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Wireless sensor network demonstrator report

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Author(s): **AITEMIN**

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1. Background: Modern Project

The MoDeRn project aims at providing a reference framework for the development and possible implementation of monitoring activities and associated stakeholder engagement during relevant phases of the radioactive waste disposal process i.e. during site characterisation, construction, operation and staged closure, as well as a post-closure institutional control phase.

Several demonstrators are included within the project to achieve its objectives. This document focuses on the explanation of the layout of the installed High Frequency Wireless (HFW) demonstrator, located at the Grimsel Test Site (GTS).

More information on the project and the demonstrator can be found in the “HFW demonstrator design plan” [1].

2. High Frequency Wireless Demonstrator

2.1 Objectives

The main objective of this installation is to demonstrate and analyse the capability of the HFW sensor network developed under MoDeRn Task 2.3 under realistic conditions i.e. embedded in the engineered barrier system.

2.2 Experimental configuration

2.2.1 General Layout of the Demonstrator

The Grimsel Test Site or GTS is at an elevation of 1,730 metres above sea level, around 450 metres depth below the surface of the Juchlistock in central Switzerland. It is linked with the northern Grimsel Pass by a short approach road and a 1.2 km horizontal access tunnel which leads to the Test Site. Despite the sometimes harsh alpine winter, all-year-round operation is guaranteed by the infrastructure of the power station company (KWO) which operates a tunnel railway and an aerial cable car when the pass road is closed.

The layout of the GTS consists of a 1000 m long branching laboratory tunnel and a central building which houses the whole infrastructure such as offices, the ventilation plant, workshops and so on. Figure 1 shows the locations of the most important experiments performed in the GTS. The laboratory tunnel has a diameter of 3.50 metres and was bored in six months using a full-face tunnelling machine (TBM).

The low-pH plug test built during ESDRED IP project is located at the end of the VE tunnel, close to the GMT experiment (marked with a red circle in Figure 1 and Figure 2 below)

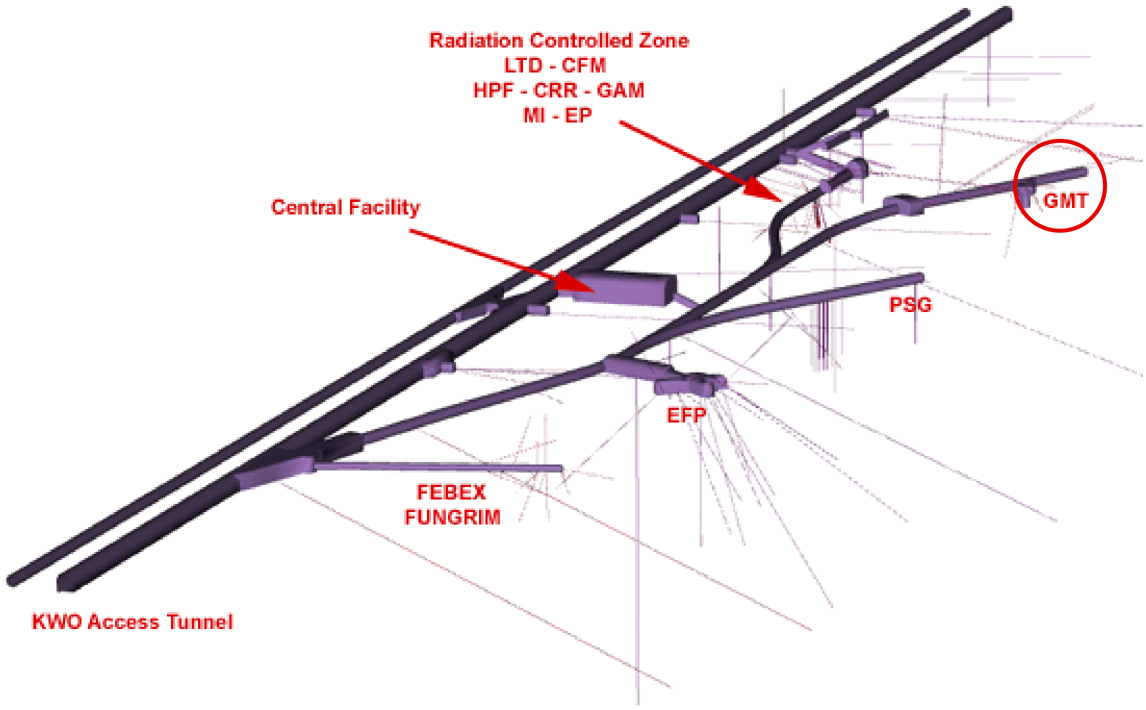

Figure 1: Layout of Grimsel Test Site (Source: NAGRA [3]).

