 6-12 and each cable has an ultimate strength of 3,180 kN. (Previously it has been stated that the type VSL 5-19 was used and that the ultimate strength was of 3,530 kN. This was however found to be erroneous during the dismantling operation). The anchorage was made through grouting along 7.5 m of the cables, while 2.5 m was free.

Load cells were mounted to three of the anchor cables to make it possible to monitor the load during the installation and also the total load from the buffer during operation.

Three hydraulic jacks were used during pre-tensioning of the anchor cables. This was made is two steps. Initially, only three anchor cables were used to keep the lid in place. The load cells were connected to these cables. The pre-tension was 40 kN for each cable. When the load on each of these three cables reached 500 kN, the load was distributed equally on all the anchor cables in the following way:

i) Three other anchor cables were each pre-tensioned to 170 kN at the same time as each of the first three cables were released to 330 kN.

ii) The three remaining cables were each pre-tensioned to 170 kN, while the six other were adjusted to 170 kN each.

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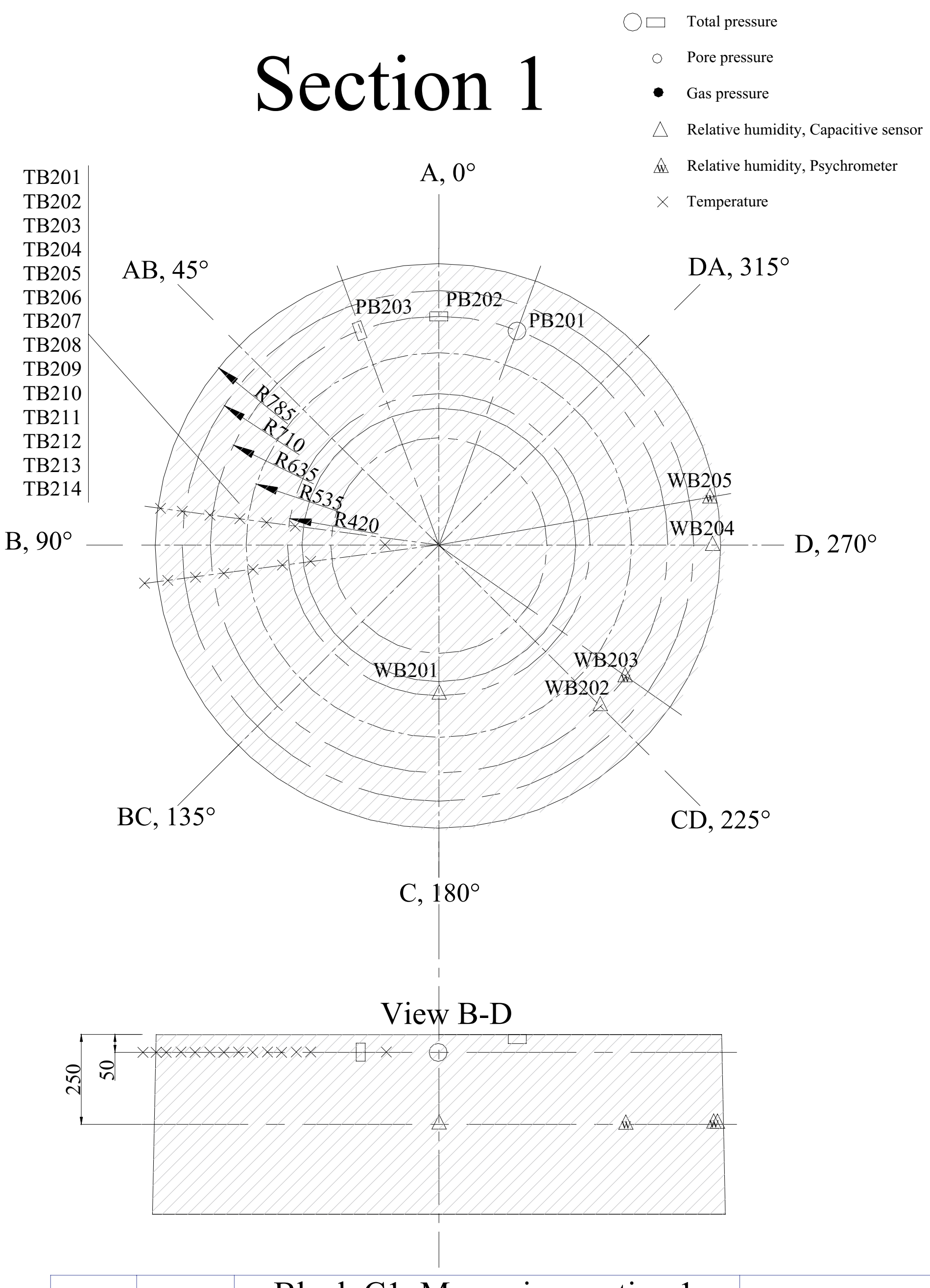
Measuring sections

RevNo	Revision note	Date	Signnature	Checked



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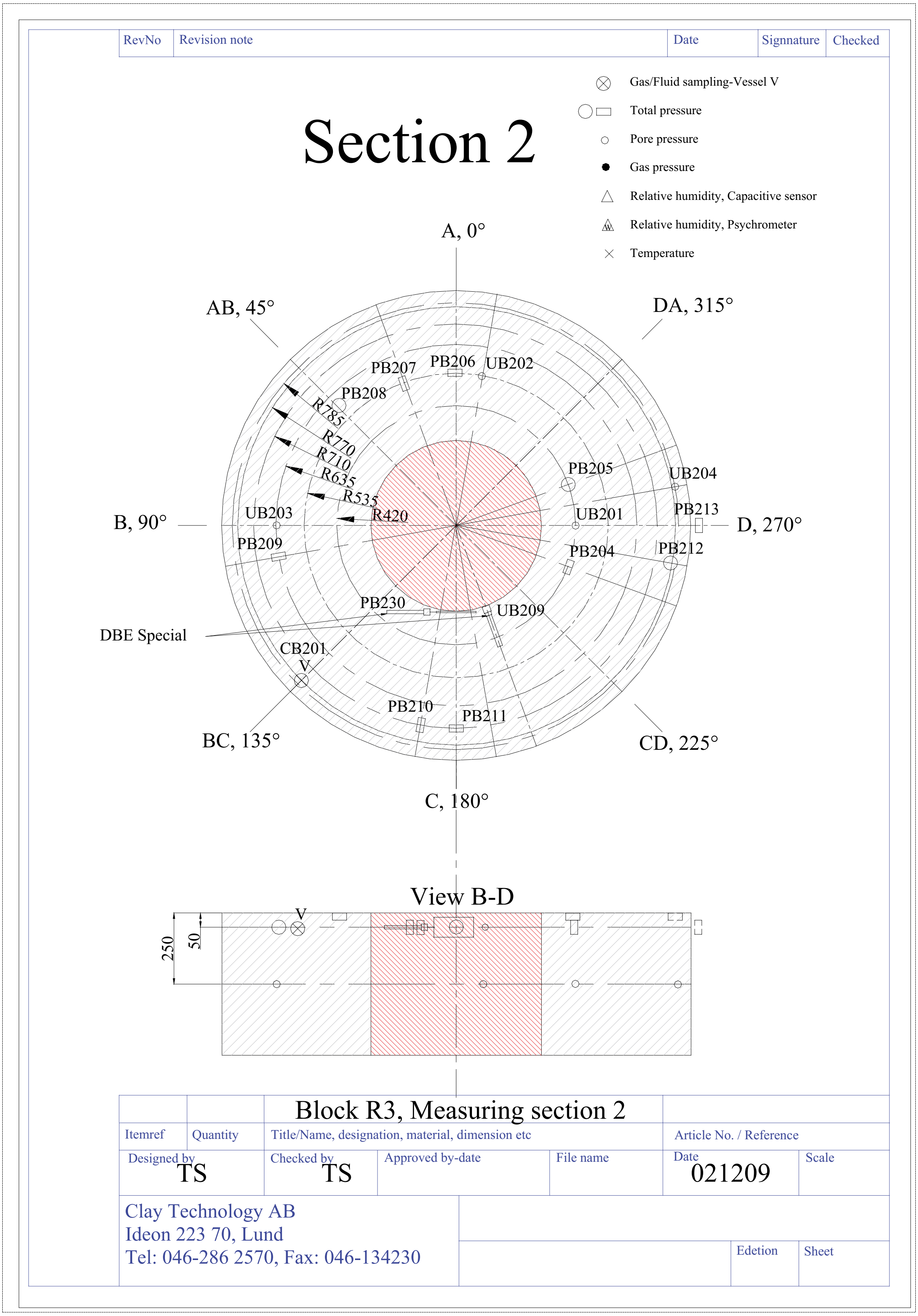
Itemref	Quantity	Title/Name, designation, material, dimension etc		Article No. / Reference	
Designed by TS	Checked by TS	Approved by-date	File name	Date 021209	Scale

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



RevNo
Revision note
Date
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Section 2
Gas/Fluid sampling-Vessel V
Total pressure
Pore pressure
Gas pressure
Relative humidity, Capacitive sensor
Relative humidity, Psychrometer
Temperature
A, 0°
AB, 45°
DA, 315°
B, 90°
D, 270°
BC, 135°
CD, 225°
C, 180°
PB207
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UB202
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R710
R635
R535
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PB205
UB204
UB203
UB201
PB213
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TS
Checked by
TS
Approved by-date
File name
Date
021209
Scale
Clay Technology AB
Ideon 223 70, Lund
Tel: 046-286 2570, Fax: 046-134230
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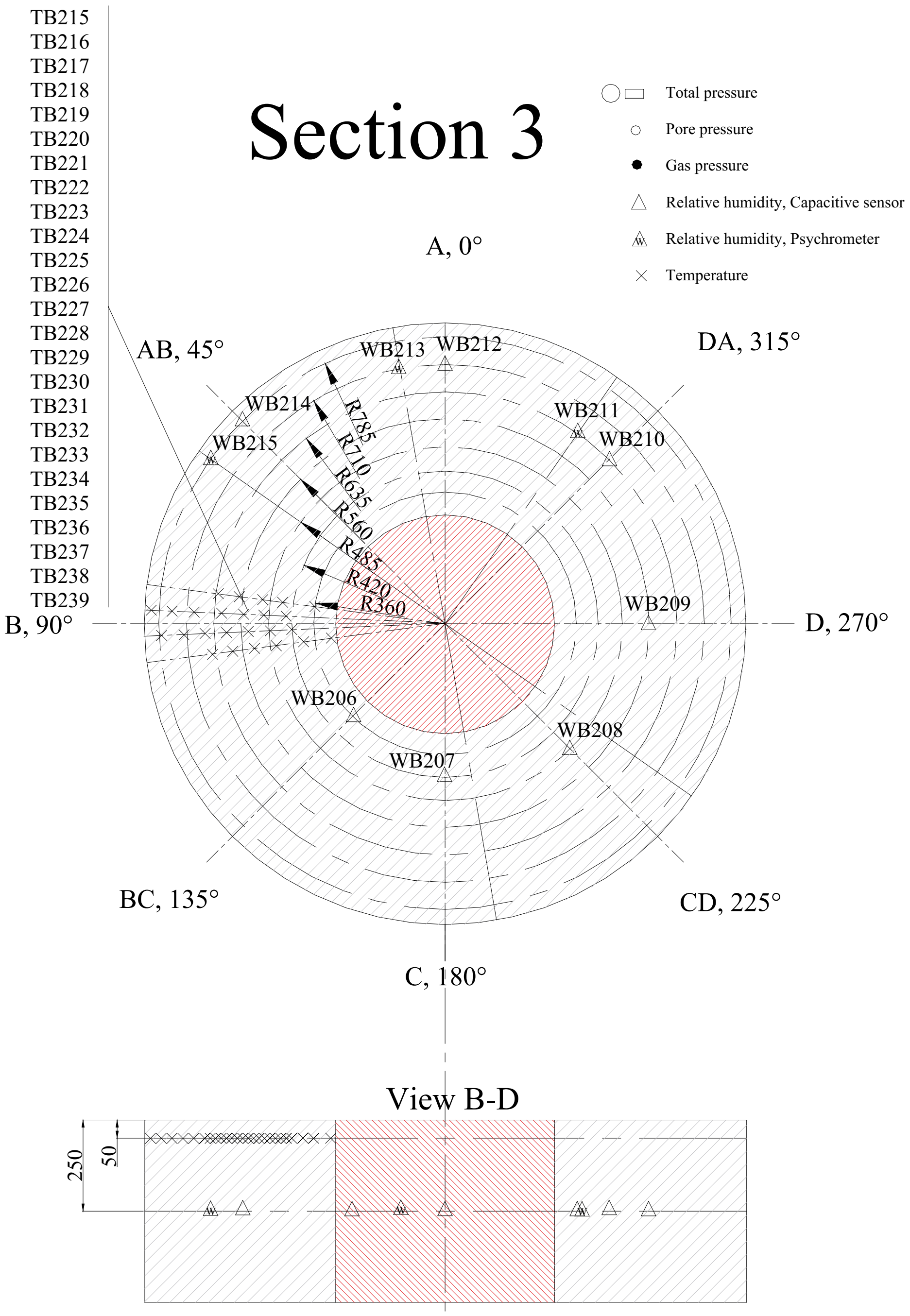

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Clay Technology AB
Ideon 223 70, Lund
Tel: 046-286 2570, Fax: 046-134230

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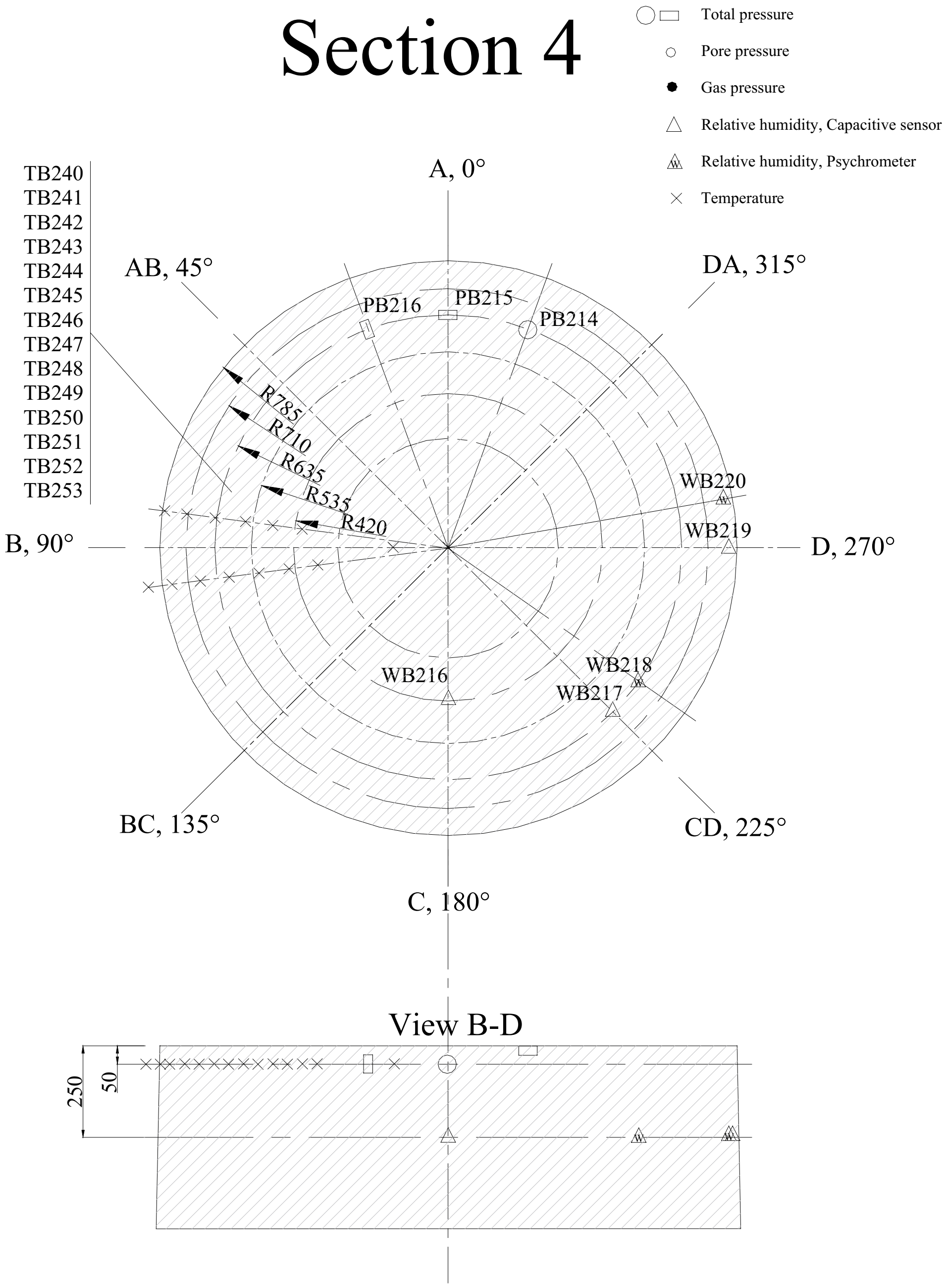

