International Progress Report

IPR-01-60

Äspö Hard Rock Laboratory

Prototype Repository

Instrumentation of buffer and backfill in Section I

Roland Pusch

Geodevelopment AB

Lennart Börgesson

Clay Technology AB

July 2001

Svensk Kärnbränslehantering AB
Swedish Nuclear Fuel
and Waste Management Co
Box 5864
SE-102 40 Stockholm Sweden
Tel +46 8 459 84 00
Fax +46 8 661 57 19

Äspö Hard Rock Laboratory

Report no.	No.
IPR-01-60	F63K
Author	Date
Pusch, Börgesson	01-07-30
Checked by	Date
Lennart Börgesson	01-10-30
Approved	Date
Christer Svemar	01-12-19

Äspö Hard Rock Laboratory

Prototype Repository

Instrumentation of buffer and backfill in Section I

Roland Pusch

Geodevelopment AB

Lennart Börgesson

Clay Technology AB

July 2001

Keywords: Instrumentation, temperature, pure water pressure, total pressure, relative humidity

PROTOTYPE REPOSITORY

PROTOTYPE REPOSITORY

Deliverable D 2

Instrumentation of buffer
and backfill in Section I

Roland Pusch
Geodevelopment

Lennart Börgesson
Clay Technology AB

July 2001

EC Contract FIKW-2000-00055

EC-5th EURATOM Framework programme 1998-2002
Key Action: Nuclear Fission

ABSTRACT

This report describes the instrumentation of backfill and buffer for study of THM processes in the Prototype Repository for recording processes up to 20 years.

The instrumentation consists of approximately 650 units of sensors for measuring:

- Temperature
- Total pressure
- Pore water pressure
- Water content

The measuring principles and number of sensors are summarized in the table:

Measuring quantity	**Measuring principle**	**Decided number of sensors in Section I**	**Planned number of sensors in Section II**
Temperature	Thermocouples	84	80
	Fibre optics	8	4
Total pressure	Vibrating wire	38	36
	Piezoresistive	38	36
Pore water pressure	Vibrating wire	26	24
	Piezoresistive	26	24
Water content	Relative humidity (capacitive method)	74	74
	Soil psychrometer	45	32
Total		339	310

The document gives the basis of the selection of the various sensors and measurement principles.

SAMMANFATTNING

Denna rapport beskriver instrumenteringen av återfyllning (backfill) och buffert för undersökning under en tid av upp till 20 år av THM-processer i Prototypförvaret . Instrumenteringen består av ca 650 sensorer för mätning av:

- Temperatur
- Totaltryck
- Porvattentryck
- Vatteninnehåll

Mätprinciperna och uppgifter om antalet sensor för olika ändamål är sammanfattade i tabellen:

Tillstånd	Mätprincip	Beslutat antal sensorer i Section I	Beslutat antal sensorer i Section II
Temperatur	Termoelement	84	80
	Fiberoptik	8	4
Totaltryck	"Svängande sträng"	38	36
	Piezoresistivitet	38	36
Porvattentryck	"Svängande sträng"	26	24
	Piezoresistivitet	26	24
Vatteninnehåll	Relativ fuktighet (kapacitivitet)	74	74
	Psychrometri	45	32
Totalt		339	310

Rapporten ger underlaget för valet av sensortyper och mätprinciper.

LIST OF CONTENTS

1 BACKGROUND AND BASIC CONDITIONS

1.1 General

A field experiment with a Prototype Repository is conducted in the Äspö Hard Rock Laboratory, north of Oskarshamn in Sweden, for demonstration of a future deep repository of nuclear spent fuel. The underground part of the laboratory consists of a main tunnel blasted as spiral and with the length 3,6 km and leading down to a depth of 450 m in the bedrock. Here, a 400 m long TBM drift has been drilled of which the Prototype Repository occupies the last 70 meters

The purpose of the Prototype Repository is to study thermal, hydraulic, mechanical, chemical and biological processes in a future deep repository for spent nuclear waste fuel. In the Prototype Repository the nuclear fuel is replaced by electrical heaters that will simulate the expected heat energy flow (approx1800 W) The electrical heaters are located inside genuine canisters consisting of a steel core surrounded by 50 mm copper in one case 30 mm copper. Figure 1-1, shows the test drift with deposition holes that is used for the Prototype Repository.

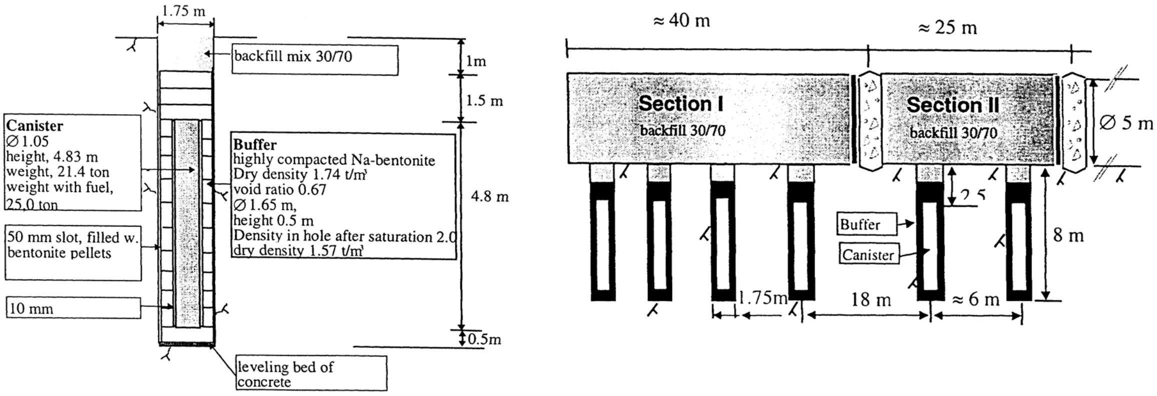


__Figure 1-1.__Deposition holes and tunnel in the Prototype Repository [1].

The main part of the instrumentation for the Prototype Repository consists of sensors in the buffer and backfill for recording:

- Temperature
- Total pressure
- Pore water pressure
- Moisture content

The installation of the instrumentation started in spring 2001 and will be completed during 2001 in Section I and during year 2002 in Section II.

1.2 Materials and field conditions

1.2.1 Buffer and backfill materials

The buffer consists of compacted blocks and pellets of MX-80 bentonite, which has a content of minus 2 µm particles of 85-95 % of which 80-90 % is montmorillonite. The water content is about 17 %. The backfill, which is applied in inclined layers compacted by a special plate vibrator, consists of a mixture of 30 % MX-80 bentonite and 70 % crushed TBM muck. The water content is about 15 %.

1.2.2 Groundwater

The salt content in the water in the groundwater is 0.7 % with calcium as major cation and clorine as major anion. The composition varies rather much. The high salt content in combination with relatively high temperatures has led to the decision to use use titanium for all exposed parts of the instruments where possible.

1.2.3 Rock structure

The rock structure is characterized by 4 major fracture sets (Two steep ones striking NW and NS, one dipping 58^o striking ENE, and one subhorizontal).

1.2.4 Pressure conditions

Rock stresses

The major principal stress in the horizontal plane is oriented approximately NNW and is about 30 MPa. The minor principal stress is steeply oriented and amounts to about 10 MPa. The intermediate principal stress is oriented is about 20 MPa.

Piezometric pressures

The piezometric pressures in the immediate vicinity of the drift is 1-3 MPa in the early part of the test but is later expected to increase to about 4 MPa.

Swelling pressures

The final swelling pressure is expected to be in the range of 5-10 MPa in the buffer and a few hundred kilopascals in the backfill. The total pressure in the buffer may be up to 15 MPa.