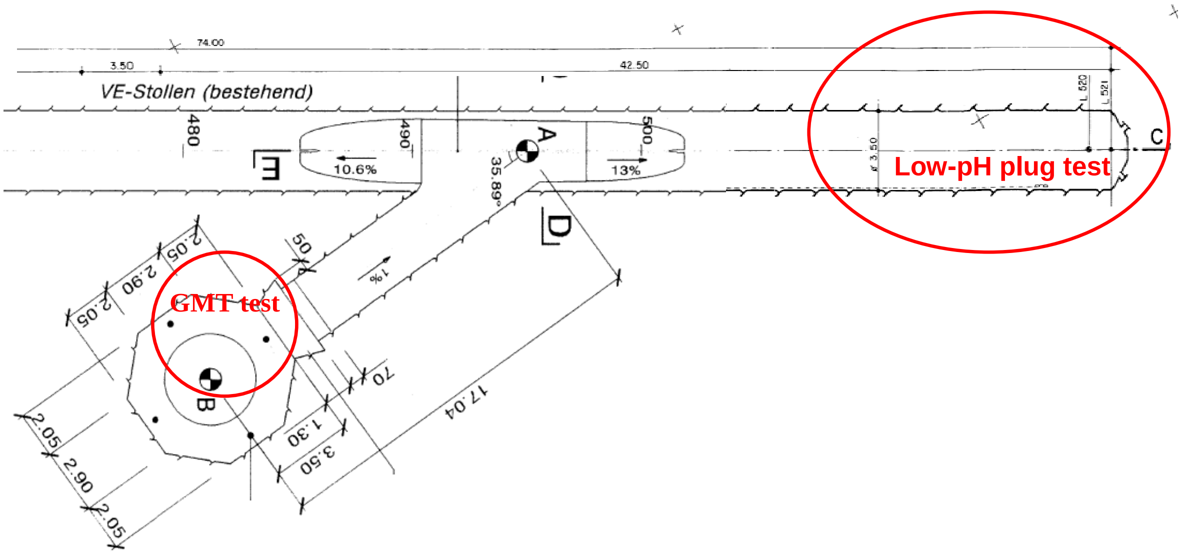

Figure 2: Location of the full-scale test in VE tunnel.

The basic layout of low-pH plug test consists of a 4 m long parallel shotcrete plug constructed at the back end of a 3.5 m diameter horizontal gallery, excavated in granite with a TBM and sealed with 1 m of highly compacted bentonite (see Figure 3). The bentonite was provided with an artificial hydration system to accelerate the saturation process.

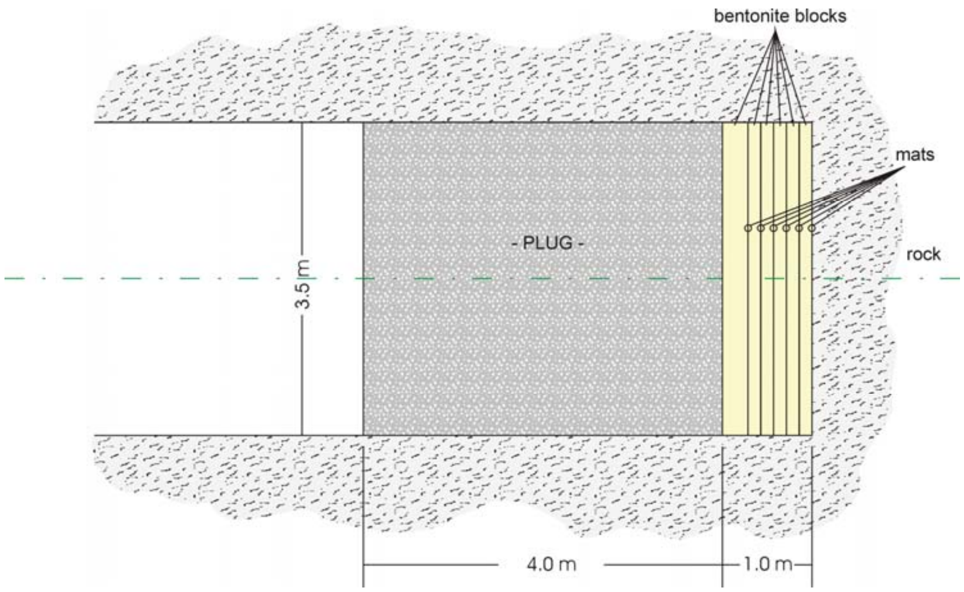

Figure 3: General layout of the full-scale test.

To monitor the performance during the test, a number of sensors were installed at different locations in the rock, in the bentonite and in the shotcrete mass: total pressure cells, humidity sensors of different types, piezometers and displacement sensors (see Figure 4 below). The sensors are mainly conventional (wired) ones but a number of them were connected to a wireless transmission system. These wireless transmitted sensors were installed as a part of the TEM Project, which is run by NAGRA at the GTS URL.

The sensors were connected, through the necessary data acquisition units, to the main DADCS for the monitoring and management of the test, which worked in unattended mode and could be contacted via a modem for remote supervision.