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Clay Technology AB
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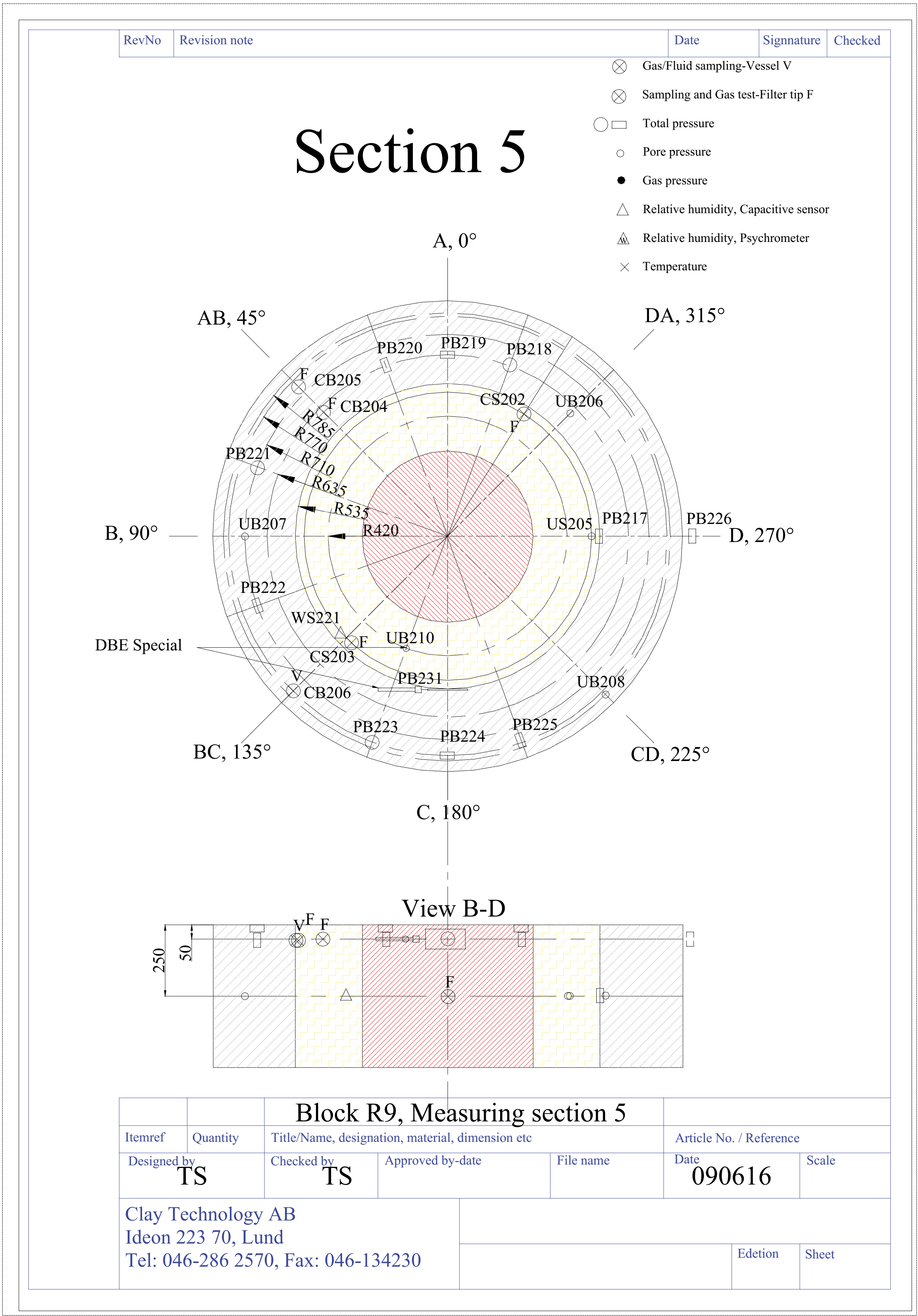
Edetion | Sheet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Sampling and Gas test-Filter tip F
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Pore pressure
Gas pressure
Relative humidity, Capacitive sensor
Relative humidity, Psychrometer
Temperature
Section 5
A, 0°
AB, 45°
DA, 315°
B, 90°
D, 270°
BC, 135°
CD, 225°
C, 180°
PB220
PB219
PB218
F CB205
F CB204
CS202
UB206
F
R785
R770
R710
R635
R535
R420
PB221
UB207
US205
PB217
PB226
PB222
WS221
DBE Special
F
UB210
CS203
V
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CB206
UB208
PB223
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PB225
View B-D
250
50
V F F
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TS
Checked by
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Approved by-date
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Clay Technology AB
Ideon 223 70, Lund
Tel: 046-286 2570, Fax: 046-134230
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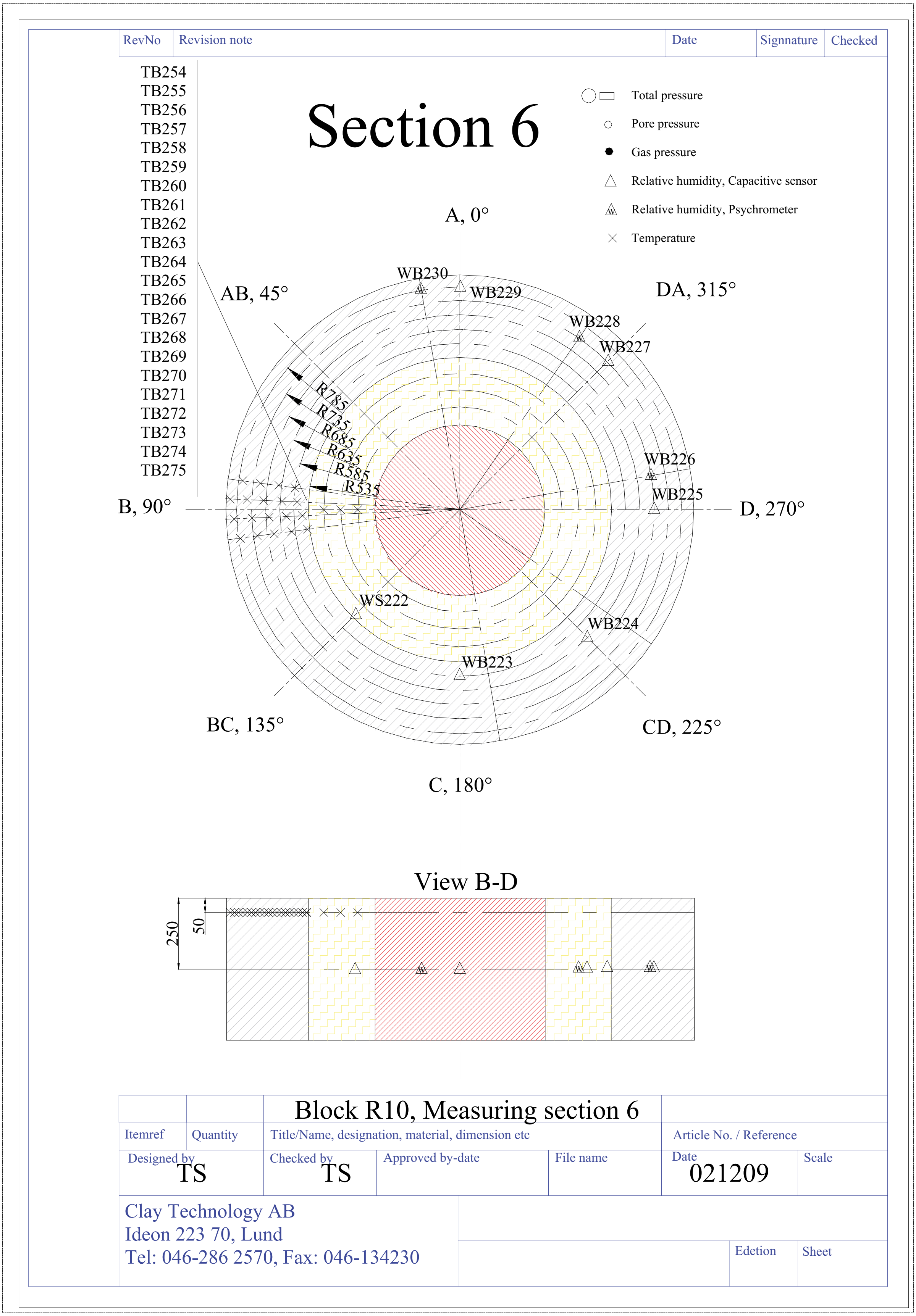
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TB266
TB267
TB268
TB269
TB270
TB271
TB272
TB273
TB274
TB275
Section 6
Total pressure
Pore pressure
Gas pressure
Relative humidity, Capacitive sensor
Relative humidity, Psychrometer
Temperature
A, 0°
AB, 45°
DA, 315°
B, 90°
D, 270°
BC, 135°
CD, 225°
C, 180°
WB230
WB229
WB228
WB227
WB226
WB225
WB224
WB223
WS222
R785
R735
R685
R635
R585
R535
View B-D
250
50
Block R10, Measuring section 6
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Article No. / Reference
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Checked by
TS
Approved by-date
File name
Date
021209
Scale
Clay Technology AB
Ideon 223 70, Lund
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Edetion
Sheet

List of installed instruments

Temperature Buffer Test, Instrumentation

Instrument type: Thermocouple
Deposition hole: DD0086G01

				Instrument position in block			
Mark	**Type**	**Installed**	**Block**	**α degree**	**r mm**	**Z mm**	**Äspö coord m**
TB201	Pentronic	2003-01-27	Cyl. 1	90	150	452	–424.914
TB202	Pentronic	2003-01-27	Cyl. 1	95	360	452	–424.914
TB203	Pentronic	2003-01-27	Cyl. 1	85	400	452	–424.914
TB204	Pentronic	2003-01-27	Cyl. 1	95	440	452	–424.914
TB205	Pentronic	2003-01-27	Cyl. 1	85	480	452	–424.914
TB206	Pentronic	2003-01-27	Cyl. 1	95	520	452	–424.914
TB207	Pentronic	2003-01-27	Cyl. 1	85	560	452	–424.914
TB208	Pentronic	2003-01-27	Cyl. 1	95	600	452	–424.914
TB209	Pentronic	2003-01-27	Cyl. 1	85	640	452	–424.914
TB210	Pentronic	2003-01-27	Cyl. 1	95	680	452	–424.914
TB211	Pentronic	2003-01-27	Cyl. 1	85	720	452	–424.914
TB212	Pentronic	2003-01-27	Cyl. 1	95	760	452	–424.914
TB213	Pentronic	2003-01-27	Cyl. 1	85	800	452	–424.914
TB214	Pentronic	2003-01-27	Cyl. 1	95	840	452	–424.914
TB215	Pentronic	2003-01-30	R4	97.5	320	2,469	–422.897
TB216	Pentronic	2003-01-30	R4	82.5	360	2,469	–422.897
TB217	Pentronic	2003-01-30	R4	97.5	390	2,469	–422.897
TB218	Pentronic	2003-01-30	R4	92.5	420	2,469	–422.897
TB219	Pentronic	2003-01-30	R4	87.5	435	2,469	–422.897
TB220	Pentronic	2003-01-30	R4	82.5	450	2,469	–422.897
TB221	Pentronic	2003-01-30	R4	97.5	465	2,469	–422.897
TB222	Pentronic	2003-01-30	R4	92.5	480	2,469	–422.897
TB223	Pentronic	2003-01-30	R4	87.5	495	2,469	–422.897
TB224	Pentronic	2003-01-30	R4	82.5	510	2,469	–422.897
TB225	Pentronic	2003-01-30	R4	97.5	525	2,469	–422.897
TB226	Pentronic	2003-01-30	R4	92.5	540	2,469	–422.897
TB227	Pentronic	2003-01-30	R4	87.5	555	2,469	–422.897
TB228	Pentronic	2003-01-30	R4	82.5	570	2,469	–422.897
TB229	Pentronic	2003-01-30	R4	97.5	585	2,469	–422.897
TB230	Pentronic	2003-01-30	R4	92.5	600	2,469	–422.897
TB231	Pentronic	2003-01-30	R4	87.5	615	2,469	–422.897
TB232	Pentronic	2003-01-30	R4	82.5	630	2,469	–422.897
TB233	Pentronic	2003-01-30	R4	97.5	645	2,469	–422.897
TB234	Pentronic	2003-01-30	R4	92.5	660	2,469	–422.897
TB235	Pentronic	2003-01-30	R4	87.5	690	2,469	–422.897
TB236	Pentronic	2003-01-30	R4	92.5	720	2,469	–422.897
TB237	Pentronic	2003-01-30	R4	87.5	750	2,469	–422.897
TB238	Pentronic	2003-01-30	R4	92.5	780	2,469	–422.897
TB239	Pentronic	2003-01-30	R4	87.5	810	2,469	–422.897
TB240	Pentronic	2003-02-12	Cyl. 2	90	150	3,983	–421.382
TB241	Pentronic	2003-02-12	Cyl. 2	95	360	3,983	–421.382
TB242	Pentronic	2003-02-12	Cyl. 2	85	400	3,983	–421.382

				Instrument position in block			
Mark	**Type**	**Installed**	**Block**	**α degree**	**r mm**	**Z mm**	**Äspö coord m**
TB243	Pentronic	2003-02-12	Cyl. 2	95	440	3,983	–421.382
TB244	Pentronic	2003-02-12	Cyl. 2	85	480	3,983	–421.382
TB245	Pentronic	2003-02-12	Cyl. 2	95	520	3,983	–421.382
TB246	Pentronic	2003-02-12	Cyl. 2	85	560	3,983	–421.382
TB247	Pentronic	2003-02-12	Cyl. 2	95	600	3,983	–421.382
TB248	Pentronic	2003-02-12	Cyl. 2	85	640	3,983	–421.382
TB249	Pentronic	2003-02-12	Cyl. 2	95	680	3,983	–421.382
TB250	Pentronic	2003-02-12	Cyl. 2	85	720	3,983	–421.382
TB251	Pentronic	2003-02-12	Cyl. 2	95	760	3,983	–421.382
TB252	Pentronic	2003-02-12	Cyl. 2	85	800	3,983	–421.382
TB253	Pentronic	2003-02-12	Cyl. 2	95	825	3,983	–421.382
TB254	Pentronic	2003-02-24	R10	~90	343	6,056	–419.309
TB255	Pentronic	2003-02-24	R10	~90	400	6,056	–419.309
TB256	Pentronic	2003-02-24	R10	~90	463	6,056	–419.309
TB257	Pentronic	2003-02-18	R10	97.5	540	6,006	–419.359
TB258	Pentronic	2003-02-18	R10	92.5	555	6,006	–419.359
TB259	Pentronic	2003-02-18	R10	87.5	570	6,006	–419.359
TB260	Pentronic	2003-02-18	R10	82.5	585	6,006	–419.359
TB261	Pentronic	2003-02-18	R10	97.5	600	6,006	–419.359
TB262	Pentronic	2003-02-18	R10	92.5	615	6,006	–419.359
TB263	Pentronic	2003-02-18	R10	87.5	630	6,006	–419.359
TB264	Pentronic	2003-02-18	R10	82.5	645	6,006	–419.359
TB265	Pentronic	2003-02-18	R10	97.5	660	6,006	–419.359
TB266	Pentronic	2003-02-18	R10	92.5	675	6,006	–419.359
TB267	Pentronic	2003-02-18	R10	87.5	690	6,006	–419.359
TB268	Pentronic	2003-02-18	R10	82.5	705	6,006	–419.359
TB269	Pentronic	2003-02-18	R10	97.5	720	6,006	–419.359
TB270	Pentronic	2003-02-18	R10	92.5	735	6,006	–419.359
TB271	Pentronic	2003-02-18	R10	87.5	750	6,006	–419.359
TB272	Pentronic	2003-02-18	R10	82.5	765	6,006	–419.359
TB273	Pentronic	2003-02-18	R10	97.5	780	6,006	–419.359
TB274	Pentronic	2003-02-18	R10	92.5	795	6,006	–419.359
TB275	Pentronic	2003-02-18	R10	87.5	810	6,006	–419.359
TB276	Pentronic	2003-02-26	Cyl. 3	90	150	7,524	–417.841
TB277	Pentronic	2003-02-26	Cyl. 3	95	360	7,524	–417.841
TB278	Pentronic	2003-02-26	Cyl. 3	85	400	7,524	–417.841
TB279	Pentronic	2003-02-26	Cyl. 3	95	440	7,524	–417.841
TB280	Pentronic	2003-02-26	Cyl. 3	85	480	7,524	–417.841
TB281	Pentronic	2003-02-26	Cyl. 3	95	520	7,524	–417.841
TB282	Pentronic	2003-02-26	Cyl. 3	85	560	7,524	–417.841
TB283	Pentronic	2003-02-26	Cyl. 3	95	600	7,524	–417.841
TB284	Pentronic	2003-02-26	Cyl. 3	85	640	7,524	–417.841
TB285	Pentronic	2003-02-26	Cyl. 3	95	680	7,524	–417.841
TB286	Pentronic	2003-02-26	Cyl. 3	85	720	7,524	–417.841
TB287	Pentronic	2003-02-26	Cyl. 3	95	760	7,524	–417.841
TB288	Pentronic	2003-02-26	Cyl. 3	85	800	7,524	–417.841
TB289	Pentronic	2003-02-26	Cyl. 3	95	825	7,524	–417.841
B290	Pentronic	2003-02-19	R12	~90	360	6,881	–418.485
B291	Pentronic	2003-02-19	R12	~90	420	6,881	–418.485
B292	Pentronic	2003-02-19	R12	~90	480	6,881	–418.485

Instrument type: Total Pressure
Deposition hole: DD0086G01

					Instrument position in block			
Mark	Type	Installed	Notes	Block	α degree	r mm	Z mm	Äspö coord m
PB201	Geokon	2003-01-27	Horizontal	Cyl. 1	340	635	502	–424.864
PB202	Geokon	2003-01-27	Radial	Cyl. 1	0	635	452	–424.914
PB203	Geokon	2003-01-27	Vertical	Cyl. 1	20	635	452	–424.914
PB204	Geokon	2003-01-29	Radial	R3	250	420	1,968	–423.397
PB205	Geokon	2003-01-29	Horizontal	R3	290	420	2,018	–423.347
PB206	Geokon	2003-01-29	Radial	R3	8	535	1,968	–423.397
PB207	Geokon	2003-01-29	Vertical	R3	20	535	1,968	–423.397
PB208	Geokon	2003-01-30	Horizontal	R3	45	585	2,018	–423.347
PB209	Geokon	2003-01-30	Vertical	R3	100	635	1,968	–423.397
PB210	Geokon	2003-01-30	Vertical	R3	170	710	1,968	–423.397
PB211	Geokon	2003-01-30	Radial	R3	180	710	1,968	–423.397
PB212	Geokon	2003-01-30	Horizontal	R3	260	748	2,018	–423.347
PB213	Geokon	2003-01-23	Radial on Rock	R3	270	875	1,950	–423.397
PB230	DBE	2003-01-29	Radial	R3	180	315	1,968	–423.397
PB214	Geokon	2003-02-12	Horizontal	Cyl. 2	340	635	4,033	–421.332
PB215	Geokon	2003-02-12	Radial	Cyl. 2	0	635	3,983	–421.382
PB216	Geokon	2003-02-12	Vertical	Cyl. 2	20	635	3,983	–421.382
PB217	Geokon	2003-02-14	Radial,against sand	R9	270	535	5,319	–420.046
PB218	Geokon	2003-02-14	Horizontal	R9	340	635	5,554	–419.811
PB219	Geokon	2003-02-14	Radial	R9	0	635	5,504	–419.861
PB220	Geokon	2003-02-14	Vertical	R9	20	635	5,504	–419.861
PB221	Geokon	2003-02-14	Horizontal	R9	70	710	5,554	–419.811
PB222	Geokon	2003-02-14	Radial	R9	110	710	5,504	–419.861
PB223	Geokon	2003-02-14	Horizontal	R9	160	745	5,554	–419.811
PB224	Geokon	2003-02-14	Radial	R9	180	770	5,504	–419.861
PB225	Geokon	2003-02-14	Vertical	R9	200	740	5,504	–419.861
PB226	Geokon	2003-01-23	Radial on Rock	R9*	270	875	5,450*	–419.861*
PB231	DBE	2003-02-14	Radial	R9	180	535	5,504	–419.861
PB227	Geokon	2003-02-26	Horizontal	Cyl. 3	340	635	7,574	–417.791
PB228	Geokon	2003-02-26	Radial	Cyl. 3	0	635	7,524	–417.841
PB229	Geokon	2003-02-26	Vertical	Cyl. 3	20	635	7,524	–417.841

* During the dismantling operation it was found that PB226 was located approx. 1 m below the stated level, i.e. outside Ring 7.