1.2.5 Temperature conditions

The ambient rock temperature is about 15^{o}C. The buffer clay will have a maximum temperature of 90^{o}C while the backfill temperature will not exceed about 40^{o}C.

2 TYPES OF MEASUREMENTS

2.1 Classification

The classification of measurements is made according to Table 2-1:

Table 2-1. *Classification of measurements.*

Class	Thermal, hydraulic and mechanical measurements
1A	"Standard measurements in a sparse and evenly distributed network
1B	"Standard measurements" concentrated to certain locations where detailed studies of THM processes are of interest
1C	"Special measurements"
2	**Other measurements as geochemical, biological, chemical etc**

2.2 "Standard measurements" (wide distribution of sensors, 1A)

The following variables are recorded:

- Temperature
- Water content
- Pore water pressure
- Total pressure

The instrumentation is sparse but sufficient to record variations in the buffer and backfill. For making it possible to compare data from the different holes the same type of sensors are used in them. In the deposition holes measurements are made at three levels, two of which are just below and above the canister. It is justified to use a rather large distance between the levels since the water-bearing rock fractures are mainly oriented vertically.

At each level measurements will be made in four vertical sections A, B, C and D (Figures 2-1 and 2-2), of which two are oriented in the axial direction of the tunnel and two at right angles or at an angle of 60 degrees to the tunnel axis (Figure 2-1).

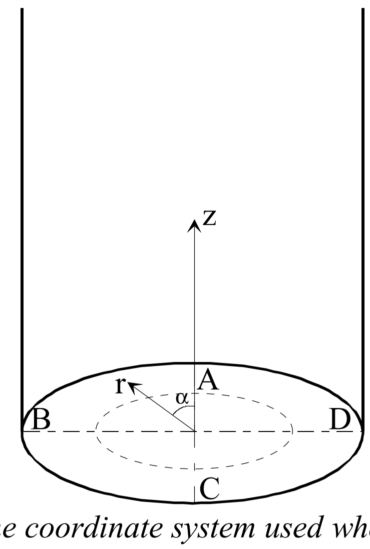


Figure 2-1. *Figure describing the coordinate system used when determining the instrument positions.*

The position of sensors in the deposition hole is shown in Figure 2-2. A vertical section A and a horizontal section just in front of the canister are instrumented more extensively than the others for evaluation of variations axially and radially. The vertical section D is instrumented with only temperature sensors.

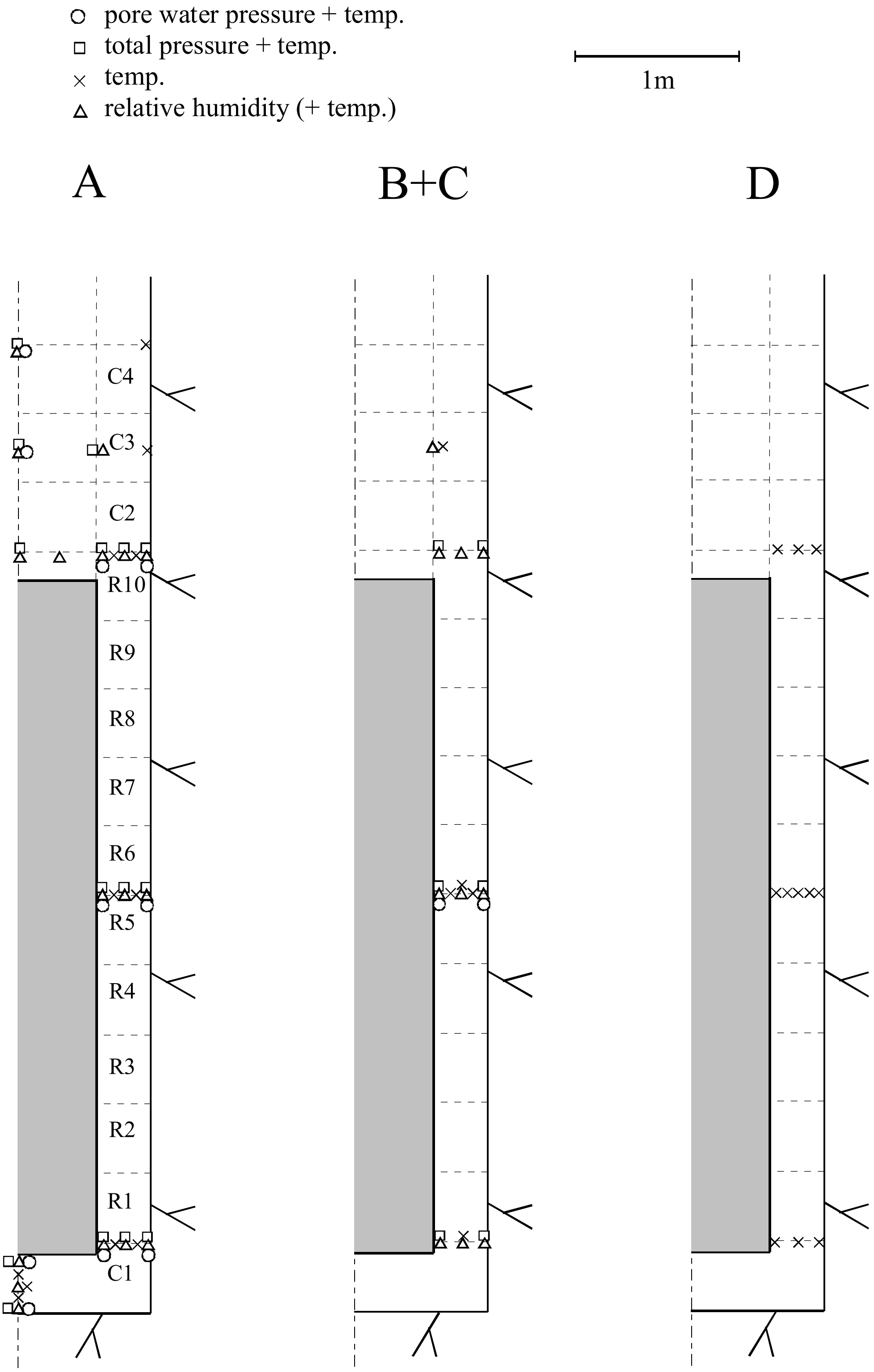


Figure 2-2. *Sensor positions in the deposition holes.*

Two different types of moisture sensors are installed at certain points. The reason is that their measuring ranges overlap and hence make them complementary. In addition, a fibre optic temperature measurement system is used for determination of surface temperature of the canisters.

The backfill will be instrumented in vertical sections straight above and between the deposition holes, which is seen in Figure 2-3. This gives information about the propagation both axially and radially around the holes. The regions between the outer holes and the plugs are expected to be less interesting and therefore sparsely instrumented.