Instrument type: Pore Pressure
Deposition hole: DD0086G01

					Instrument position in block			
Mark	Type	Installed	Notes	Block	α degree	r mm	Z mm	Äspö coord m
UB201	Geokon	2003-01-29		R3	270	420	1,768	–423.597
UB202	Geokon	2003-01-29		R3	350	535	1,768	–423.597
UB203	Geokon	2003-01-29		R3	90	635	1,768	–423.597
UB204	Geokon	2003-01-29		R3	280	785	1,768	–423.597
UB209	DBE	2003-01-29		R3	200	315	1,968	–423.397
US205	Geokon	2003-02-14	In sand	R9	270	510	5,304	–420.061
UB206	Geokon	2003-02-14		R9	315	635	5,304	–420.061
UB207	Geokon	2003-02-14		R9	90	710	5,304	–420.061
UB208	Geokon	2003-01-23		R9	225	785	5,304	–420.061
UB210	DBE	2003-02-14	In sand	R9	150	510	5,304	–420.061

Instrument type: Relative Humidity
Deposition hole: DD0086G01

					Instrument position in block			
Mark	Type	Installed	Notes	Block	α degree	r mm	Z mm	Äspö coord m
WB201	Rotronic	2003-01-27		Cyl.1	180	420	252	–425.114
WB202	Vaisala	2003-01-27		Cyl.1	225	635	252	–425.114
WB203	Wescor	2003-01-27		Cyl.1	235	635	252	–425.114
WB204	Rotronic	2003-01-27		Cyl.1	270	785	252	–425.114
WB205	Wescor	2003-01-27		Cyl.1	280	785	252	–425.114
WB206	Vaisala	2003-01-30		R4	135	360	2,269	–423.097
WB207	Rotronic	2003-01-30		R4	180	420	2,269	–423.097
WB208	Vaisala	2003-01-30		R4	225	485	2,269	–423.097
WB209	Rotronic	2003-01-30		R4	270	560	2,269	–423.097
WB210	Vaisala	2003-01-30		R4	315	635	2,269	–423.097
WB211	Wescor	2003-01-30		R4	325	635	2,269	–423.097
WB212	Rotronic	2003-01-30		R4	0	710	2,269	–423.097
WB213	Wescor	2003-01-30		R4	10	710	2,269	–423.097
WB214	Vaisala	2003-01-30		R4	45	785	2,269	–423.097
WB215	Wescor	2003-01-30		R4	55	785	2,269	–423.097
WB216	Rotronic	2003-02-12		Cyl.2	180	420	3,783	–421.582
WB217	Vaisala	2003-02-12		Cyl.2	225	635	3,783	–421.582
WB218	Wescor	2003-02-12		Cyl.2	235	635	3,783	–421.582
WB219	Rotronic	2003-02-12		Cyl.2	270	785	3,783	–421.582
WB220	Wescor	2003-02-12		Cyl.2	280	785	3,783	–421.582
WS221	Vaisala	2003-02-18	In sand	R9	135	525	5,304	–420.061
WS222	Vaisala	2003-02-18	In sand	R10	135	525	5,806	–419.559
WB223	Rotronic	2003-02-18		R10	180	585	5,806	–419.559
WB224	Vaisala	2003-02-18		R10	225	635	5,806	–419.559
WB225	Rotronic	2003-02-18		R10	270	685	5,806	–419.559
WB226	Wescor	2003-02-18		R10	280	685	5,806	–419.559
WB227	Vaisala	2003-02-18		R10	315	735	5,806	–419.559
WB228	Wescor	2003-02-18		R10	325	735	5,806	–419.559
WB229	Rotronic	2003-02-18		R10	0	785	5,806	–419.559
WB230	Wescor	2003-02-18		R10	10	785	5,806	–419.559
WB231	Rotronic	2003-02-26		Cyl.3	180	420	7,374	–417.991
WB232	Vaisala	2003-02-26		Cyl.3	225	635	7,374	–417.991
WB233	Wescor	2003-02-26		Cyl.3	235	635	7,374	–417.991
WB234	Rotronic	2003-02-26		Cyl.3	270	785	7,374	–417.991
WB235	Wescor	2003-02-26		Cyl.3	280	785	7,374	–417.991

Instrument type: Water sampling
Deposition hole: DD0086G01

					Instrument position in block			
Mark	Type	Installed	Notes	Block	α degree	r mm	Z mm	Äspö coord m
CB201	CT	2003-01-30	Vessel-PEEK	R3	135	770	1,968	–423.3973
CS202	CT	2003-02-17	Filter tip in sand	R9	328	505	5,304	–420.061
CS203	CT	2003-02-17	Filter tip in sand	R9	135	505	5,304	–420.061
CB204	CT	2003-02-14	Filter tip in bentonite	R9	45	625	5,474	–419.891
CB205	CT	2003-02-14	Filter tip in bentonite	R9	45	715	5,474	–419.891
CB206	CT	2003-02-14	Vessel-PEEK	R9	135	770	5,504	–419.861

Instrument type: Thermocouples in rock
Deposition hole: DD0086G01

Mark	Level m	Direction	Distance from rock surface m
TR201	0	Center	0.000
TR202	0	Center	0.375
TR203	0	Center	0.750
TR204	0	Center	1.500
TR205	0.61	10°	0.000
TR206	0.61	10°	0.375
TR207	0.61	10°	0.750
TR208	0.61	10°	1.500
TR209	0.61	80°	0.000
TR210	0.61	80°	0.375
TR211	0.61	80°	0.750
TR212	0.61	80°	1.500
TR213	0.61	170°	0.000
TR214	0.61	170°	0.375
TR215	0.61	170°	0.750
TR216	0.61	170°	1.500
TR217	3.01	10°	0.000
TR218	3.01	10°	0.375
TR219	3.01	10°	0.750
TR220	3.01	10°	1.500
TR221	3.01	0°	0.000
TR222	3.01	80°	0.375
TR223	3.01	80°	0.750
TR224	3.01	80°	1.500
TR225	3.01	170°	0.000
TR226	3.01	170°	0.375
TR227	3.01	170°	0.750
TR228	3.01	170°	1.500
TR229	5.41	10°	0.000
TR230	5.41	10°	0.375
TR231	5.41	10°	0.750
TR232	5.41	10°	1.500
TR233	5.41	80°	0.000
TR234	5.41	80°	0.375
TR235	5.41	80°	0.750
TR236	5.41	80°	1.500
TR237	5.41	170°	0.000
TR238	5.41	170°	0.375
TR239	5.41	170°	0.750
TR240	5.41	170°	1.500

Appendix 3

Result from leveling and interface measurements

Results from measurements of interfaces at installation.

Block	Angle (°)	Inner radius (mm)	Outer radius (mm)		Slot width (mm)
			Upper	Lower	
C4	0		785.5	793.1	80
	90		786.2	795.2	73
	180		785.5	793.1	77
	270		786.2	795.2	80
C3	0		785.8	795.0	95
	90		784.0	791.5	93
	180		785.8	795.0	90
	270		784.0	791.5	83
R12	0	535.7	813.5	824.0	70
	90	535.4	813.5	824.1	60
	180	535.7	813.5	824.0	52
	270	535.4	813.5	824.1	58
R11	0	535.2	813.2	823.4	70
	90	535.3	814.0	823.5	62
	180	535.2	813.2	823.4	47
	270	535.3	814.0	823.5	62
R10	0	535.2	813.0	823.9	64
	90	534.8	813.5	824.0	64
	180	535.2	813.0	823.9	60
	270	534.8	813.5	824.0	63
R9	0	535.7	813.5	824.2	61
	90	534.8	813.0	823.5	55
	180	535.7	813.5	824.2	55
	270	534.8	813.0	823.5	65
R8	0	535.0	814.0	823.6	61
	90	535.1	813.8	823.5	54
	180	535.0	814.0	823.6	56
	270	535.1	813.8	823.5	60
R7	0	535.3	813.0	823.6	58
	90	535.3	813.8	823.0	56
	180	535.3	813.0	823.6	65
	270	535.3	813.8	823.0	66
C2	0		784.5	792.5	85
	90		785.0	792.9	92
	180		784.5	792.5	92
	270		785.0	792.9	85

Results from measurements of interfaces at installation (cont.).

Block	Angle (°)	Inner radius (mm)	Outer radius (mm)		Slot width (mm)
			Upper	Lower	
R6	0	315.1	815.7	825.0	72
	90	318.0	815.6	825.8	47
	180	315.1	815.7	825.0	48
	270	318.0	815.6	825.8	71
R5	0	318.6	815.2	825.9	76
	90	319.5	815.2	825.7	48
	180	318.6	815.2	825.9	42
	270	319.5	815.2	825.7	68
R4	0	318.0	815.5	825.3	60
	90	316.5	815.4	825.8	52
	180	318.0	815.5	825.3	56
	270	316.5	815.4	825.8	68
R3	0	319.5	815.4	825.2	63
	90	315.8	815.3	824.9	53
	180	319.5	815.4	825.2	66
	270	315.8	815.3	824.9	67
R2	0	318.6	815.6	825.3	52
	90	320.0	815.4	825.3	52
	180	318.6	815.6	825.3	65
	270	320.0	815.4	825.3	65
R1	0	318.5	815.5	825.4	48
	90	318.8	815.6	826.2	52
	180	318.5	815.5	825.4	69
	270	318.8	815.6	826.2	62
C1	0		785.2 *	793.5 *	87
	90		785.1 *	793.2 *	85
	180		785.2 *	793.5 *	90
	270		785.1 *	793.2 *	93

* Calculated as average diameters of C4, C3 and C2

Levelling of blocks, heaters and plates during installation (levels given according to the Äspö 96 coordinate system)

Surface	Angle					
	0	**90**	**180**	**270**	**Centre**	**Comment**
C4	–417.291	–417.295	–417.296	–417.292	–417.294	
C3	–417.788	–417.794	–417.794	–417.788	–417.798	
Heater II	–418.334	–418.335	–418.338	–418.337	–418.336	
R12	–418.297	–418.303	–418.302	–418.296	–	
R11	–418.801	–418.805	–418.808	–418.803	–	
R10	–419.305	–419.310	–419.312	–419.306	–	
R9	–419.807	–419.813	–419.815	–419.809	–	
R8	–420.314	–420.320	–420.321	–420.316	–	Calculated from R9 levels and heights
R7	–420.822	–420.828	–420.830	–420.825	–	
PEEK	–421.322	–421.325	–421.328	–421.324	–	
C2	–421.329	–421.333	–421.335	–421.331	–421.332	
Heater I	–421.862	–421.864	–421.867	–421.864	–421.864	
R6	–421.832	–421.838	–421.840	–421.835	–	
R5	–422.334	–422.337	–422.342	–422.338	–	
R4	–422.842	–422.845	–422.850	–422.843	–	
R3	–423.343	–423.349	–423.352	–423.345	–	
R2	–423.850	–423.855	–423.856	–423.852	–	
R1	–424.356	–424.360	–424.361	–424.360	–	
C1	–424.861	–424.865	–424.865	–424.863	–424.864	
Conc.	–425.365	–425.365	–425.365	–425.365	–	Average of 13 measurments

Appendix 4

Heating system

Temperature Buffer Test

Heating System

"As built" report

Bárcena, I., García-Siñeriz, J.L.
Aitemin

A4.1 Abstract

The present document is framed within the TBT Project currently running at the Äspö Hard Rock Laboratory in Sweden. The project simulates two different confinement methods for a vertical deposition of HLW, by means of two electrical heaters placed into a vertical deposition hole excavated in the rock.

All the heating system, including both heaters, the power control system and the data acquisition, display and control system was supplied, installed and commissioned by AITEMIN in February and March 2003.

The description of the heating system and the installation operation is presented in this report.

A4.2 Background

The AEspoe Hard Rock Laboratory (AEHRL) was constructed by SKB (Swedish Nuclear Fuel and Waste Management Co, Sweden) aiming at the research, development and demonstration of deep disposal of spent nuclear fuel.

The site for the emplacement of the laboratory was selected in 1986, and the construction phase extended from 1990 to 1995.

The AEHRL consists of a long ramp excavated in granite, starting in the Simpevard peninsula and heading northwards up to the southern coast of the Aespoe island, where the ramp turns into a helical shape down to a depth of 450 m. The total length of the ramp is 3,600 m (see Figure A4-1). Apart from the ramp itself, access to the different levels of the laboratory from the surface facilities is provided by a hoist.

One of the experiments carried out in the laboratory is the TBT, led by ANDRA and participated by SKB. This project is a vertical demonstration of two different confinement metods for HLW.

The test site is a vertical deposition hole excavated in the rock with push boring technique, measuring 1.75 m diameter and extending downwards to about 8 m depth. Two electrical heaters were introduced into the hole, surrounded by a buffer made of highly compacted bentonite blocks for one of the heaters, and a combination of bentonite blocks and compacted sand for the other. For each heater 6 thermocouples were installed inside for condition monitoring, and 11 thermocouples were placed at different points of the external surface, to be used for temperature control. The top of the hole was sealed with a concrete plug and a steel confinement lid (Figure A4-2).

The heating system was completed with a power control system and a data acquisition, display and control system that was linked to the main data acquisition network of the Laboratory.

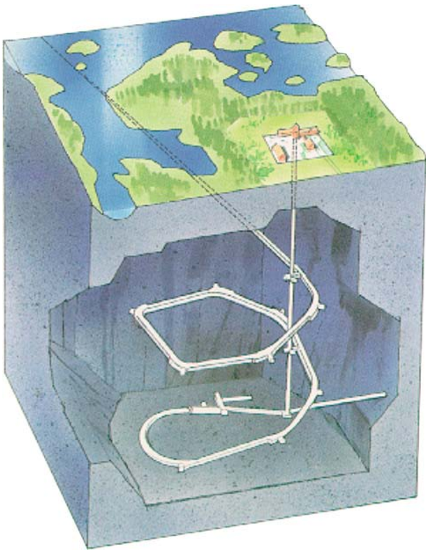


Figure A4-1. AEspoe Hard Rock Laboratory (AEHRL)

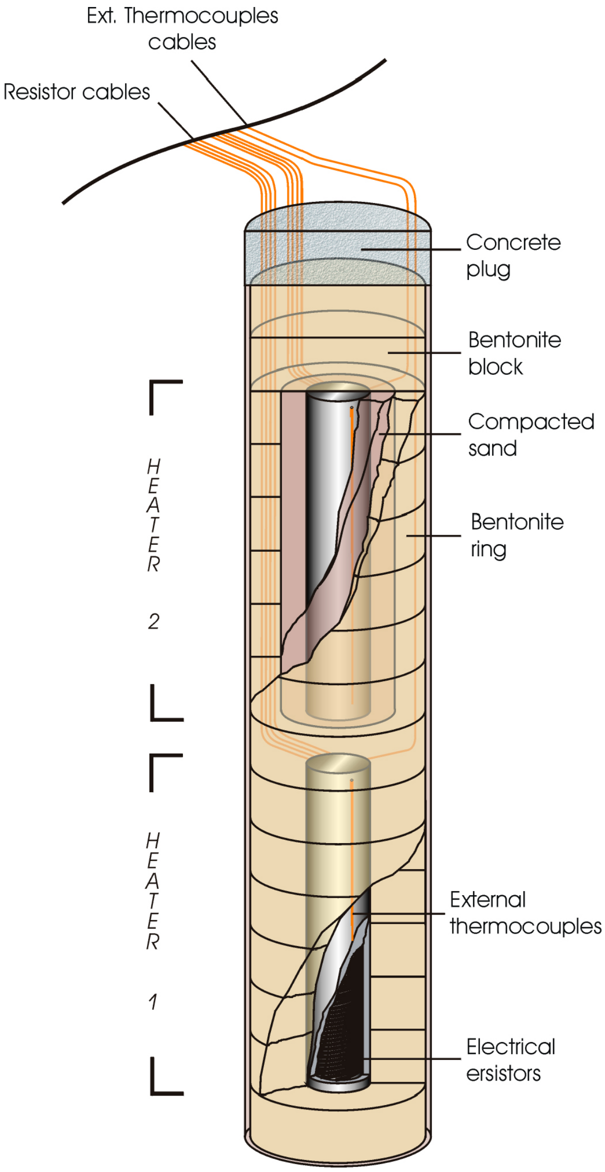


Figure A4-2. TBT Layout

A4.3 Description of the heating system

A4.3.1 Basic specifications

The basic specifications provided by ANDRA for the heaters design were the following:

Shape:	Cylindrical
Total length:	3 m
Diameter:	610 mm*
Power:	Peak 700 W/m**
Casing material:	Carbon steel
Max. surface temperature:	225°C
Max. external pressure***:	12 MPa
Test duration:	7 years

Notes:

(*) Initially established at 600 mm, it was increased up to 610 mm to simplify the mechanical construction.

(**) Initially 600 W/m, ir was upgraded to 700 W/m to handle predicted power peaks.

(***) Combination of bentonite swelling pressure plus expected pore pressure in the buffer.

Other requirements:

- The two heaters had to be mechanically independent to enable the possibility of carrying out a separate retrieval of the units in the future.
- Power regulation had to be independent for each unit.
- The heaters had to include all the instruments and components required for power regulation.
- Cables and/or tubes had to be taken out from the heaters in a direction perpendicular to their axis.

A4.3.2 Design criteria

From the different possible options, the adopted technical solution was that of two electrical heaters, constructed as fully independent units, and placed one on top of the other as shown in Figure A4-2. This solution has the following advantages:

- It is simple and reliable. The life of the electrical resistors may be extended with an adequate design (de-rating) and by installing redundant elements.
- Connections are minimized and can be constructed in a gas-tight mode. They can be flexible, and have a reduced diameter.
- There are no moving parts of fluids as it would be the case for instance of oil heaters. Tubes and other hot connections are avoided.
- Power regulation system can be done easily using electronic systems requiring minimal maintenance.

The only disadvantage of this configuration is the impossibility of servicing the heating units once they are put in place. However, this was compensated by increasing the reliability of the critical elements (i.e. the heating resistors). As a reference, the heaters used in the FEBEX experiment, that were designed and constructed with the same philosophy, have been in operation for more than 9 years (and the remaining one still goes on) without any problem.

A4.3.3 General description of the system

The heating system consists of the three main components:

- Heaters
- Power regulation system
- Data acquisition, display and control system

The basic constructive characteristics of the heaters and the power regulation system are the following:

Heaters:

Mechanical construction: each heater was constructed in a fully closed cylindrical body made on carbon steel with welded lids, in order to avoid joints. The inner part of the container was flushed with helium to remove as much as possible the air inside and hence minimise internal corrosion.

Electrical design: shielded heating elements were placed inside the heaters in such a way that the heat distribution was uniform. The elements were redundant by a factor of three for enhanced reliability. The connection cables came out through the upper lid using high temperature gas-tight cable entries. These elements had a continuous metal sheath along their full length, till the connection box in the gallery, in order to avoid connections both inside the heaters and in the buffer area. Besides, for mechanical protection given the bentonite sweling pressures expected, the elements were enclosed into copper pipes along their length in the buffer and up to the connection box. Six temperature sensors were installed inside each heater to monitor the internal temperature. These were mechanically protected in the same way.

Power regulation system:

Independent static power regulation systems were installed for each resistor element. Each circuit was galvanically isolated to reduce the effects of potential isolation failures. Power control was conceived so to allow both constant power and constant temperature control modes, using phase-angle regulation mode to minimise mechanical stresses in the heating elements. Eleven temperature sensors were placed in the outer surface of the heaters to serve as reference for the power regulation system when working in the constant temperature mode. These sensors were redundant by a factor of three.

Data acquisition, display and control system:

Comprising a signal conditioning and data logging unit, an uninterrupted power supply unit and a host computer with the necessary software to steer the heating strategy, to acquire, store and share the generated data, and to be operated remotely.

A4.4 Heaters

A4.4.1 Mechanical construction

A general view of the mechanical construction of the heaters is shown in Figure A4-3. The outer container was made with a seamless tube and two welded lids. The wall thickness of the outer container was 50 mm, whereas the lids were a bit thicker.

An internal tube with an outer diameter of 457,2 mm was be mounted inside, to serve as support for the heating elements. These were wound around this tube and fixed to it with metal brackets. The gap between both tubes was 26,4 mm. A number of spacer blocks were fixed to the inner tube to center it and to protect the heating elements during the assembly process.

The cold terminals of the 3 heating elements were taken out of the main body across holes drilled in the upper lid. These were sealed by means of compression glands and a high temperature epoxy compound. A similar solution was be adopted for the six internal thermocouples. The tightness of the heater body is guaranteed by these seals.

One-way valves were installed at the inner side of the heater lids to allow the flushing with helium after the welding of the lid (Figure A4-4).