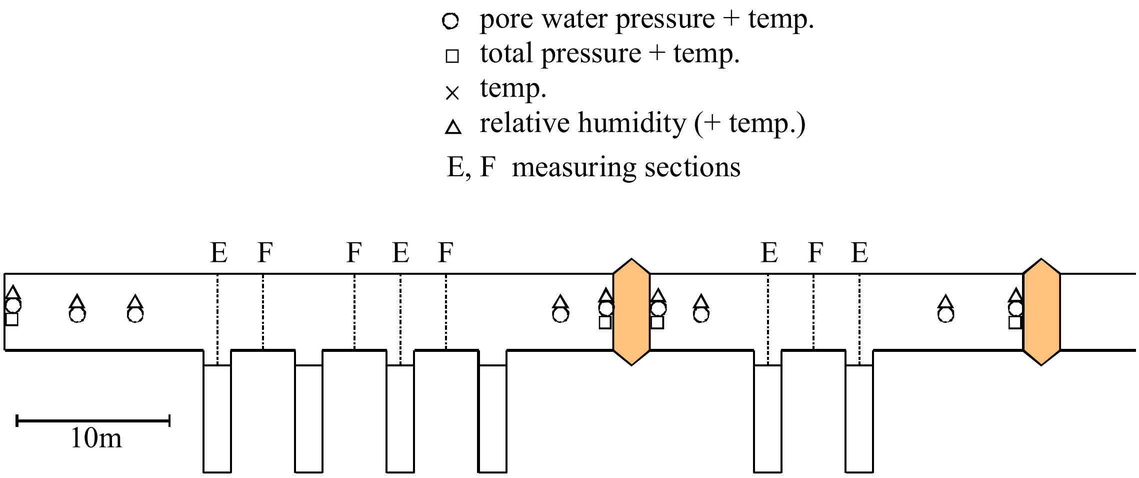
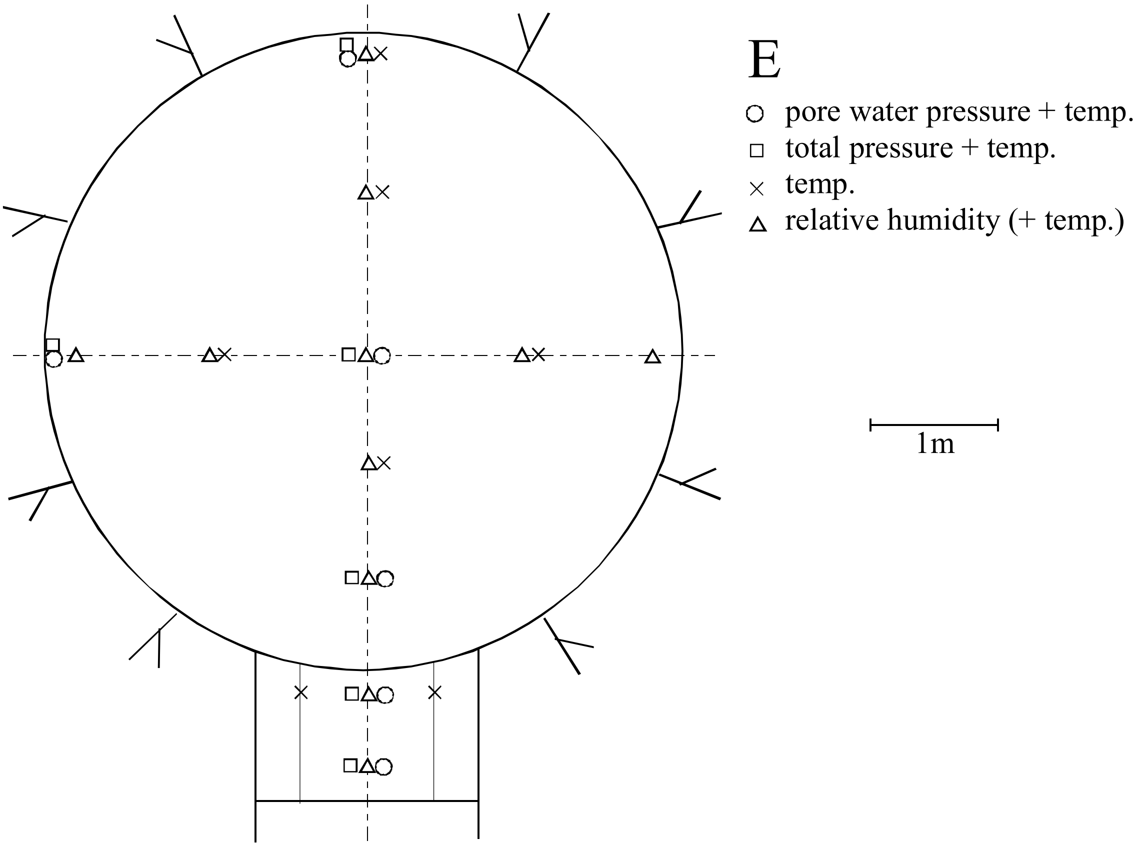


Figure 2-3. *Instrumentation of backfill in the tunnel.*

The sensor positions in sections E and F respectively are shown in Figure 2-4.



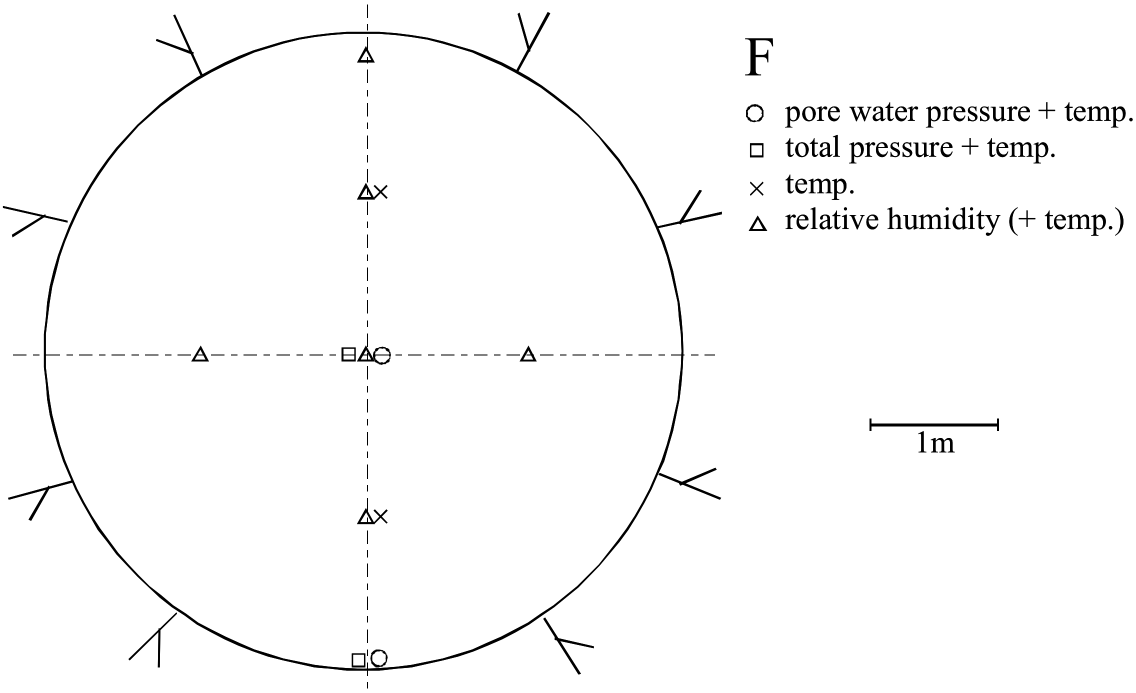


Figure 2-4. *Sensor positions in the backfilled tunnel.*

2.3 "Standard measurements" (dense sensor distribution, 1B)

A more dense sensor distribution may be applied for recording processes of particular importance:

- Water saturation process of buffer and backfill close to water-bearing fractures
- Temperature development at joints between bentonite blocks
- Dessication of blocks adjacent to the canister

2.4 Special measurements (1C)

Recording is also made of:

- Displacements
  - Movement of canister
  - Swelling of bentonite causing displacement of the backfill
  - Swelling and shrinkage of bentonite blocks due to water migration
- Air and gas pressure

Canister movements are measured by straine gauges below one canister and at the lower end of it for recording lateral displacements [2].

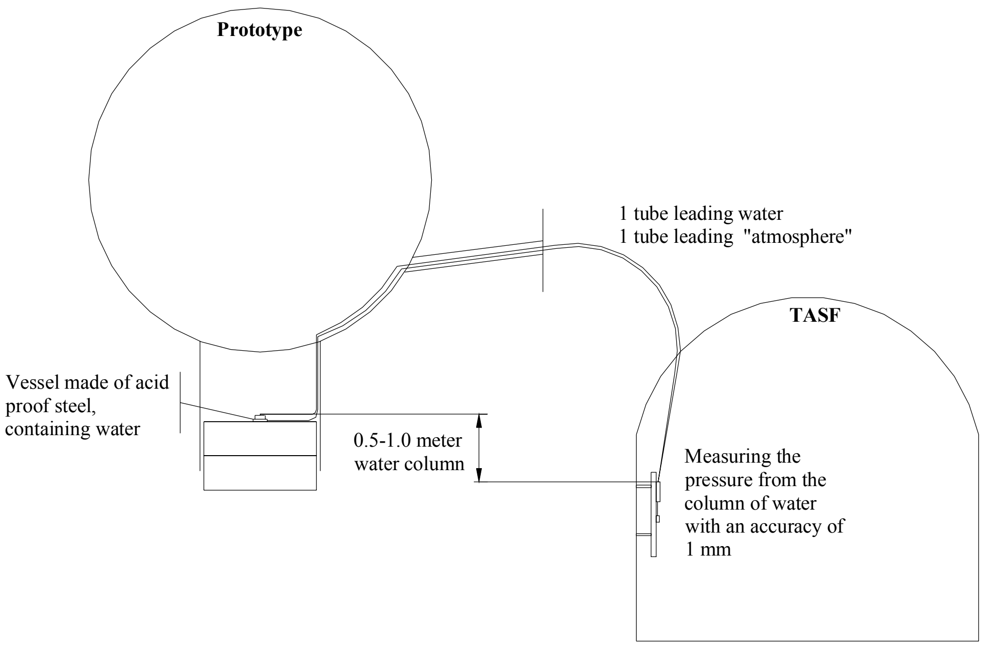


Figure 2-5. *Schematic view showing how the displacement of the surface between bentonite and backfill is planned to be measured.*

3 INSTRUMENTATION

3.1 Conditions

A number of gauges will be installed for measuring temperature, rate of wetting and evolution of pressure and they have to stand the temperature and pressure that will prevail in the different parts of the test area. The sensors will operate in the following temperature and pressure ranges:

- 0-40 °C in backfill
- 0-120 °C in buffer
- 0-15 MPa total pressure
- 0-5 MPa pore water pressure

3.2 Temperature

Measuring principle – Vibrating wires

The vibrating wire temperature-measuring device uses a sensor body and a wire with different thermal coefficients of expansion. This means that when the temperature changes, the frequency of the wire changes as well. The vibrating wire measuring principle is described in more detail in the chapter describing pressure measurements.

Measuring principle - Thermocouples

Thermocouples consist of two conductors of different metals or alloys that are joined together end-to-end. A potential (electromotive force) is produced at the contact surface between the two metals and is the measure of the temperature. When the conductirs are connected to a reading device a potential is also produced at its contacts. The result is that the reading device will measure the difference between the two potentials. Therefore, the temperature of the reading device, i.e. the reference temperature, has to be known in order to obtain a temperature value at the joint (the measuring point). The reference temperature is often measured by means of a resistance temperature sensor.

Common thermocouple types are shown in Table 3-1.

Table 3-1. *Common thermocouple types*

Material	Type	Range
Copper-Constantan	T	-200 - 400 °C
Chromel-Constantan	E	-200 - 900 °C
Chromel-Alumel	K	-200 - 1200 °C

A non-calibrated thermocouple gives temperature data with an accuracy of ± 3 °C at the temperatures expected in the Prototype Repository.

Measuring principle – Resistivity

Resistive temperature detectors or RTDs are normally made of platinum (Pt 100 sensors) or semiconductors.

The correlation between the resistance, R_t, and the temperature, T, for the Pt 100 sensor is approximately following a quadratic equation within a large temperature range (0 - 600 °C) as follows:

$$R_t = R_0(1 + AT + BT^2) \tag{3-1}$$

A temperature sensor of semiconductor type is often called thermistor but also PTC or NTC resistance. PTC stands for "positive temperature coefficient" and NTC for "negative temperature coefficient ". The measuring range for the semiconductor sensors stretches from almost absolute zero to 300 °C.

Measuring principle – Fibre optical sensors

Optical fibre temperature measurement systems are often called Distributed Temperature Sensing (DTS) or Fibre Temperature Laser Radar (FTR).

The measuring principle is shown in Figure 3-1. A laser light source sends a light pulse into one of the ends of an optical fibre. Most of the light is transported all the way through the fibre and exits the fibre at the other end. A smaller part of the light is scattered and reflected through all the fibre backwards in the direction to the light source. The backscattering light is called Rayleigh scattering light and is a result of density variation in the fibre material. The backscattering light is analysed with respect to the Raman scattering spectrum, which consists of a shorter wavelength (Stokes light) and a longer wavelength (Anti-Stokes light) than the original laser light wavelength. The intensity ratio between the Stokes light and the Anti-Stokes light is a measure of the temperature. The time it takes for the backscattering light to return to the light source is a measure of the position along the fibre. As a result, a temperature profile is achieved along all the cable length. The measurements are not sensitive to electromagnetic interference.

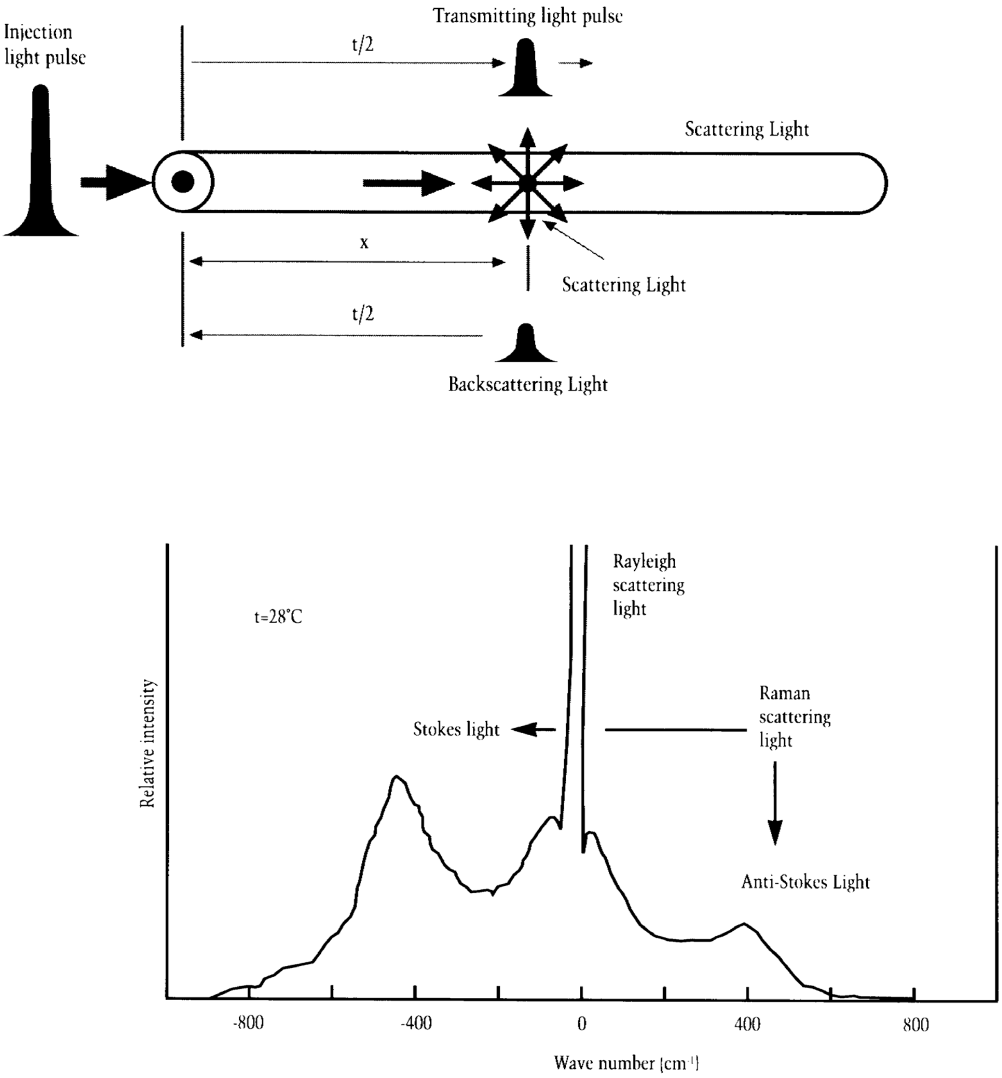


Figure 3-1. *Backscattering light generation in an optical fibre (upper part). The Raman scattering spectrum in an optical fibre (lower part).*

Since integration of the measurement signal, which can be regarded as a stochastic variable, has to be made with respect to time, the result gives the average temperature along a defined length of the cable. A special sensor called spot sensor made of several meters of cable, which is coiled and encapsulated, is used where more precise location of the measuring point is required.