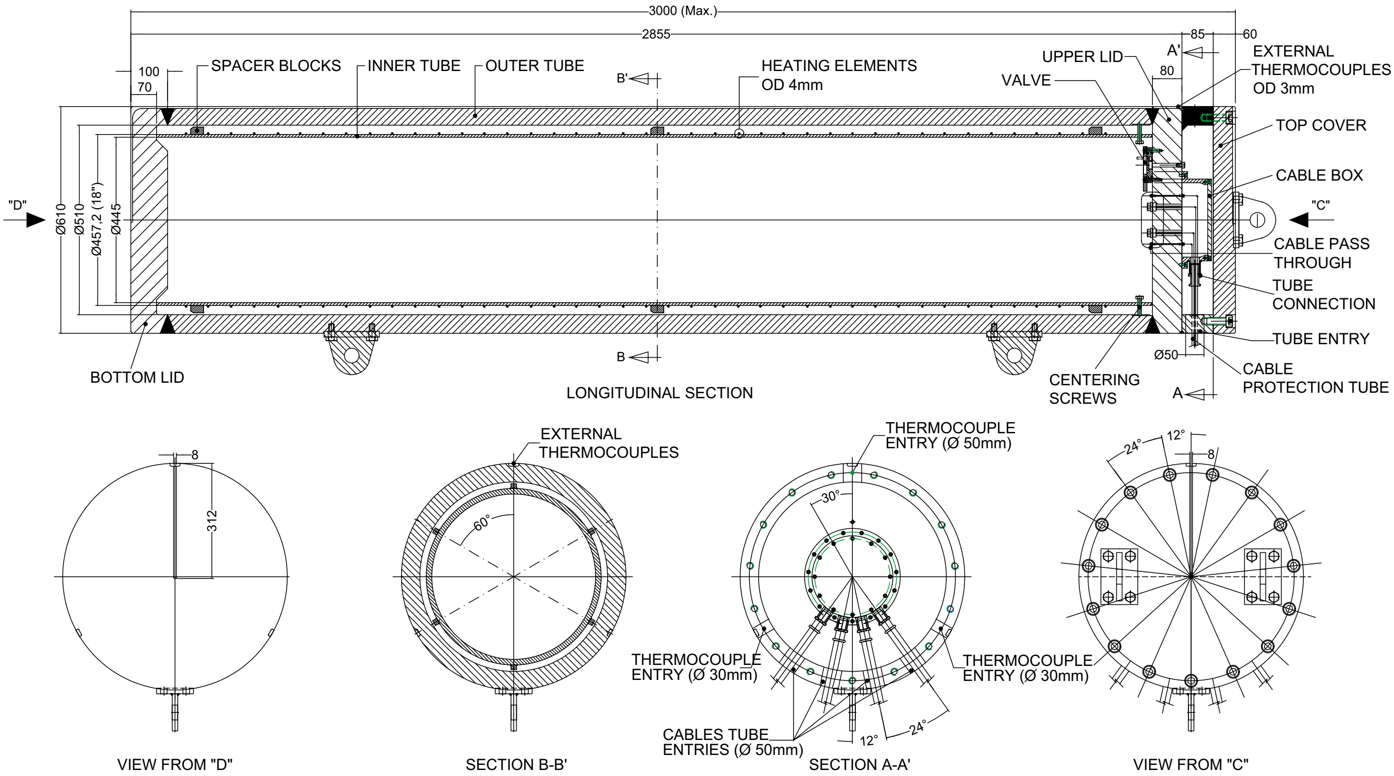


Figure A4-3. *Heaters layout*

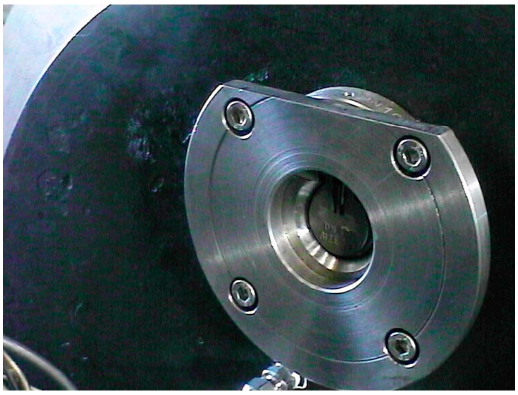


Figure A4-4. *One-way valve at the inner side of the heater lid*

At the outer part of the upper lid there was a double enclosure:

– The first enclosure was a water tight box *(the cable box)* used for conducting all the metal sheathed cables (heating elements and internal thermocouples) into copper tubes that protected these cables along their way through the buffer and up to the service gallery. The main function of these tubes was to provide mechanical protection, but they also gave to the cables an additional protection against water, served as electric ground connection and reduced the EMI that could be generated by the power cables. The *cable* box was filled also with a high temperature epoxy compound for improved tightness.

– The second enclosure was basically a mechanical protection for the *cable* box and cables, and supported the weight of the upper heater (or bentonite blocks). This enclosure was not water-tight, and was filled with 4 mm diameter glass balls to allow water inflow but to prevent the ingress of bentonite.

The basic mechanical characteristics of the heaters are given in Table A4-1.

Table A4-1. Basic mechanical characteristics of the heaters

External Dimensions	Diameter	610 mm
	Length	3 m
	Total weight (estimated)	2,760 kg
Outer body	Wall thickness	50 mm
	Material	Carbon steel
Inner tube	Outer diameter	457 mm
	Thickness	6 mm

Annex I includes a more detailed drawing of the mechanical construction of the heater.

A4.4.2 Heating elements

Power requirements

According to the specifications provided by ANDRA, the power required to reach the target temperature of 225°C at the external part of the heater is 600 W/m, but it is expected that in some phases of the experiment power peaks of up to 700 W/m may be required. Considering a safety factor of 1,4 on this last figure, the resulting power for design purposes is 980 W/m. There are three independent heating elements for redundancy reasons, and each one of them is able to provide such power.

Characteristics of the heating elements and installation

Each heating element is a mineral insulated heating cable, composed by three parts: the heating cable, two cold ends and two connection cables (Figure A4-5).

The heating cables have a metallic sheath along their full length, made on Inconel 600 and with an external diameter of 4 mm. The active part has a resistor core made in Tophet (80% Ni, 20% Cr) and the insulation is made of compressed magnesium oxide. This part measures 25 m in length for each heating element and is wound around the heater inner tube, with a separation between turns of 150 mm (Figure A4-6 and Figure A4-7).

The cold ends have the same sheath and insulation than the active part, but have a low resistance core. The internal joints making the connection between the heating cable and the cold end provide an adequate continuity of the Inconel 600 sheaths, having the same diameter as the cables (4 mm).

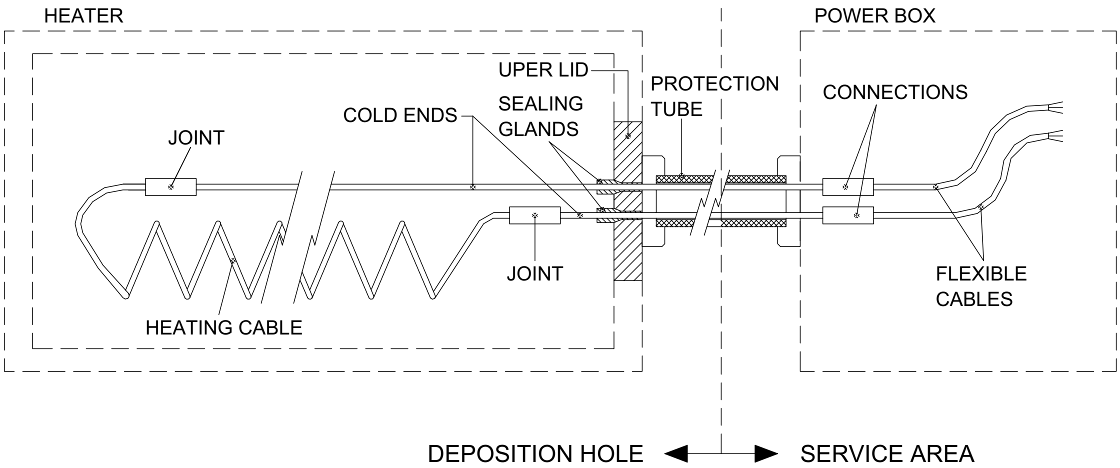


Figure A4-5. *Layout of the heating elements.*

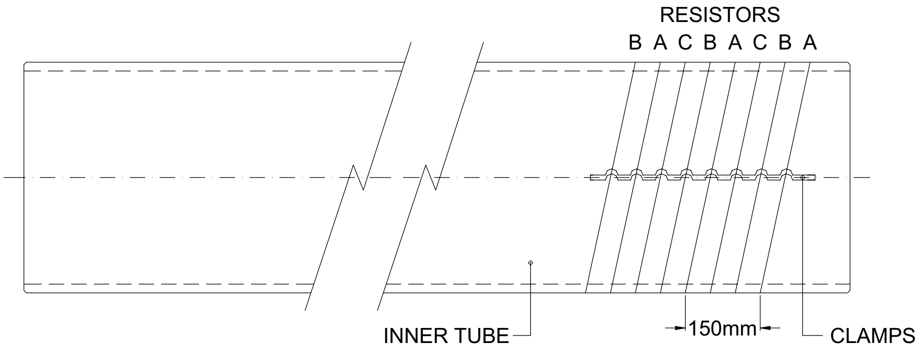


Figure A4-6. *Layout of heating elements around the inner tube.*

Figure A4-7. *Heater construction: external case, inner tube with heating elements wound up and lid with passthroughs.*

Table A4-2 summarises the basic characteristics of the heating elements.

Table A4-2. Characteristics of the heating elements.

		Active part	Cold ends
External diameter		4 mm	4 mm
Sheath material		Inconel 600	Inconel 600
Insulation		MgO	MgO
Core Resistance (20°C)		0,78 Ω/m	0,04 Ω/m
Continuous service temp.		> 600°C	> 600°C
Length	Lower unit	25 m	15,5/13 m
	Upper unit	25 m	12/9,5 m

The six cold ends were taken out of each heater across cable passthroughs in the upper lid. Tightness was achieved by using ¼” NPT cone-shaped compression glands made on AISI 316L stainless steel, certified to operate up to 400°C and 200 bar. The holes were also sealed on their outer part with a high temperature epoxy compound that has a working temperature over 250°C (Figure A4-8).

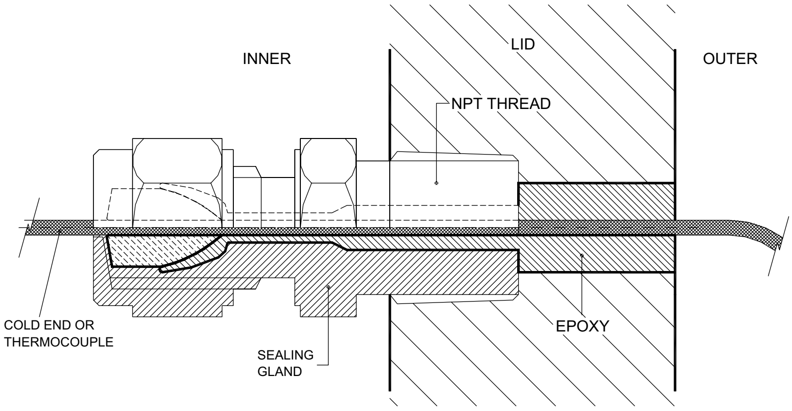


Figure A4-8. *Cable passthroughs on the heater upper lid.*

After crossing the upper lid, the heating elements cables, as well as the internal thermocouples, were introduced into protection tubes made of copper (one for each heating element and one for the six internal thermocouples), coupled to the cable exit box (Figure A4-9). This box, and the horizontal section of the protection tubes, was also sealed with the high temperature epoxy compound for enhanced tightness.

The chamber around the cable exit box was filled up with glass balls to avoid ingress of bentonite, and the second lid was placed (Figure A4-10).

The copper protection tubes were extended all the way up to the gallery (see Figure A4-5). The horizontal part was introduced into slots excavated in the bentonite and the vertical part into slots excavated in the surface of the deposition hole (Figure A4-11). The extended part of the tubes up to the gallery was filled up with a special resin which provided both electrical and mechanical protection to the cold ends. The length of the cold ends was calculated for reaching the wall of the gallery in the vicinity of the deposition hole (about 3 m from the concrete plug).

At the end of the metal sheath, a connection was made to a standard Teflon insulated flexible cable. This connection was made encapsulated with an external diameter of about 10 mm and a typical working temperature up 200°C, and was located inside the corresponding cable connection boxes at the service gallery. In order to assure the isolation of the connection against the ambient moisture, also through the inside of the cables, all the connections were embedded into resin caps into the connection boxes. An electrical isolating resin was used, and the electric wires into the caps were left exposed in order to assure a complete tightness with the resin.

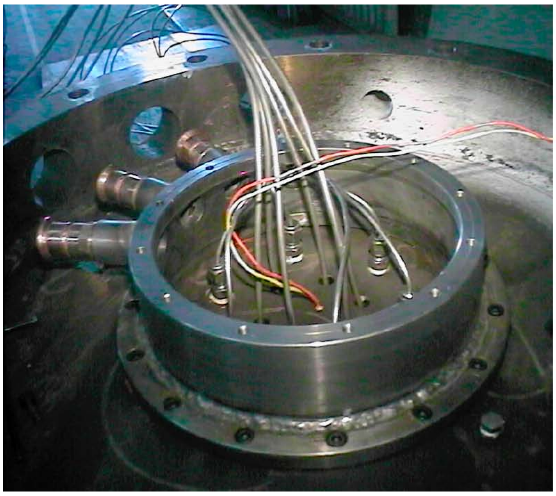


Figure A4-9. *Passthroughs with open cable exit box (left) and box closed with copper protection tubes and external thermocouples (right).*

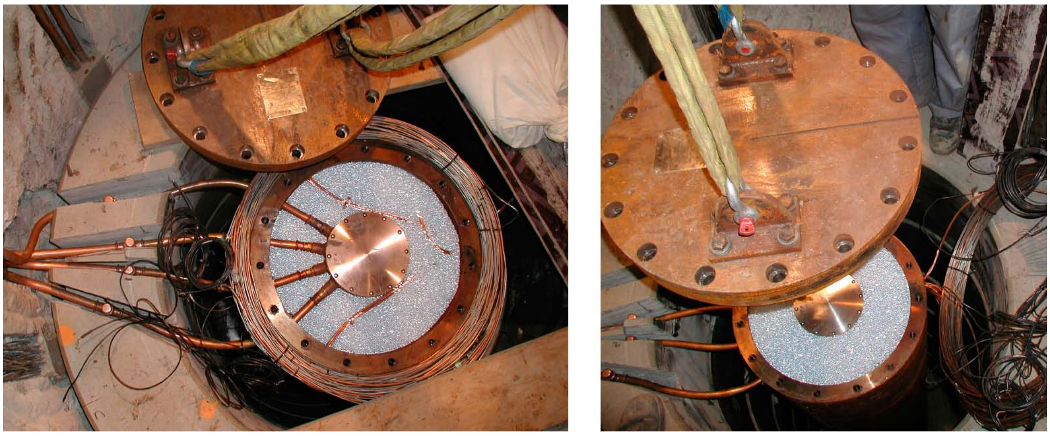


Figure A4-10. Filling of upper chamber with cristal balls and closure of second lid.

Figure A4-11. Protection tubes installed along rock slot in lower heater (left) and detail of installation in upper heater (right).

A4.4.2.3 Internal thermocouples

Six thermocouples were installed inside each heater to monitor the temperature conditions inside the unit. These are type "J" thermocouples class 1 (range 0–750°C), calibrated at 4 points: 0, 100, 225 and 350°C. Two thermocouples were be installed at 200 mm from each end of the inner tube, at opposites sides, and the third pair was placed in the middle of the heater. All thermocouples have the same sheath than the heating elements (Inconel 600), with an outer diameter of 3 mm. They were led through the heater lid and up to the gallery in the same way as the cold ends from the heating elements.

A4.5 Power regulation system

A4.5.1 Description of operation

The power regulation system consists of seven cabinets (see Figure A4-12):

- PR1 and PR2: Power control cabinets.
- HR1 and HR2: Connection cabinets.
- DL: Data Logger cabinet.
- ETR1 and ETR2: External Thermocouples Readers cabinets.

The power regulation of each heater is carried out from cabinets PR1 and PR2 for heater 1 and 2 respectively. The three resistors of each heater are connected to each PR cabinet after passing through intermediate junction cabinets called HC1 and HC2.

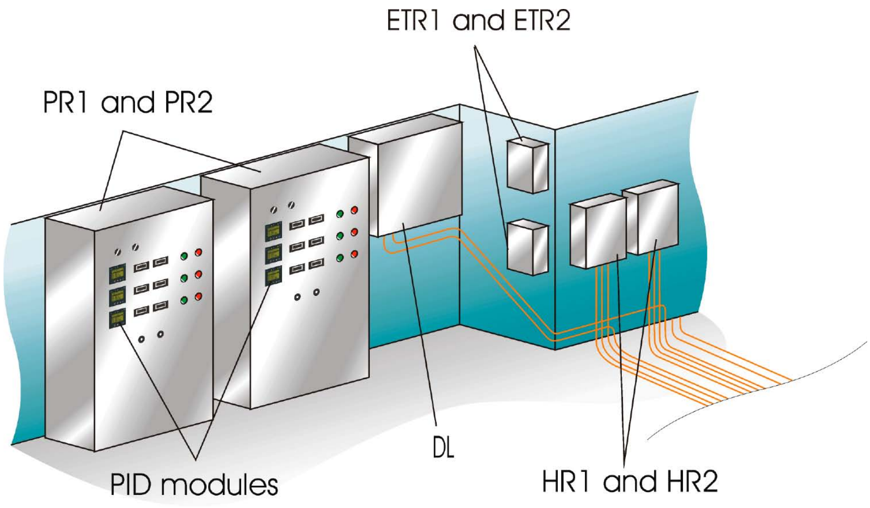


Figure A4-12. *Power Regulation System.*

The power regulation is based on single-phase static regulators, operating in phase angle mode, in order to minimise thermal stresses at the heating elements.

Each heating element unit is powered from a different mains phase and have a fully independent power regulation channel. For each channel, the circuit comprises the following components (Figure A4-14):

- Overload and short-circuit protections
- Galvanic isolation transformer
- Voltage presence relay
- Ultra-fast fuses for the semiconductor components
- Thyristor module make WATLOW model DIN-A-MITE
- PID controller make PMA model KS98
- Voltage and current indication (true RMS values)
- Insulation monitor
- Local set-point selector (key protected)
- Set-point and actual maximum external temperature indications
- EMC filter at mains and output

Each thyristor module is controlled by a PID auto-tuning module (Figure A4-13). Each module receives the signals from almost all the installed instruments (except for heaters internal thermocouples that are read by the data logger). The signals connected to each unit are:

– Current, voltage and isolation from its heating element (3 analog signals 4–20 mA type)

– Working mode (remote/local) and control mode (power/temperature) for each heater power regulation cabinet PR1 and PR2 (2 digital signals), and power on/off and isolation defect for each resistor (2 additional digital signals)

– Heaters external temperatures (11 analog signals mV type) that are read by a dedicated data converter connected to the PID modules by a high speed can bus.

These signals are digitised, processed and transmitted to the host computer through a serial link.

The normal mode of operation is “constant power”: the PID controller receives an external set-point in power, compares it with the feedback of the actual power applied to the heater, and adjusts the power in the heating element by regulating the voltage applied to the element, so to keep the power constant at the set-point value.

Figure A4-13. Power regulation cabinet for heater 2 with PID modules.

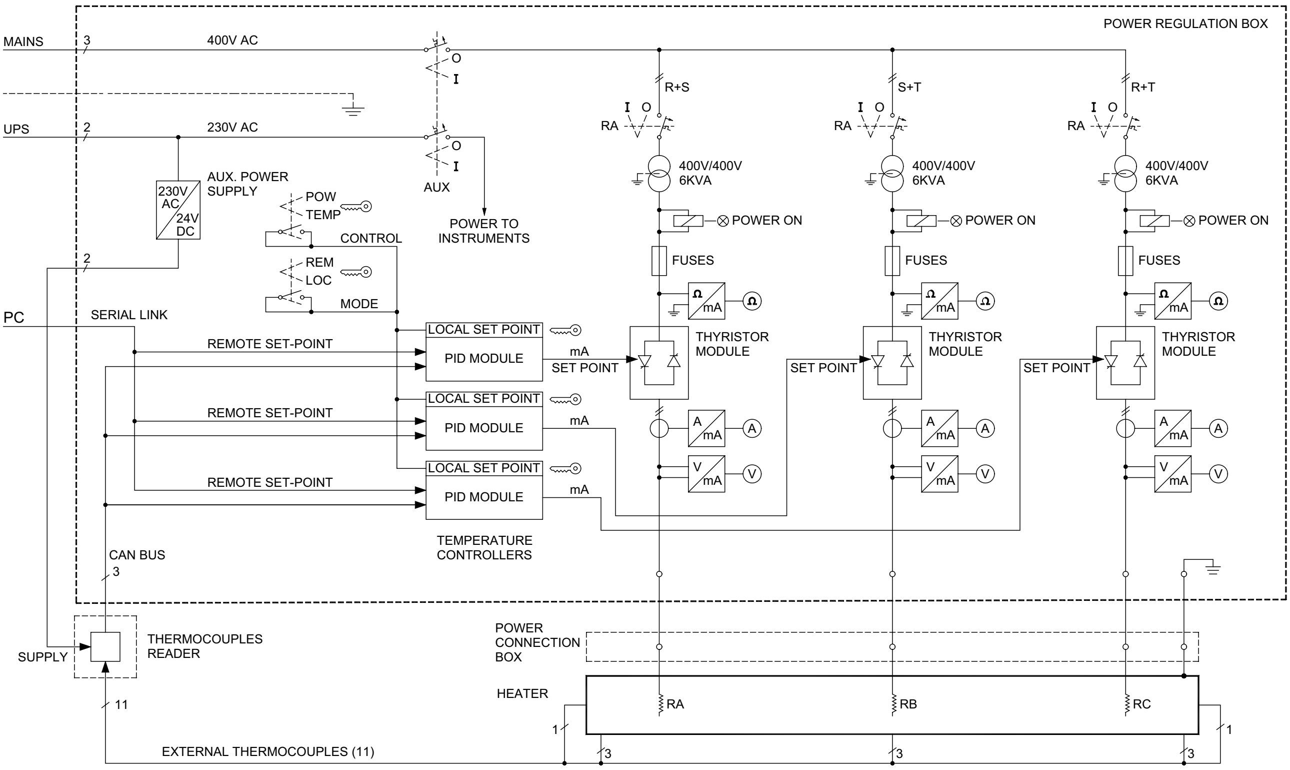


Figure A4-14. Power regulation system.