The spatial resolution is defined as the distance along which the measuring signal changes from 10 % to 90 % of the actual temperature difference at a stepwise temperature change as can be seen in Figure 3-2. The average temperatures achieved are shown in Table 3-2. Figure 3-3 illustrates the position of optical fibres for measuring the surface temperature of the canisters.

Table 3-2. *Average temperatures along the optical fibre*

Distance a-b in graph A	t_0
Distance c-d in graph B	t_0+plus 10 % of the difference between t_1 and t_0
Distance e-f in graph C	t_0+plus 90 % of the difference between t_1 and t_0
Distance g-h in graph D	t_1

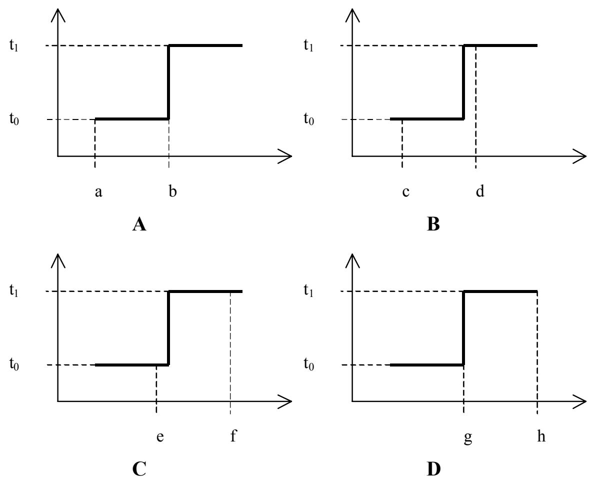


Figure 3-2. *Definition of the spatial resolution, which in these graphs is equal to the distance between position c and e.*

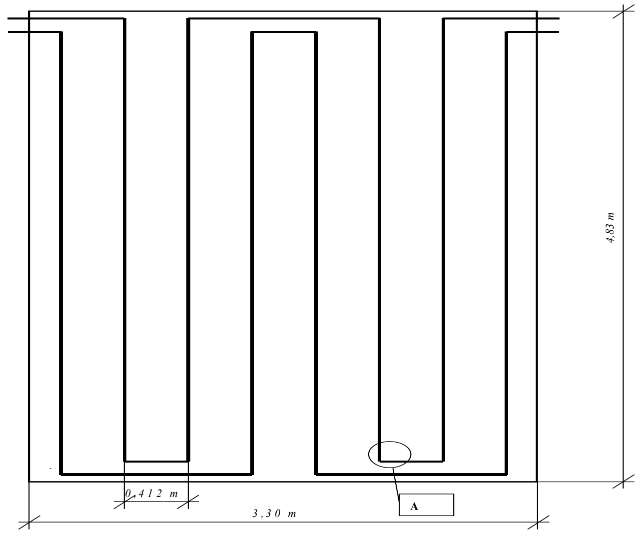


Figure 3-3. *Two optical fibre cables with protection tube of Inconel 625 for measurement of the canister surface temperature (surface unfolded). The cables enter and exit at almost the same position. Bendings are shaped as a quarter circle with a radius of 20 cm. The cable is placed in an etched channel on the surface. It has a width and a depth of about 2 mm.*

<u>Selected sensors</u>

The temperature is measured by means of thermocouples, type K. Optical fibre systems are also used. The required measurement range is 0-200°C. The sensors are placed in housings or sheaths made of corrosion-resistant material. Sheathed sensors are protected over the entire distance from the measuring point to the data collecting equipment.

The maximum length of the temperature sensor including cabling is about 100 m and the average length 75 m. Extension cables are placed in sealed protection tubes, which are sealed against the surroundings.

The total number of temperature sensors that will be used in the Prototype Repository is about 210 units. The types, positions and numbers are summarized in Sections 5 and 6.

3.3 Water content

The water content will be measured for getting information on the rate of water uptake. The following four methods can be used:

1. Capacitivity sensors measuring relative humidity in the pore system
2. TDR (Time Domain Reflectometry) sensors measuring the volumetric water content
3. Psychrometers measuring relative humidity in the pore system
4. Resistivity sensors measuring the volumetric water content.

Measuring principle – TDR

The TDR measurement system consists of the following main components:

- A time domain reflectometer (network cable test analyser).
- In-situ probe designed as a wave-guide
- Coaxial cable connecting the reflectometer with the wave-guide

The advantages of the TDR measurement system are that the probe is robust, stable and durable and that it has a high sensitivity over the entire measuring range of 0-100 %. Also, it gives instant information on the volumetric water content, i.e. the quantity of water in a specific volume of the material.

The measuring principle is as follows. A voltage pulse is sent out from the reflectometer, through the coaxial cable and to the wave-guide, which is embedded in the material in which the water content is to be measured. When the pulse reaches the wave-guide, an electromagnetic wave is produced in the surrounding material. At the end of the wave-guide, the voltage pulse is reflected back to the source. The time for the pulse to be transported forward and backward along the wave-guide is a function of the permittivity of the surrounding material. Since the water has a significant higher permittivity than soil and rock material, the recorded travel time is a measure of the water content in the material.

The relationship between travel time t, length of the wave-guide l, light velocity in vacuum c_0 and permittivity in the surrounding material ε_r is given by Eq.(3-2):

$$t = \frac{2l}{c_0} \cdot \sqrt{\varepsilon_r} \qquad (3\text{-}2)$$

By means of the above equation, the permittivity can be calculated ε_r. The volumetric water content can then be calculated by means of an empirical correlation between the permittivity ε_r and the volumetric water content θ_v. An example of such a correlation is given by Eq(3-3):

$$\varepsilon_r = 3{,}03 + 9{,}3\theta_v + 146\theta_v^{\,2} - 76{,}7\theta_v^{\,3} \qquad (3\text{-}3)$$

The following factors affect the accuracy of measurement and applicability of the TDR measurement method:

- Measurements represent a very small volume, which yields weak signals.
- There are density variations in the surrounding material.
- There may be incomplete contact between the wave-guide and the surrounding material.
- Temperature dependency.
- High salinity content in the surrounding material weakens the measuring signal. Still, this problem can be minimized by covering the wave guide with some plastic material, e.g. PVC.

Measuring principle - Capacitivity

By using the capacitivity method the relative humidity of the content of the pores can be measured.

The sensor consists of a pair of electrodes separated by a polymer film. The quantity of moisture that is absorbed by the polymer film is controlled by the relative humidity of the surrounding air. The capacitance is affected by the absorbed water quantity and is equivalent to the relative humidity and thus the water content in the surrounding material.

Measuring principle - Psychrometry

Soil psychrometers are used for measurement of the dry and the wet temperature in the pore volume of a material.

The sensor consists of two thermocouples of which one is used for cooling by the Peltier effect and the other for temperature measurement. The sensor is cooled down below the dew point after which the cooling is interrupted. Knowledge of the wet temperature, which can be read when the condensed water evaporates, and the dry temperature gives the relative humidity and thus the water content in the surrounding material.

Measuring principle - Resistivity

The electrical resistivity of a soil material is a function of water content and salinity. A resistive sensor consists of four isolated electrodes mounted along a rod of polyurethane. A current passes through the two outer electrodes while the voltage between the two inner electrodes is measured. The current and the voltage are then used for calculation of the resistivity and thus the water content.

Comparison of methods

The psychrometer is used in the backfill where the relative humidity will be 95-100 %. These sensors are also expected to be useful when the buffer is nearly water saturated.

The measuring range is as given by Table 3-4:

Table 3-4. *Measuring ranges of moisture sensors.*

Capacitive sensor	0-100 % relative humidity
TDR	0-100 % volumetric water content
Psychrometer	95-100 % relative humidity
Resistive sensor	0-100 % relative humidity

Selected sensors

Moisture sensors of the following types were selected:

1. Capacitive sensors for the buffer material
2. Psychrometers for the backfill material

The maximum length of the temperature sensor including cabling is about 100 m and the average length 75 m. Extension cables are placed in sealed protection tubes. which are sealed against the surroundings.

The total number of moisture sensors in the Prototype Repository is 77 in the drift, and 148 in the deposition holes. The types, positions and numbers are summarized in Sections 5 and 6.

The maximum distance between the pressure gauge and the data acquisition system is 100 m. If possible, the electronic unit of the measuring system is placed either outside the tunnel or in a waterproof cabinet or chest.

The measuring system includes gauges, signal cables, electronic units and necessary equipment for data processing and will produce results in the form of output signals of 4-20 mA or a binary signal through a serial communication device.

Electrical and signal cables shall either resist the specified pressure and be protected against water leakage after moisture saturation, or be placed in tubes which protect against mechanical damage and water leakage. The gauges are protected against mechanical damage from the surrounding material.

3.4 Pressure

3.4.1 Total pressure and pore water pressure

Measurement principle - Hydraulic pressure cells

For recording the total pressure, i.e. the sum of effective soil pressure and porewater pressure, the system consists of an oil- or gas filled pressure cell that is connected to an oil-filled pump circulation system with a control valve and pressure gauge. The valve, which regulates the oil flow in the system, is equipped with a diaphragm exposed to the soil on one side while the other is connected to the circulation system. The measuring sequence begins with starting the pump and slowly increasing the pressure until the valve opens, which corresponds to the total soil pressure.

For recording porewater pressures the pressure cell is replaced by a ceramic or metallic filter attached to the diaphragm of the valve.

Measurement principle - Piezoresistivity

The piezoresistive sensor uses a strain gauge of semiconductor material. The gauge is bonded to a diaphragm, which is in contact with the surrounding material. The electrical resistance of the sensor is measured and gives the pressure of the surrounding material.

Measurement principle – Vibrating wires

A vibrating wire sensor uses a wire, which in one end is attached to the backside of a pressure diaphragm and held under tension. Pressure acting on the other side of the diaphragm causes wire tension and thus changes the natural frequency of the wire.

There are two different types of vibrating wire sensors:

- Pluck and read
- Auto-resonant

The pluck and read type uses a voltage pulse applied to an electromagnetic coil to pluck the wire, i.e. pull the wire to one side and release it. The sensors also use a permanent magnet, which, together with the vibrating wire, induces a sinusoidal voltage in the coil. The frequency of the voltage is measured yielding the pressure. The pluck and read type is shown in Figure 3-4.

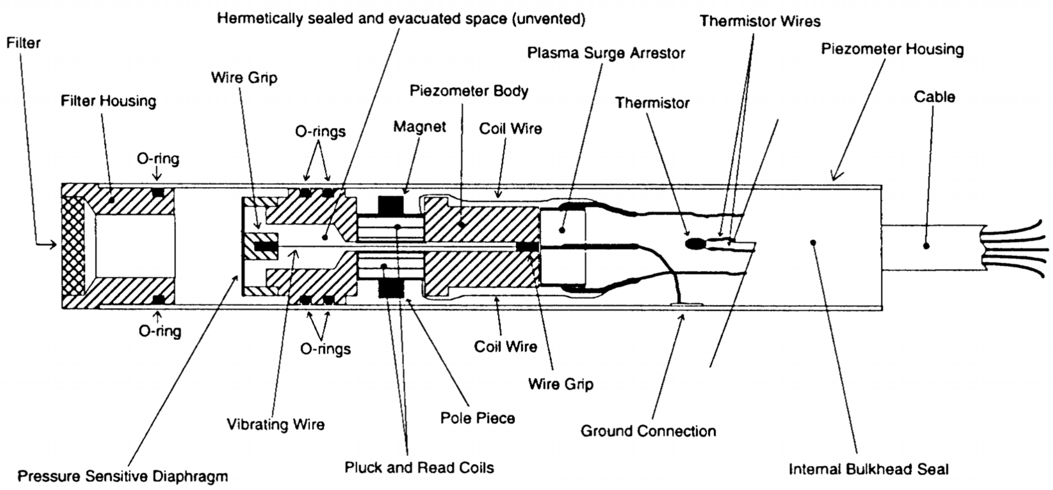


Figure 3-4.*Pressure sensor of vibrating wire type using the pluck and read method.*

The auto-resonant type uses an electromagnetic coil that causes the wire to continuously vibrate at its natural frequency. A second coil is used to measure the frequency of the wire and thus the pressure.

Measurement principle – Fibre optics

Fibre optic measuring principle for pressure measurements is based on the following techniques and equipments:

- Intensity modulation
- Bragg gratings
- Fabry-Pérot interferometer

Change of the light amplitude (i.e. intensity modulation) is the oldest of the three techniques. A disadvantage of this technique is that the amplitude is affected by ageing.

A Bragg grating sensor consists of an optical fibre, which has been processed by UV radiation to obtain a repeated change from one refractive index to another along the fibre. The working principle is shown in Figure 3-5. At each change from the one refractive index to the other a reduced part of the incoming light is reflected back. The reflected light has its maximum intensity at the wavelength λ_β, which is equal to $2n\Lambda$ where n is the average of the two different refractive indexes and Λ is the distance between two adjacent pair of indexes. A pressure sensor is designed such that the pressure to be measured affects the characteristics of the grating and thus the wavelength of the reflected light.

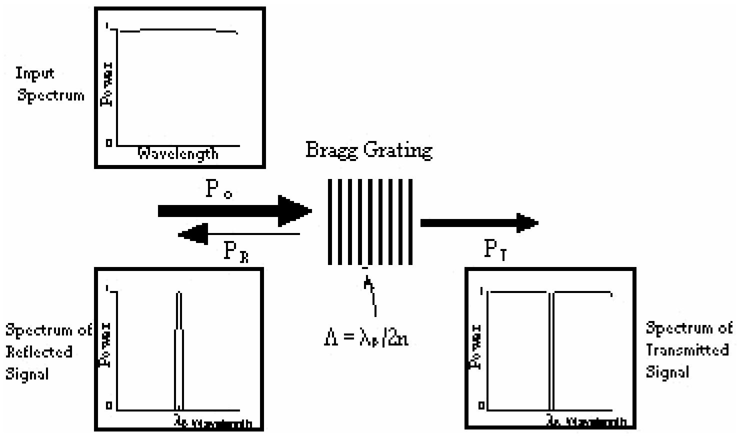


Figure 3-5. *Principle of Bragg grating.*

The working principle of the Fabry-Pérot interferometer is as follows (cf. Figure 3-6):

1. White light is sent through an optical switch to the sensors where the Fabry-Pérot interferometer is located. In principle, the Fabry-Pérot interferometer is made of two standard multimode optical fibres with the end tips directed towards each other. The tips are covered with a semi-reflecting mirror and have a distance or "cavity length" between that is affected by the pressure.
2. The wavelength-modulated light is reflected back and transported via the switch and through the lens into the analyser which works as an optical cross-correlator.