The maximum temperature at the heater surface will be limited to 225°C. For that purpose the controller selects the highest temperature among all the thermocouples installed at the outer surface of the heaters. If the limit is reached the operation mode will change automatically to "constant temperature" and the highest temperature will be use as feedback reference for the control loop.

Alternatively, the system can also operate in "constant temperature" mode at any time.

The set-point value (target power or temperature depending on the control mode selected) will normally be provided by the computer system (remote control), as a function of the experiment needs. In case of failure of the computer system or because of functional reasons, it is also possible to adjust manually the set-point at the power regulation unit.

The actual voltage applied and current consumption of each heating element (true RMS values), as well as the isolation to earth, will be measured by means of electrical signal converters. These converters will provide a 4–20 mA output that will be used for local indication and also as an input to the data acquisition and control system.

A4.5.2 Instrumentation

The external temperature of the heaters is measured by eleven thermocouples type "J" class 1 (range 0–750°C) calibrated for 4 points: 0, 100, 225 and 270°C. Three groups of three thermocouples, were installed at 120 mm from each heater end, and at the middle of the heater, in a 120° array. Two additional thermocouples were installed in the centre of the bottom lid and the top cover.

All the thermocouples were sheathed in the same material as the heating elements (Inconel 600), with an outer diameter of 3 mm. Additionally, they were protected against corrosion by means of 6 mm outer diameter copper tubing up to the gallery surface. The active junctions of each thermocouple were provided with a stud termination in order to bolt the end to the heater surface. The thermocouples were installed in 7.5 mm deep grooves machined along the heater body external surface. At the upper part, they were taken to the top chamber across entries drilled also at 120° (Figure A4-9). From this chamber they were led across the bentonite buffer up to a slot excavated at the surface of the deposition hole, orientated opposite to the slot corresponding to the power cables.

A4.6 Data acquisition, display and control system

A4.6.1 Functions and structure

The functions of the dedicated data acquisition, display and control system (DADCS) are the following:

1. To acquire, store and display the information provided by the installed instruments (thermocouples and electrical signal converters).
2. To generate the commands required at each moment for the power regulation, upon the basis of the experiment control strategy.
3. To transfer information to the general data acquisition system installed at Äspö.
4. To enable remote access to the system for remote monitoring and maintenance.

The DADCS is composed of the following main components:

- Signal conditioning and data logging unit.
- Host Computer (PC).
- Uninterrupted Power Supply unit.

An overview of the DADCS structure is shown in Figure A4-15. The following sections describe the main components of the system.

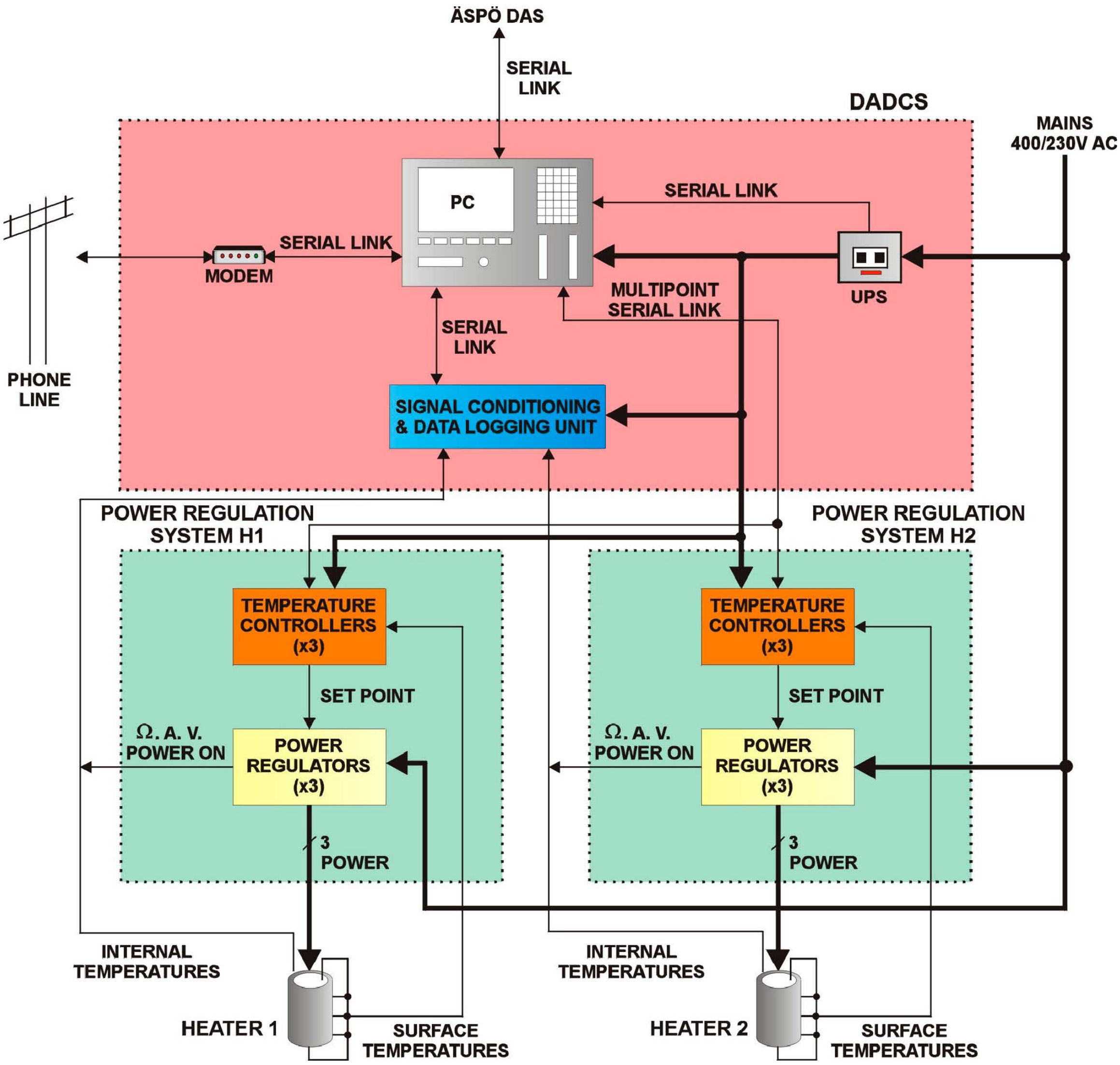


Figure A4-15. *Structure of the data acquisition, display and control system (DADCS).*

A4.6.2 Description of components

Data logging unit

This is a general conditioning/acquisition and data logging unit that receives the signals from heaters internal thermocouples.

These signals are digitised, stored in the internal memory, and transmitted to the host computer through a serial link. The internal data logging capability of this unit provides a redundant storage of data, enabling the recovery of the information in case of PC failure. The information can be recovered totally or in part, depending on the scan rate, memory size and failure duration.

Host Computer

The host computer (PC) is a standard industrial computer (Figure A4-16). The PC reads the data from the PID modules and the logging unit, and processes, displays, and stores these data in an internal data base. The computer also generates the power or temperature set point for the heater power regulation units, as a function of the programmed control strategy, which can be configured and adapted to each situation either locally or remotely. Finally all these data are transmitted to the general Data Acquisition System of the Äspö laboratory by means of an OPC server.

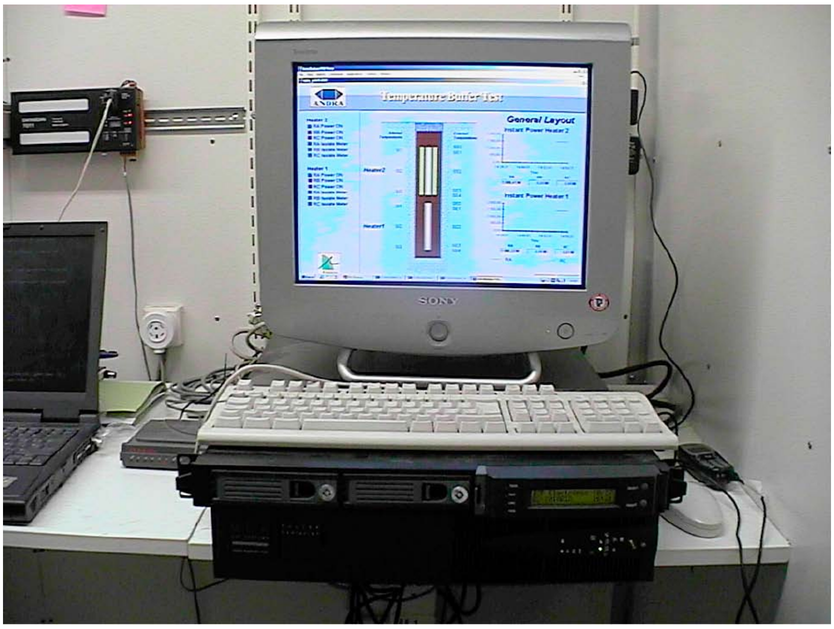


Figure A4-16. *Host computer.*

A general purpose SCADA firmware is used to perform the following main functions:

- Continuous data acquisition from PID modules and the data logging.
- Data conversion into physical units.
- Adaptation of conversion functions.
- Data presentation (text and graphical).
- Data storage into internal data base.
- Heaters set point calculation and writing to the power regulation units.
- Display of heaters status and alarms generation.

The data base at the PC contains the values of the measurements each ten minutes period.

Remote access to the host computer is possible via the Äspö network, using a well proven dedicated communications firmware. This allows the remote supervision of the heater control, and the remote modification of the power control strategy, if necessary.

Uninterrupted Power Supply

The PC, the data logging unit, the power controllers and the auxiliary power of the power regulation system are backed-up from an Uninterrupted Power Supply (UPS). In case of mains network shutdown, the UPS guarantees the power supply to these devices for a 10–15 minutes time period.

The UPS features a built-in firmware which enables to perform the UPS supervision from the host computer through a RS-232 serial link. The UPS works in the "on-line" mode (output voltage is separated from input and battery-buffered), minimising disturbances from mains network.

A4.7 Quality control

a) Mechanical construction

The construction of the heater body was carried out according to AD-Merkblatter (DIN) code, at a mechanical construction plant having a certified ISO quality system and certified procedures.

A full Program of Inspection Points was applied during the construction of the heaters. It included the following certificates and controls:

- Certificates of materials.
- Certificates of welding filler metal.
- Welder Qualification Test Reports.
- Welding Procedure Specifications.
- Welding Procedure Assessment Records.
- Radiographic testing of welding seam of lower lids.
- Ultrasonic testing of welding seam of lower and upper lid.
- Magnetic particles of 10 % of all welding seams.
- Dye penetrant examination of circular welding seams at grooved points to house external thermocouples.
- Helium flushing.

b) Electrical components

The heating elements and the thermocouples were purchased to a manufacturer having a certified ISO quality system. Length, Resistance and insulation checks were carried out on reception and throughout the installation until the commissioning of the heating system.

c) CE marking

The complete heating system was designed and assembled to comply with LVD 73/23/EEC (Low Voltage Directive) and a Declaration of Conformity will be provided concerning the applicable standards: IEC605519-1 (1984-11) and IEC60519-2 (1992-01).

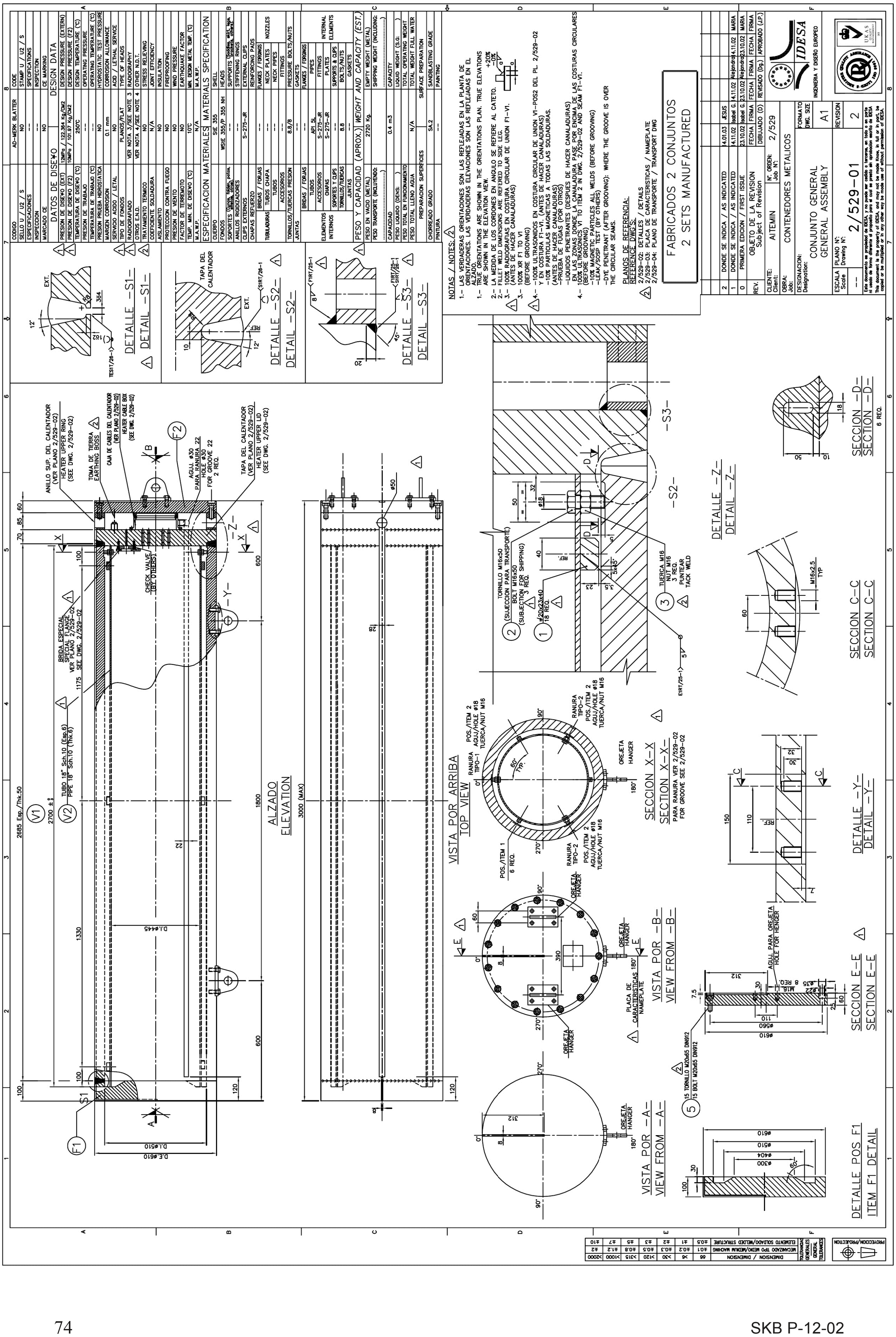
Regarding the compatibility with EMC 99/336/EEC (Electro Magnetic Compatibility) and because of the thyristor control mode selected (phase-angle that it is not CE marked by the manufacturer: WATLOW USA) the compliance with EMC directive could not be initially guaranteed. In this sense several precautions were introduced to minimise the EM effects as: the installation of EMC filters at mains and output for each thyristor module and the shielding and grounding of the resistors power cables from power connection boxes up to the heater body. Additionally, pre-compliance EMI measurements were done by AITEMIN during functional test, prior to delivery, and afterwards by SKB at Äspö laboratory after delivery.

d) Functional tests

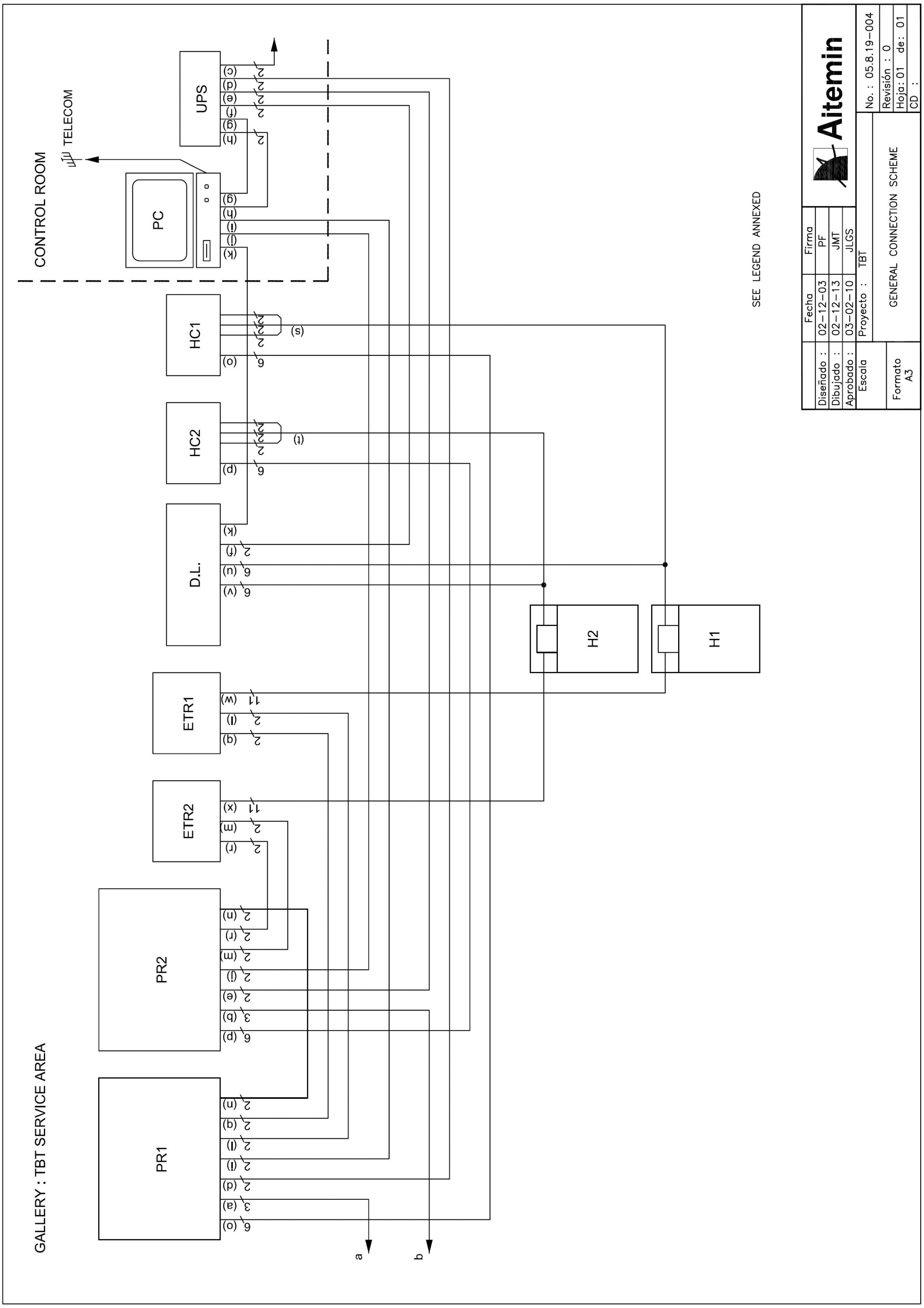
Complete functional tests were carried out by AITEMIN after assembling the heating units, prior to delivery.

List of drawings	
2/529-01	: GENERAL ASSEMBLY
05.8.19-004H0101	: GENERAL CONNECTION SCHEME
05.8.19-005H0101	: GALLERY LAYOUT: ELECTRICAL BOXES
05.8.19-006H0105	: PR1: WIRING DIAGRAM
05.8.19-006H0205	: RC-A: WIRING DIAGRAM
05.8.19-006H0305	: RC-B: WIRING DIAGRAM
05.8.19-006H0405	: RC-C: WIRING DIAGRAM
05.8.19-006H0505	: PR1 AND PR2: DISTRIBUTION OF ELECTRIC AND ELECTRONIC COMPONENTS
05.8.19-007H0101	: PR2: WIRING DIAGRAM
05.8.19-008H0101	: HEATER 1: POWER CONNECTION BOX WIRING DIAGRAM
05.8.19-009H0101	: HEATER 2: POWER CONNECTION BOX WIRING DIAGRAM
05.8.19-010H0101	: ETR1: POWER CONNECTION BOX WIRING DIAGRAM
05.8.19-011H0101	: ETR2: POWER CONNECTION BOX WIRING DIAGRAM
05.8.19-012H0101	: DATA LOGGER UNIT: WIRING DIAGRAM

Drawings



FABRICADOS 2 CONJUNTOS
2 SETS MANUFACTURED
ALZADO
ELEVATION
VISTA POR ARRIBA
TOP VIEW
SECCION X-X
VISTA POR -B-
VIEW FROM -B-
VISTA POR -A-
VIEW FROM -A-
DETALLE POS F1
ITEM F1 DETAIL
SECCION E-E
DETALLE -Y-
DETAIL -Y-
SECCION C-C
DETALLE -Z-
DETAIL -Z-
SECCION -D-
AITEMIN
CONTENEDORES METALICOS
CONJUNTO GENERAL
GENERAL ASSEMBLY
2/529-01
IDESA

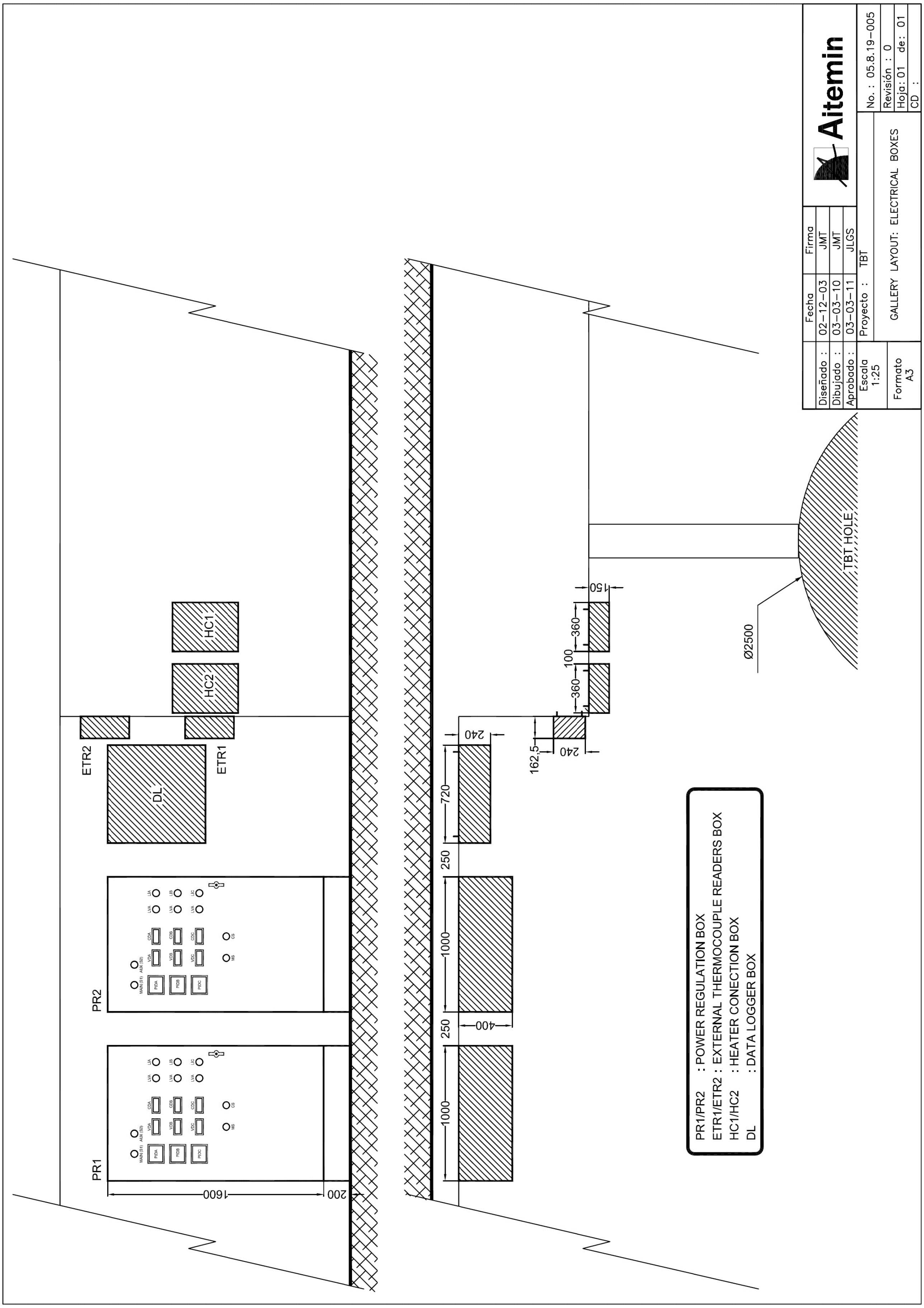

CONTROL ROOM
TELECOM
UPS
PC
HC1
HC2
D.L.
ETR1
ETR2
PR2
PR1
H1
H2
GALLERY : TBT SERVICE AREA
SEE LEGEND ANNEXED
Aitemin
No. : 05.8.19-004
Revisión : 0
Hoja: 01 de: 01
CD :
Fecha
Firma
Diseñado : 02-12-03 PF
Dibujado : 02-12-13 JMT
Aprobado : 03-02-10 JLGS
Escala
Proyecto : TBT
GENERAL CONNECTION SCHEME
Formato A3

LEGEND 1: Equipment Drawing: 05.8.19-004

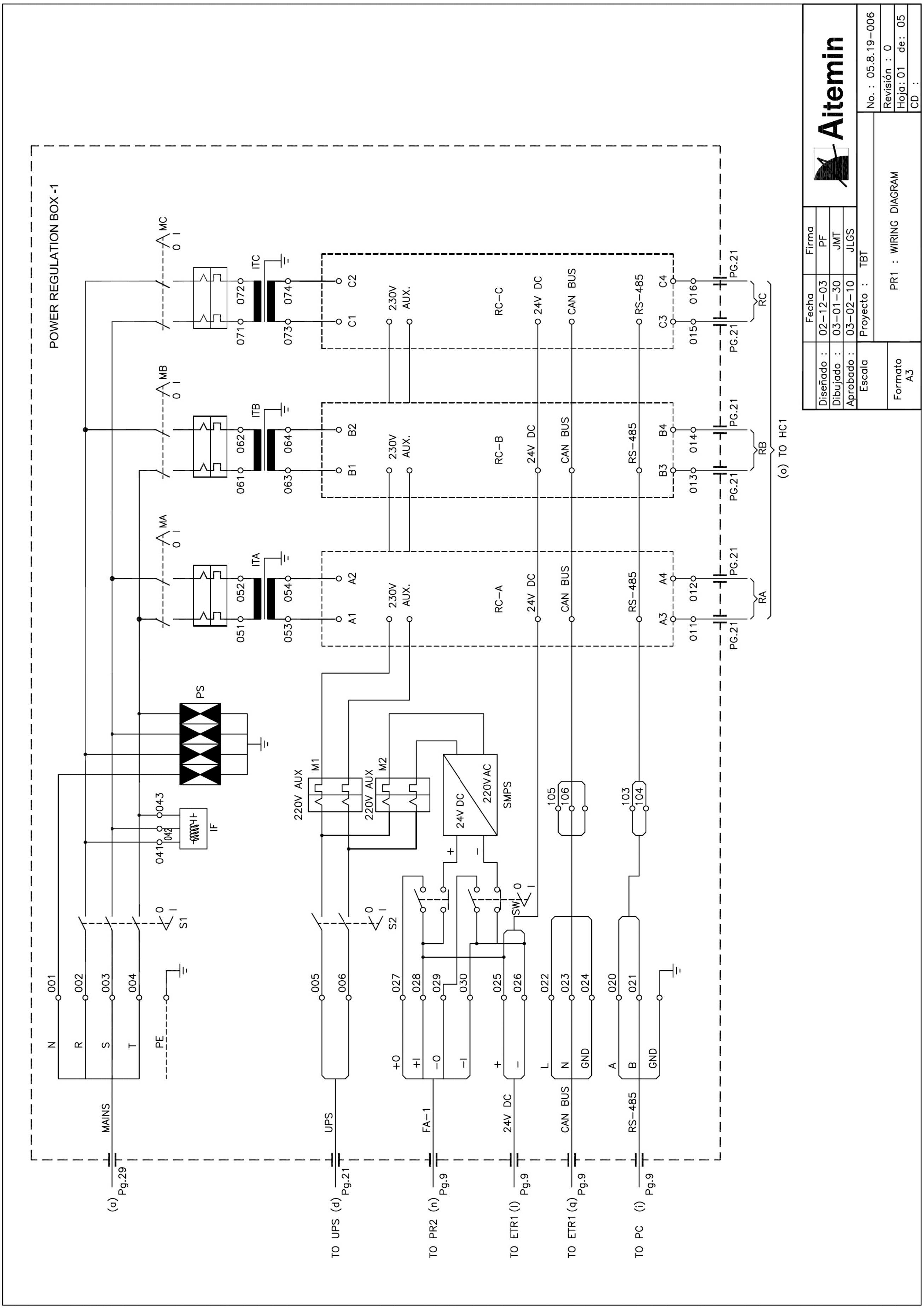
ITEM	DESCRIPTION
H1	Heater 1
H2	Heater 2
PR1	Power Regulation unit for Heater 1
PR2	Power Regulation unit for Heater 2
ETR1	Heater 1: Surface thermocouples reader
ETR2	Heater 2: Surface thermocouples reader
DL	Data Logger unit
HC1	Heater 1: Power connection box
HC2	Heater 2: Power connection box
PC	Host Computer
UPS	Uninterrupted Power Supply
TELECOM	Telephone network connection (DISABLED)

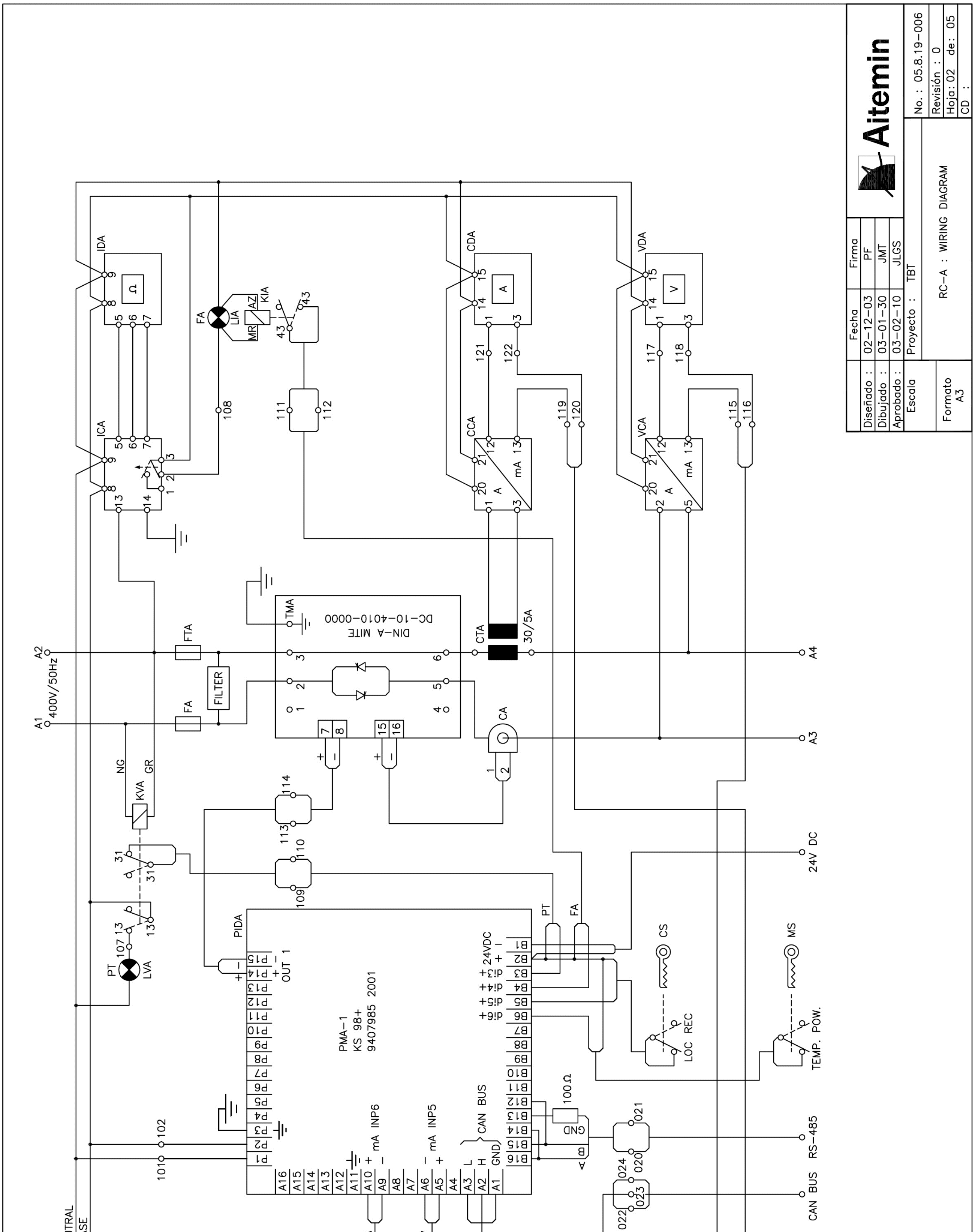
LEGEND 2: Cables Drawing: 05.8.19-004

CABLE	DESCRIPTION	MAX. POWER	MIN. SECTION	NOTE	COMMENTS
a	MAINS Heater 1, 3 AC 400V 50Hz	3 x 8.205 W	0,6/1kV 3x2,5 mm2	SKB	
b	MAINS Heater 2, 3 AC 400V 50Hz	3 x 8.205 W	0,6/1kV 3x2,5 mm2	SKB	
c	MAINS UPS, AC 230V 50Hz	2.000 W	3x1,5 mm2	SKB	
d	AUX. from UPS to PR1, AC 230V 50Hz	70 W	3x1,5 mm2	SKB?	
e	AUX. from UPS to PR2, AC 230V 50Hz	70 W	3x1,5 mm2	SKB?	
f	MAINS from UPS to DL, AC 230V 50Hz	130W	3x1,5 mm2	SKB?	
g	MAINS from UPS to PC, AC 230V 50Hz	325W	3x1,5 mm2	AIT	
h	RS-232, UPS to PC		4x0,25 mm2+P	AIT	
i	RS-232/485, PR1 to PC		4x2x26AWG+P (twisted pairs)	AIT	
j	RS-232/485, PR2 to PC		4x2x26AWG+P (twisted pairs)	AIT	
k	RS-232, DL to PC		4x0,25 mm2+P	AIT	
l	ETR1 MAINS from PR1, DC 24V	1,5 A	3x1 mm2	AIT	
m	ETR2 MAINS from PR2, DC 24V	1,5 A	3x1 mm2	AIT	
n	24 V DC from PR1 to PR2	1,5 A	3x1 mm2	AIT	
o	Power to Heater 1, PR1 to HC1, 3 AC 400V 50Hz	3 x 8.205 W	6x1x6mm2+P	AIT	
p	Power to Heater 2, PR2 to HC2, 3 AC 400V 50Hz	3 x 8.205 W	6x1x6mm2+P	AIT	
q	CAN BUS1, PR1 to ETR1		4x2x26AWG+P (twisted pairs)	AIT	
r	CAN BUS1, PR1 to ETR1		4x2x26AWG+P (twisted pairs)	AIT	
s	Power to Heater 1, HC1 to H1, 3 AC 400V 50Hz	3 x 8.205 W	6xResistors Cold ends	AIT	Two cold ends from each resistor externally protected by a cooper tube type Mapress of 22 mm outer diameter from H1 cables box up to ETR1 box
t	Power to Heater 1, HC1 to H1, 3 AC 400V 50Hz	3 x 8.205 W	6xResistors Cold ends	AIT	Two cold ends from each resistor externally protected by a cooper tube type Mapress of 22 mm outer diameter from H2 cables box up to ETR2 box
u	Internal thermocouples from H1 to DL		6xTc type J	AIT	Six units package externally protected by a cooper tube type Mapress of 22 mm outer diameter from H1 cables box up to DL
v	Internal thermocouples from H1 to DL		6xTc type J	AIT	Six units package externally protected by a cooper tube type Mapress of 22 mm outer diameter from H2 cables box up to DL
w	Surface thermocouples from H1 to ETR1		11xTc type J	AIT	Each units externally protected by a cooper tube of 6 mm outer diameter from H1 up to surface
x	Surface thermocouples from H2 to ETR2		11xTc type J	AIT	Each units externally protected by a cooper tube of 6 mm outer diameter from H2 up to surface
y	RS-232, SKB PC to PC		4x0,25 mm2+P	AIT	
z					