3. The modulated light is focused by means of the cross-correlator on a certain pixel on a CCD array. This also means that each pixel on the CCD array is associated with a predefined cavity length and hence a corresponding pressure.

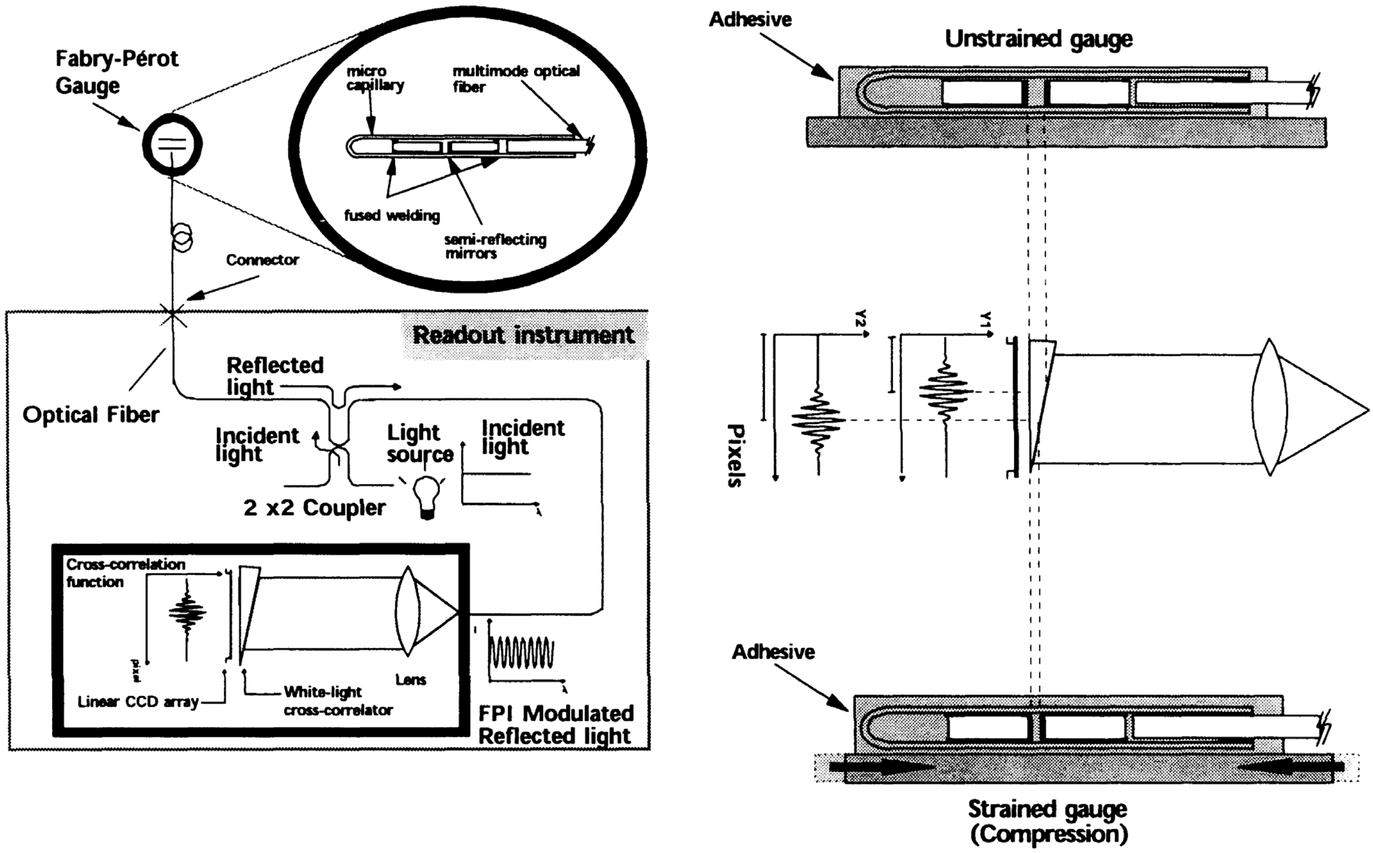


Figure 3-6. Working principle of the Fabry-Pérot interferometer used for pressure or strain measurements.

<u>Selected sensors</u>

The following types were selected:

1. Piezoresistive sensors
2. Vibrating wire sensors

The maximum length of the temperature sensor including cabling is about 100 m and the average length 75 m. Extension cables are placed in sealed protection tubes. which are sealed against the surroundings.

The measuring system includes gauges, signal cables, electronic units and necessary equipment for data processing and will produce results in the form of output signals of 4-20 mA or a binary signal through a serial communication device.

Electrical and signal cables resist the specified pressure and are protected against water leakage after moisture saturation, or placed in tubes that protect them against mechanical damage and water leakage. The gauges are protected against mechanical damage from the surrounding material.

The total number of total pressure gauges and porewater pressure sensors in the Prototype Repository is 128 in Section I and for Section II 120, respectively. The type, number and location of sensors are summarized in Sections 5 and 6.

3.5 Cables and tubings

Protection tubes of titanium are used in the buffer where the temperature is expected to reach 100 °C. Fittings are of type Swagelok and made of titanium. Signal cables will be located in protection tubes of Tecalan (polyamide 1 and 12) in the drift and also in the lead-throughs from the tunnel.

In principle separate signal cables are used for connecting the sensor to the data collecting equipment outside the tunnel. Some measurement systems require short cables and some electronically equipment will therefore be encased in waterproof cabinets of corrosion-proof material and placed in the tunnel. This is the case for the moisture measurement sensors of capacitivity type and the TDR sensors.

Lead-throughs for cables and tubes have been built in the rock between the Prototype Repository drift and the G drift. They consist of tubes with sealed flange joints like in the Backfill and Plug Test.

Most of the cables from the deposition hole to the G drift are located in protection tubes (one for each sensor) which are evenly distributed in the gap between the bentonite blocks and the rock wall. Some cables are placed in protection tubes in vertical slots in the rock wall (three slots in total, one for each instrumented level).

Table 3-5 shows the numbers and cables for the fibre optic temperature measurement system DTS/FTR.

Table 3-5. *Cable lengths for optical fibre optic temperature measurement system DTS/FTR.*

	Section I	Section II
Number of cables		
Number of deposition holes	4	2
Number of cables on each canister surface	2	2
Total number of cables	8	4
Deposition hole		
Cable spacing, m	1	1
Hole depth, m	8	8
Hole diameter, m	1,75	1,75
Canister length, m	4,8	4,8
Canister diameter, m	1,05	1,05
Number of parallel slots on canister surface	4	4
Cable length on the canister surface, m	22,50	22,50
Additional cable length	200	200
Total cable length, m	222	222
Total		
Total length of cable, m	1780	890

4 MEASURING POINTS IN THE TEST DRIFT

The number of measuring points is summarized in Table 4-1. It should be noticed that temperature measurements using the distributed optical fibre measurement system, DTS/FTR, yield an average temperature along a line rather than at a specific point.