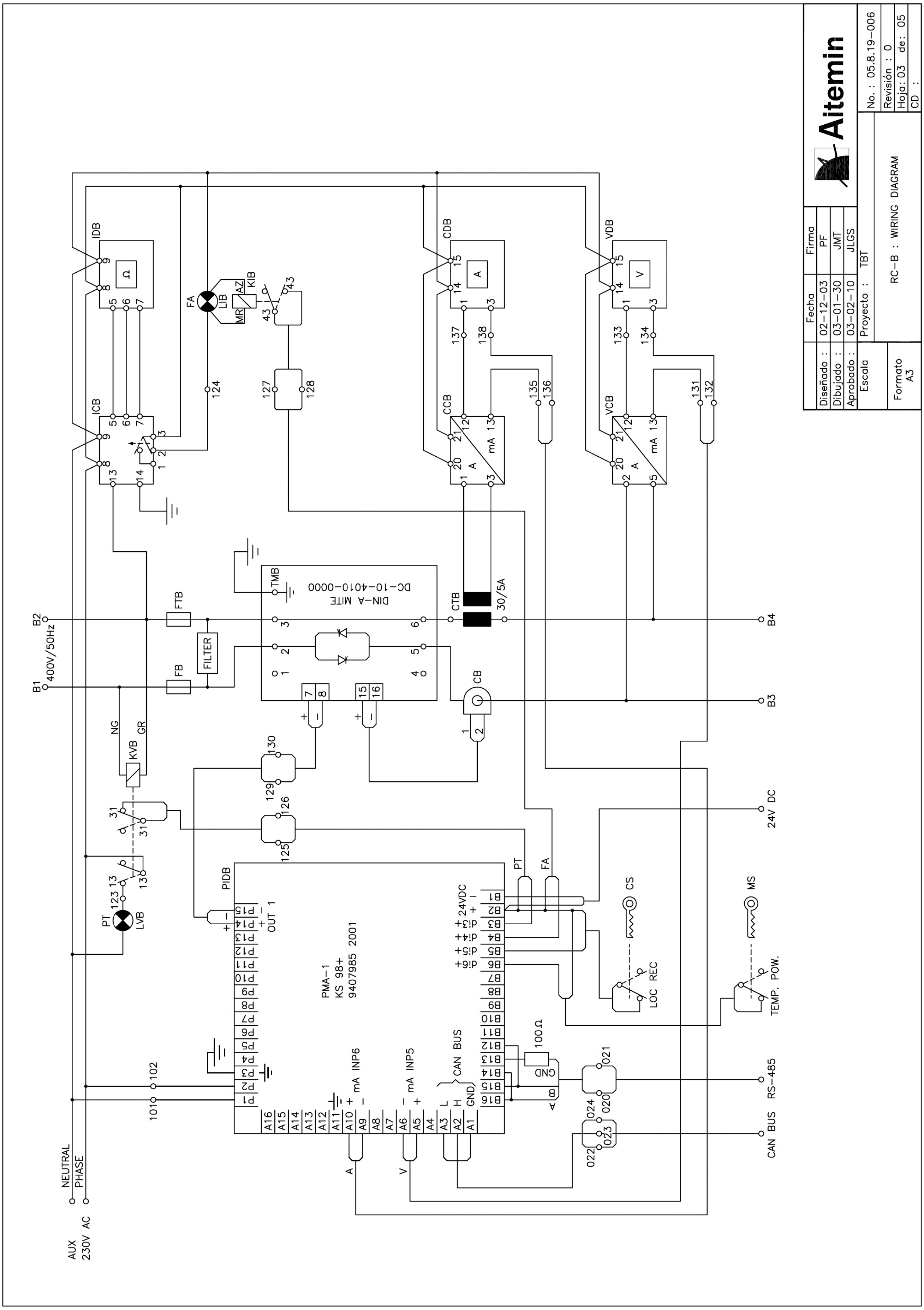


PR1/PR2 : POWER REGULATION BOX
ETR1/ETR2 : EXTERNAL THERMOCOUPLE READERS BOX
HC1/HC2 : HEATER CONECTION BOX
DL : DATA LOGGER BOX
PR1
PR2
ETR1
ETR2
HC1
HC2
DL
TBT HOLE
Ø2500
1600
200
1000
250
400
720
240
162,5
360
100
150
Fecha
Firma
Diseñado : 02-12-03 JMT
Dibujado : 03-03-10 JMT
Aprobado : 03-03-11 JLGS
Escala 1:25
Proyecto : TBT
Formato A3
GALLERY LAYOUT: ELECTRICAL BOXES
Aitemin
No. : 05.8.19-005
Revisión : 0
Hoja: 01 de: 01
CD :

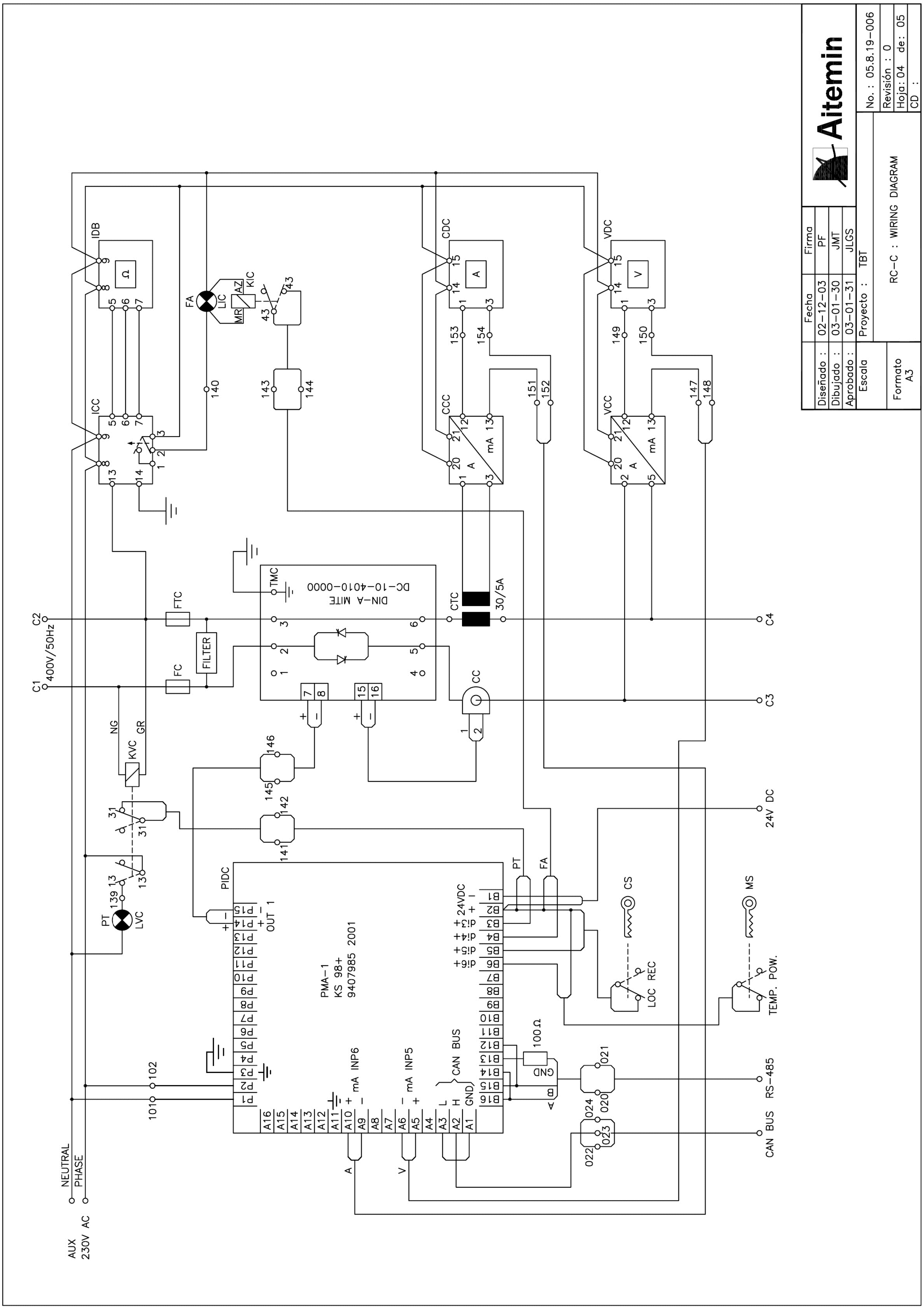

POWER REGULATION BOX -1
Aitemin
No. : 05.8.19-006
Revisión : 0
Hoja: 01 de: 05
CD :
Fecha
Firma
Diseñado : 02-12-03 PF
Dibujado : 03-01-30 JMT
Aprobado : 03-02-10 JLGS
Escala
Proyecto : TBT
PR1 : WIRING DIAGRAM
Formato A3
RC-A
RC-B
RC-C
230V AUX.
24V DC
CAN BUS
RS-485
PS
IF
SMPS
24V DC
220V AC
220V AUX M1
220V AUX M2
S1
S2
SW
ITA
ITB
ITC
MA
MB
MC
RA
RB
RC
(o) TO HC1
MAINS
UPS
FA-1
24V DC
CAN BUS
RS-485
(a) Pg.29
TO UPS (d) Pg.21
TO PR2 (n) Pg.9
TO ETR1 (l) Pg.9
TO ETR1 (q) Pg.9
TO PC (i) Pg.9

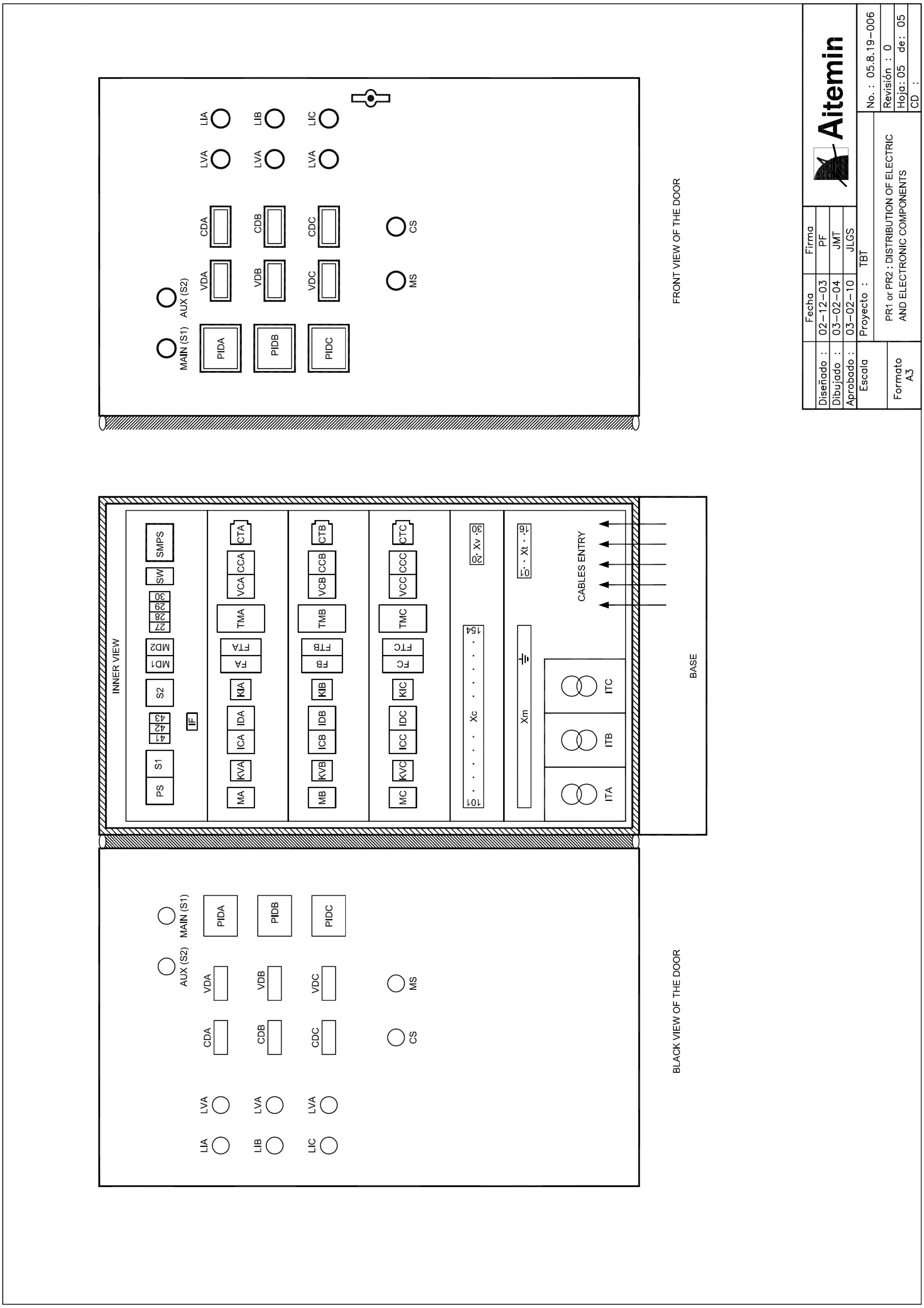


Aitemin
No. : 05.8.19-006
Revisión : 0
Hoja: 02 de: 05
CD :
RC-A : WIRING DIAGRAM
Diseñado : 02-12-03 PF
Dibujado : 03-01-30 JMT
Aprobado : 03-02-10 JLGS
Escala
Proyecto : TBT
Formato A3
Fecha
Firma
400V/50Hz
AUX 230V AC
NEUTRAL
PHASE
FTA
FA
FILTER
KVA
NG
GR
DIN-A MITE
DC-10-4010-0000
TMA
CTA
30/5A
CA
IDA
ICA
CDA
CCA
VDA
VCA
LIA
KIA
LVA
PT
PIDA
PMA-1
KS 98+
9407985 2001
OUT 1
mA INP6
mA INP5
CAN BUS
24VDC
100Ω
GND
LOC REC
TEMP. POW.
CS
MS
24V DC
RS-485
CAN BUS
A1
A2
A3
A4

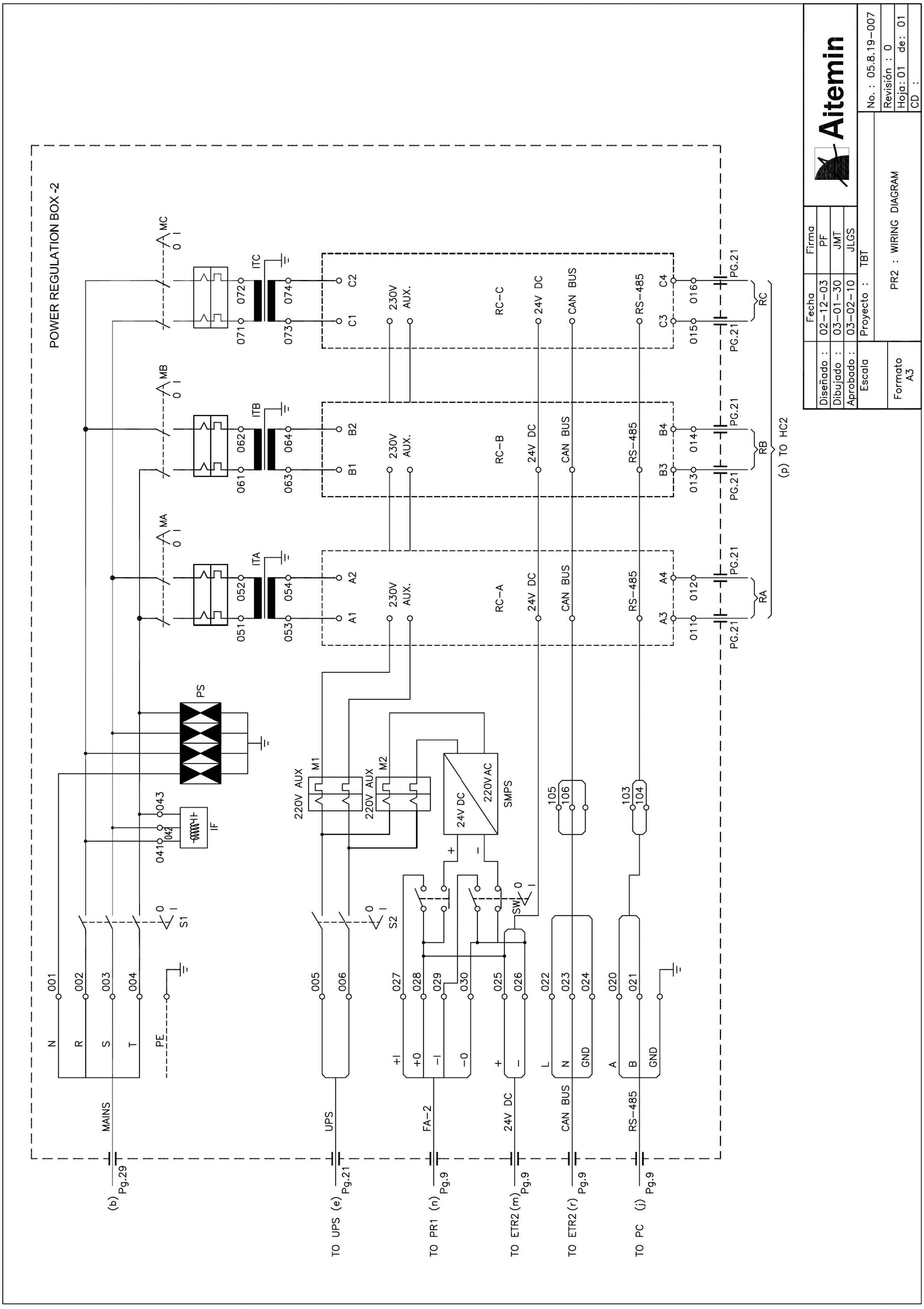


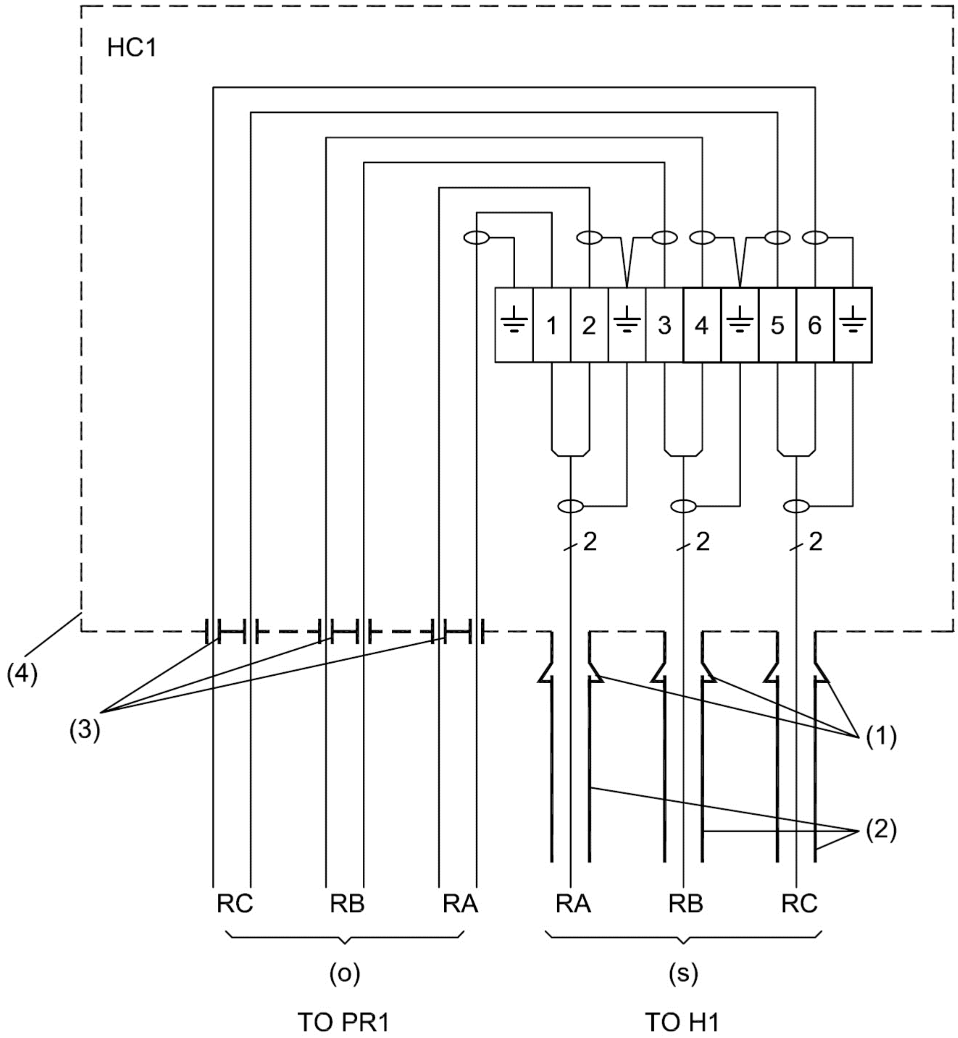
Aitemin
No. : 05.8.19-006
Revisión : 0
Hoja: 03 de: 05
CD :
Fecha
Firma
Diseñado : 02-12-03 PF
Dibujado : 03-01-30 JMT
Aprobado : 03-02-10 JLGS
Escala
Proyecto : TBT
RC-B : WIRING DIAGRAM
Formato A3
AUX 230V AC
NEUTRAL
PHASE
B1
B2
400V/50Hz
B3
B4
24V DC
RS-485
CAN BUS
IDB
ICB
CDB
CCB
VDB
VCB
KIB
KVB
FTB
FB
FILTER
CTB
30/5A
CB
TMB
DIN-A MITE
DC-10-4010-0000
PIDB
PMA-1
KS 98+
9407985 2001
OUT 1
mA INP6
mA INP5
CAN BUS
24VDC
CS
MS
LOC REC
TEMP. POW.
100Ω
LVB
LIB


Aitemin
No. : 05.8.19-006
Revisión : 0
Hoja: 04 de: 05
CD :
Fecha
Firma
Diseñado : 02-12-03 PF
Dibujado : 03-01-30 JMT
Aprobado : 03-01-31 JLGS
Escala
Proyecto : TBT
Formato A3
RC-C : WIRING DIAGRAM
PMA-1
KS 98+
9407985 2001
DIN-A MITE
DC-10-4010-0000
400V/50Hz
AUX 230V AC
NEUTRAL
PHASE
24V DC
RS-485
CAN BUS



FRONT VIEW OF THE DOOR
INNER VIEW
BLACK VIEW OF THE DOOR
BASE
CABLES ENTRY
MAIN (S1)
AUX (S2)
PIDA
PIDB
PIDC
VDA
VDB
VDC
CDA
CDB
CDC
LVA
LIA
LIB
LIC
MS
CS
PS
S1
S2
41
42
43
IF
MD1
MD2
27
28
29
30
SW
SMPS
MA
KVA
ICA
IDA
KIA
FA
FTA
TMA
VCA
CCA
CTA
MB
KVB
ICB
IDB
KIB
FB
FTB
TMB
VCB
CCB
CTB
MC
KVC
ICC
IDC
KIC
FC
FTC
TMC
VCC
CCC
CTC
101
Xc
154
Xv
Xm
Xt
ITA
ITB
ITC
Aitemin
Diseñado : 02-12-03 PF
Dibujado : 03-02-04 JMT
Aprobado : 03-02-10 JLGS
Fecha
Firma
Escala
Proyecto : TBT
Formato A3
PR1 or PR2 : DISTRIBUTION OF ELECTRIC AND ELECTRONIC COMPONENTS
No. : 05.8.19-006
Revisión : 0
Hoja: 05 de: 05
CD :


POWER REGULATION BOX -2
Aitemin
No. : 05.8.19-007
Revisión : 0
Hoja: 01 de: 01
CD :
Diseñado : 02-12-03 PF
Dibujado : 03-01-30 JMT
Aprobado : 03-02-10 JLGS
Escala
Proyecto : TBT
Formato A3
Fecha
Firma
PR2 : WIRING DIAGRAM
MAINS
UPS
FA-2
24V DC
CAN BUS
RS-485
(b) Pg.29
TO UPS (e) Pg.21
TO PR1 (n) Pg.9
TO ETR2 (m) Pg.9
TO ETR2 (r) Pg.9
TO PC (j) Pg.9
(p) TO HC2
RC-A
RC-B
RC-C
230V AUX.
SMPS
24V DC
220VAC
220V AUX
PS
IF
S1
S2
SW
ITA
ITB
ITC
MA
MB
MC
RA
RB
RC
PG.21



(o) - 6x1x6mm2 +P

(s) - Resistors Cold Ends

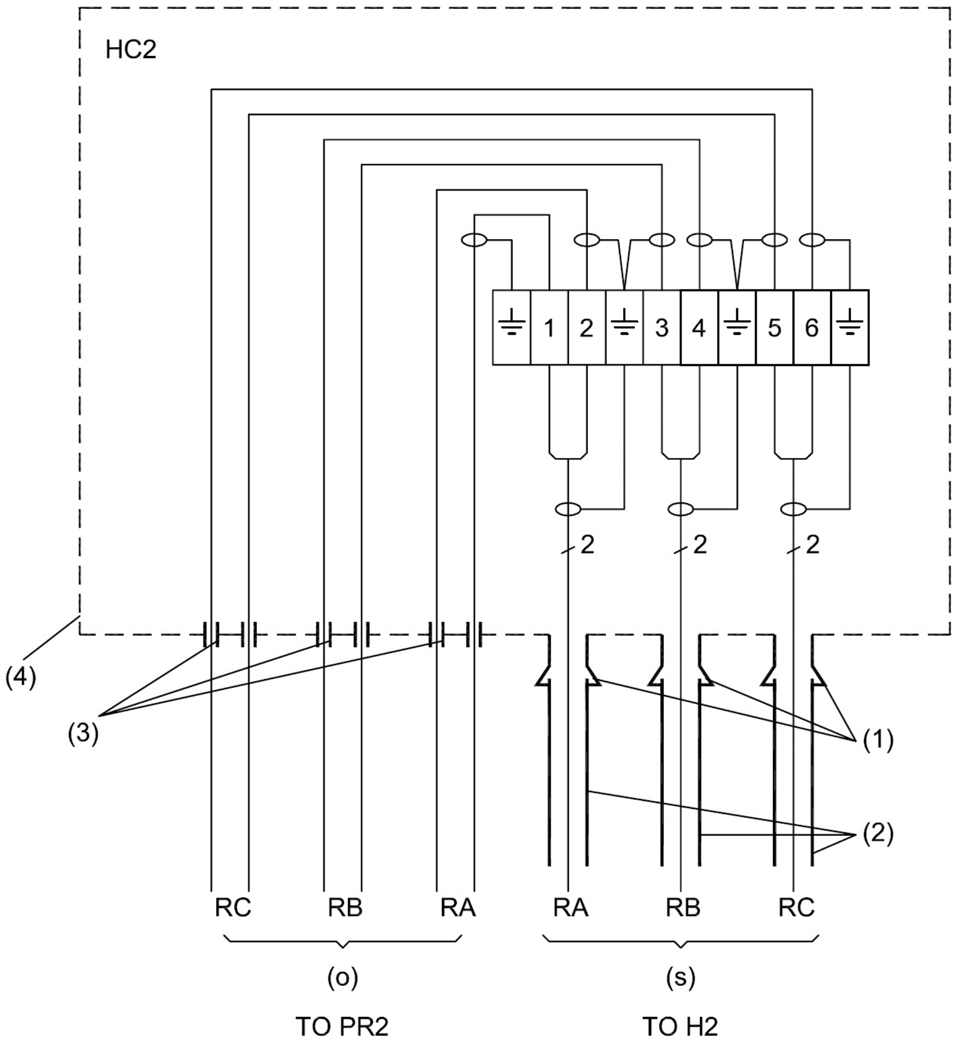
(1) - Mapress Cu Racord R1/2"

(2) - Mapress Cu Tube Ø 22mm

(3) - Plastic Cable Glands IP 68 (Pg.11)

(4) - ELDOM SS 304 Box 360x480x150mm (WxHxD)

	Fecha	Firma	Aitemin
Diseñado :	03-01-16	PF	
Dibujado :	03-01-30	JMT	
Aprobado :	03-02-10	JLGS	
Escala ——	Proyecto : TBT		No. : 05.8.19-008
Formato A-4	HEATER 1 : POWER CONNECTION BOX WIRING DIAGRAM		Revisión : 0
			Hoja : 01 de : 01
			CD :



(o) - 6x1x6mm2 +P

(s) - Resistors Cold Ends

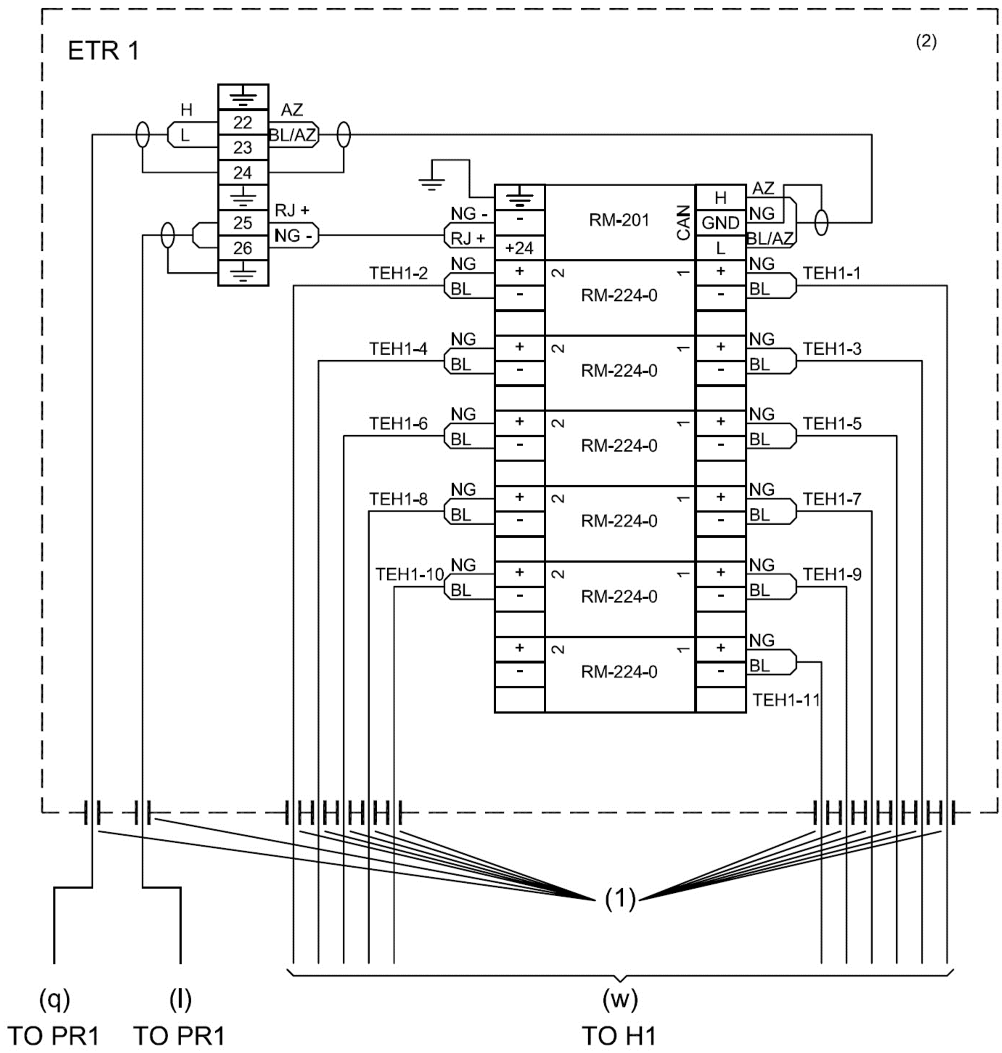
(1) - Mapress Cu Racord R1/2"

(2) - Mapress Cu Tube Ø 22mm

(3) - Plastic Cable Glands IP 68 (Pg.11)

(4) - ELDOM SS 304 Box 360x480x150mm (WxHxD)

	Fecha	Firma	Aitemin
Diseñado :	03-01-16	PF	
Dibujado :	03-01-30	JMT	
Aprobado :	03-02-10	JLGS	
Escala ——	Proyecto : TBT		No. : 05.8.19-009
Formato A-4	HEATER 2 : POWER CONNECTION BOX WIRING DIAGRAM		Revisión : 0
			Hoja : 01 de : 01
			CD :



(1) - Plastic Cable Glands IP 68 (Pg.11)

(2) - ELDOM SS 304 Box 240x360x162,5mm (WxHxD)

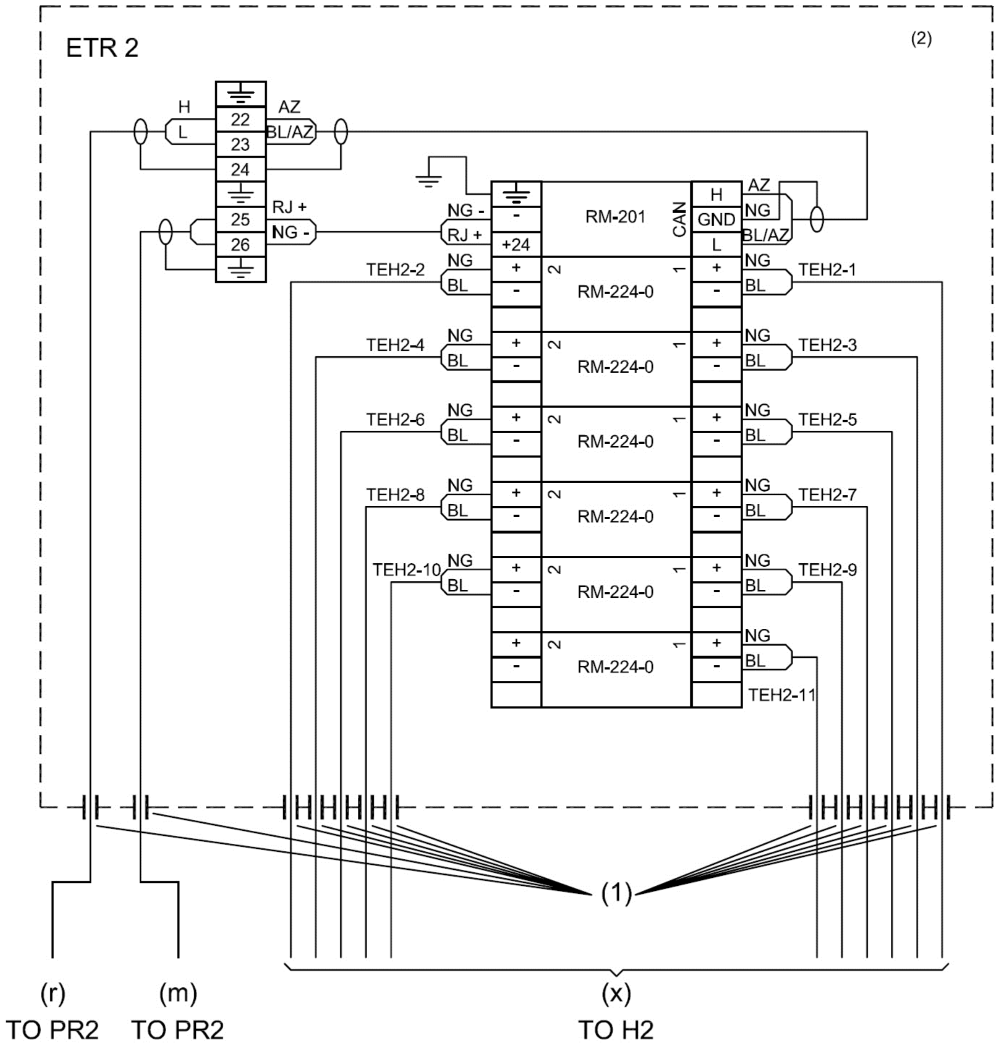
(q) - CAN BUS

(l) - MAINS 24V DC

(w) - 11 x Tc Type J

NG = BLACK
BL = WHITE
AZ = BLUE
RJ = RED

	Fecha	Firma	Aitemin
Diseñado :	03-01-16	PF	
Dibujado :	03-01-30	JMT	
Aprobado :	03-02-10	JLGS	
Escala ——	Proyecto : TBT		No. : 05.8.19-010
Formato A-4	ETR 1 : POWER CONNECTION BOX WIRING DIAGRAM		Revisión : 0
			Hoja : 01 de : 01
			CD :



(1) - Plastic Cable Glands IP 68 (Pg.11)

(2) - ELDOM SS 304 Box 240x360x162,5mm (WxHxD)

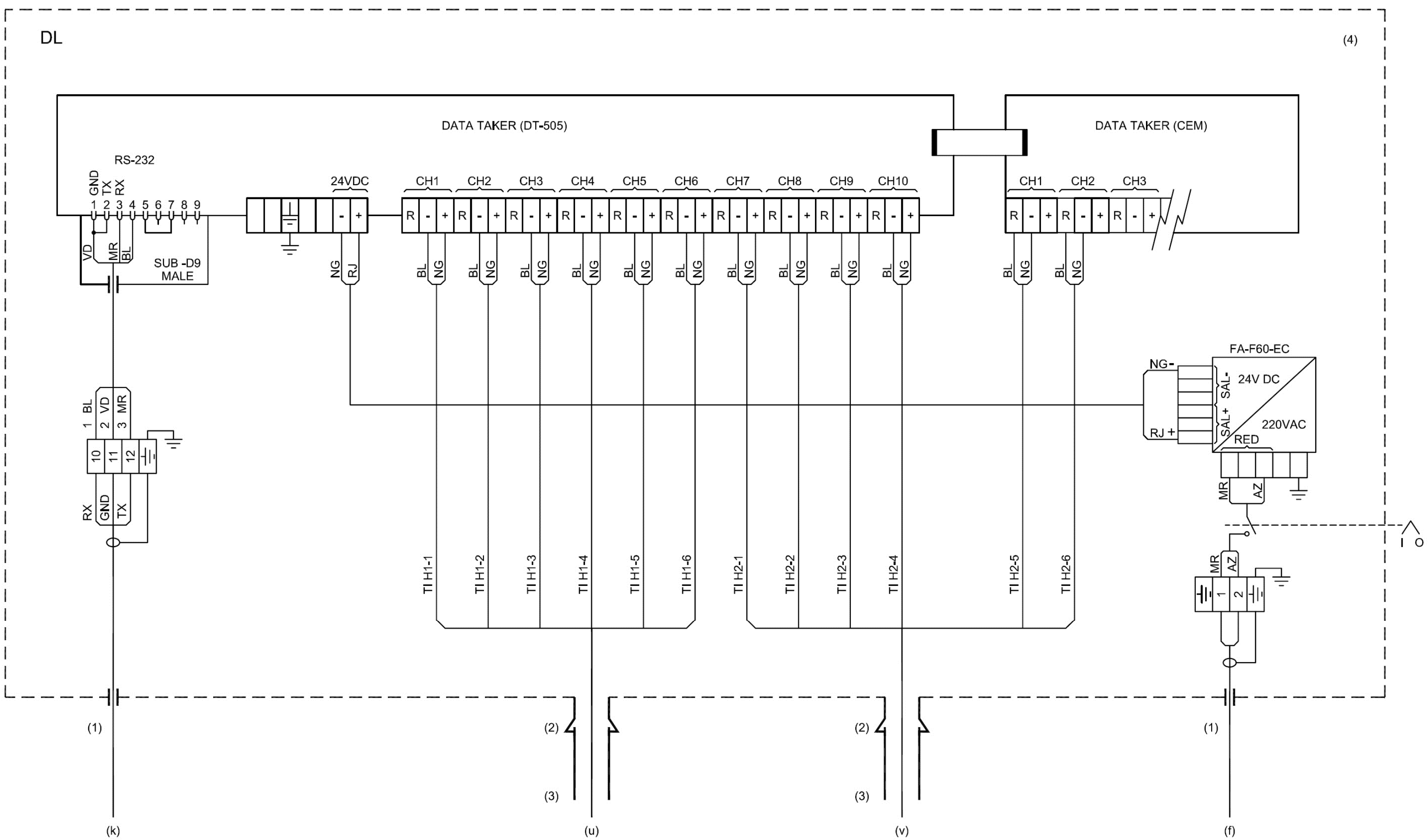
(r) - CAN BUS

(m) - MAINS 24V DC

(x) - 11 x Tc Type J

NG = BLACK
BL = WHITE
AZ = BLUE
RJ = RED

	Fecha	Firma	Aitemin
Diseñado :	03-01-16	PF	
Dibujado :	03-01-30	JMT	
Aprobado :	03-02-10	JLGS	
Escala ——	Proyecto : TBT		No. : 05.8.19-011
			Revisión : 0
Formato A-4	ETR 2 : POWER CONNECTION BOX WIRING DIAGRAM		Hoja: 01 de: 01
			CD :



(1) - Plastic Cable Gland
(2) - Mapress Cu Racord R1/2"
(3) - Mapress Cu Tube Ø 22mm
(4) - ELDOM SS 304 Box 720x720x24mm (WxHxD)
(u) = (v) - 6xTc Type J
(k) - RS-232 to PC
(f) - MAINS 220V AC to UPS

BL = WHITE
NG = BLACK
MR = BROWN
AZ = BLUE
VD = GREEN
RJ = RED

	Fecha	Firma
Diseñado :	02–12–03	PF
Dibujado :	03–02–03	JMT
Aprobado :	03–02–10	JLGS
Escala	Proyecto : TBT	
Formato A3	DATA LOGGER UNIT WIRING DIAGRAM	

Aitemin

No. : 05.8.19–012
Revisión : 0
Hoja: 01 de: 01
CD :