Table 4-1. *Number of measuring points and their distribution among different measuring quantities.*

Part of the drift, type of recording	Drift	Deposition holes	Total number
Section I			
Temperature	20	64	84
Total pressure	20	56	76
Pore water pressure	24	28	52
Water content	45	74	119
Total number	*109*	*222*	*331*
Section II, planned			
Temperature	16	68	84
Total pressure	16	56	72
Pore water pressure	20	28	48
Water content	32	74	106
Total number	*84*	*226*	*310*

Where possible, two measuring principles are used for each measuring quantity both in the tunnel and the deposition holes. Some measuring principles for moisture measurement are not suitable in all cases. The capacitive sensor for relative humidity measurements has a high uncertainty in the range 95 to 100 % RH. This measuring principle gives a low accuracy when the backfill and buffer are close to saturation. Soil psychrometer, on the other hand, is not suitable for use in soil materials where the relative humidity is lower than 95 %. TDR may be difficult to use for measurement of water content gradients because of the probe design.

The two measuring principles for temperature measurements that were selected are the distributed optical fibre temperature measurement system (DTS/FTR) and thermocouples. Temperature sensors are also built into pressure and relative humidity sensors.

For measuring the canister surface temperature optical fibre systems with several fibre cables will be used in order to get redundance (cf. Table 3-5).

5 SELECTION OF MEASUREMENT PRINCIPLES AND DISTRIBUTION OF SENSORS

The measuring principles and the distribution of sensors are shown in Table 5-1. Table 5-2 gives data of the sensors.

Table 5-1. *Measuring principles used for instrumentation of the Prototype Repository*

Measuring quantity	**Measuring principle**	**Number of sensors in Section I**		**Planned number of sensors in Section II**	
		Tunnel	**Deposition hole**	**Tunnel**	**Deposition hole**
Temperature	Thermocouple	20	64	16	64
	Fibre optic (DTS/FTR)	0	8	0	4
Total pressure	Vibrating wire	10	28	8	28
	Piezoresistive	10	28	8	28
Pore water pressure	Vibrating wire	12	14	10	14
	Piezoresistive	12	14	10	14
Water content	Relative humidity (capacitive method)	0	74	0	74
	Soil psychrometer	45	0	32	0
Total		109	230	84	226

Table 5-2. *Sensor data.*

	Material in sensor	**Number of sensors in Section I**
Temperature		
Thermocouple	Cupro-nickel	84
Fibre optic (DTS/FTR)	Inconel 625	8 (cables)
Total pressure		
Vibrating wire	Titanium in deposition holes and AISI 316 in tunnel	38
Piezoresistive sensors	Titanium	38
Pore water pressure		
Vibrating wire	Titanium in deposition holes and AISI 316 in tunnel	26
Piezoresistive sensors	Titanium	26
Water content		
Relative humidity (capacitive method)	Protection tubes of titanium	74
Soil psychrometer	Protection tubes of titanium	45

The basis for the selection of measuring principles is as specified in Table 5-3.

Table 5-3. *Basis for selecting measuring principles and types of sensors.*

Measuring principle	Motivation
Thermocouples	1. Reliable technique 2. Low cost 3. Sufficiently long-term stable at the temperatures expected in the Prototype Repository 4. The sensor (i.e. joint) and thermocouple wire are covered by a metal sheath which protects against water leakage and in some extent from electromagnetic fields 5. The sheath is made of Cupro-Nickel which probably is sufficiently corrosion-resistant in the environment expected in the Prototype Repository
Optical fibre temperature measurement system, DTS/FTR	1. Temperature profiles can be monitored easily 2. Small dimensions 3. Gives a large amount of information in relation to the number of cables 4. Protection tube is made of Inconel 625 which probably is sufficiently corrosion-resistant in the environment expected in the Prototype Repository 5. Insensitive to electromagnetic interference
Vibrating wire for total pressure and pore water pressure	1. Reliable technique 2. The sensor housing and pressure diaphragm can be made of titanium 3. The measuring signal is composed of a frequency of a varying voltage and is completely insensitive to electromagnetic interference 4. The sensor has no built-in electronics 5. Long-term stable 6. The sensor can be equipped with a built-in thermistor
Piezoresistive for total pressure and pore water pressure	1. The sensor housing and pressure diaphragm can be made of titanium 2. The method is probably long-term stable 3. The sensor has small dimensions 4. The cable has a small dimension and be laid in a protection tube made of Inconel 625
Capacitive sensor for measuring relative humidity in pore volume	1. The probe contains limited or no electronics 2. The probe has small dimensions 3. The probe can be equipped with a built-in temperature sensor of type Pt 100 4. Large measuring range (however slightly less accurate in the range of 95-100 % relative humidity)
Soil psychrometer for measuring dry and wet temperature in pore volume	1. Low cost 2. High accuracy at high relative humidity expected in the backfill material

Table 6-1 shows a list of suppliers of measuring equipment and the different measuring principles that were selected for the experiment.

Table 6-1. *List of suppliers of the instrumentation.*

Variable	Measuring principle	Supplier	Country	Representative in Sweden
Temperature	Vibrating wire	Geokon	USA	Bemek
	Thermocouple	Roctest	Canada	
		Geokon	USA	Bemek
		Pentronic	Sweden	
		Glötzl	Germany	
		Fisher-Rosemount	Sweden	
		BICC Thermoheat	England	
	Resistive temperature sensor	Rotronic	Switzerland	
		Glötzl	Germany	
	Fibre optic	Roctest	Canada	
		BICC Thermoheat	England	
		York Sensors	England	
Total pressure and pore water pressure	Hydraulic pressure cells	Glötzl	Germany	
	Piezoresistive sensors	Geokon	USA	Bemek
		Kulite	Holland	Sensotest
		Roctest	Canada	
	Vibrating wire	Geokon	USA	Bemek
		Roctest	Canada	
		Glötzl	Germany	
		Geonor	Norway	
	Fibre optic sensors	Glötzl	Germany	
		Roctest	Canada	
Water content	TDR	Nagra	Switzerland	
		Environmental Sensors	Canada	
		Soilmoisture Equipment	USA	Geologic
	Capacitive sensors	Rotronic	Switzerland	
		Vaisala	Finland	Vaisala
	Soil psychrometer	Wescor	USA	
	Resistive sensors	Clay Technology and LTH	Sweden	

7 COLLECTION AND PRESENTATION OF RESULTS

An intelligent measuring unit, Datascan, is used for collection of measurement results together with special data loggers for soil psychrometers and vibrating wire sensors. It has two units, one for analogous channels and one for digital channels. The maximum number of analogues channels per unit is 16. Several units can be connected to each other, forming a data acquisition system for 1,000 channels. A PC is communicating with the system by means of the RS-232 or RS-485 port. Thermocouples, Pt 100 sensors, piezoresistive pressure sensors etc. can directly be connected to a Datascan unit.

A software program, Orchestrator, is used for storing and presentation of measurement result. The standard version of Orchestrator contains a driver for communication with a Datascan system. Drivers are also available for other manufactures such as Campbell Scientifics loggers of type CR7 and CR10, which are often used in combination with soil psychrometers and vibrating wire pressure sensors, which require some control. It may be necessary to develop drivers or software components for other measuring equipment.

Special measuring system as optical fibre measurement systems require special software for configuration of the measurements. The software will also include special tools for graphical presentation of the measurement result. This type of software is to be regarded as a complement to Orchestrator.

The data acquisition system consists of a number of Windows NT or Windows 95/98 computers forming a workgroup. Techniques as NetDDE and DCOM are used for interprocess communication between different computers in the network.

8 ACKNOWLEDGEMENTS

This report is based on documents prepared by Mats Collin and the staff of Clay Technology AB, IDEON, Lund, Sweden.

9 REFERENCES

[1] Svemar C, Pusch R, 2000. Prototype Repository, Project description FIKW-CT-2000-00055. Int. Progress Report IPR-00-30, SKB, Stockholm.

[2] Sande´n T, 2001. Prototype Repository, Additional measurements in buffer and backfill. Activity Plan AP TD F63-01-054