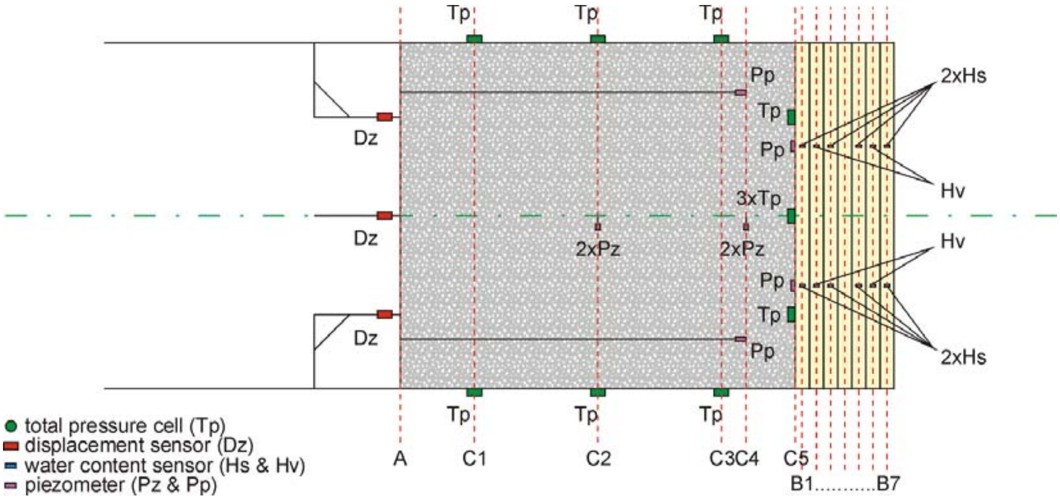

Figure 4: Layout of instrumentation (wired transmitted sensors only).

Additionally, NDA and ETH installed a non-intrusive monitoring system. It consisted in the performance, from six linear boreholes (each 25 m long) excavated around the gallery, of different series of non-intrusive seismic tomography measurements along the lifetime of the experiment – this work has continued within the MoDeRn project [3]. In addition, 25 single-component geophones with a natural frequency of 100 Hz were installed at the front face of the concrete plug.

2.2.2 Installation procedure

2.2.2.1 General info and preliminary works

The HFW system was installed at the GTS after the end of MoDeRn Task 2.3. This task consisted of selecting a number of pre-candidate frequencies to be used, and testing their penetration capabilities through different materials, first in laboratory set-up and afterwards in field scenarios. As a result, the best frequency was selected and the communication system was designed [2]. Subsequently, a total of six HFW sensing units, a receiver and a controller were produced (see Figure 5). The main specifications of the nodes are as follows:

- VHF band MHz radio transceiver;
- Inputs for up to 6 general purpose sensors [0-2v, 0-10v, 4-20mA, digital];
- Robust, compact and high pressure resistant reinforced polyester enclosure;
- Built-in lithium battery. Expected life time: 1-25 years (depending of the specific application requirements);
- Dimensions: 190 x Ø75 mm

Figure 5: Left, wireless nodes and receiver unit; right, controller unit.

Main specifications of the controller unit are:

- VHF band MHz radio transceiver;
- Up to 16 wireless nodes management;
- 5.4” TFT graphic display and friendly user interface for real time data visualization;
- Configuration parameters and data accessible both locally and remotely via Ethernet, Internet (built-in web server), MODBUS-TCP, etc.;
- IP54 plastic-metallic enclosure;
- Wide input voltage [9-24v] and low power consumption.

Figure 6 shows a sketch of a node, which can measure pore pressure, total pressure, relative humidity and temperature. Finally only five nodes were planned to be installed [1], two of them to be installed in the bentonite to measure pore pressure, total pressure and relative humidity, whereas the other three nodes had to be placed in the rock and the shotcrete plug, measuring pore pressure only.

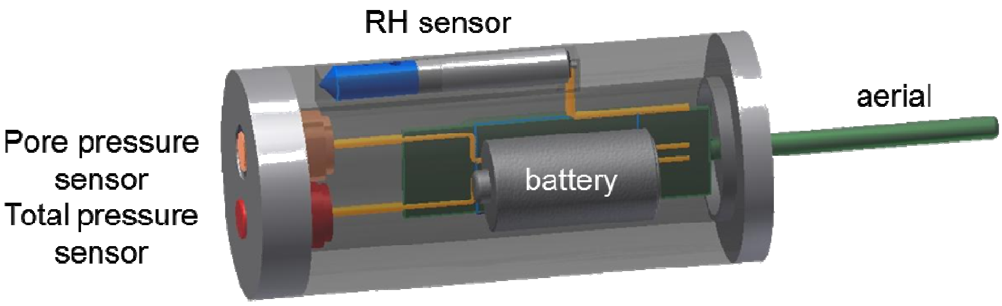

Figure 6: Sketch of a HFW node.

2.2.2.2 Boreholes drilling

Five boreholes were drilled by the end of October 2011, four at the plug and one in the rock, to house the five foreseen nodes. The boreholes have an inner diameter of approximately 86 mm in order to house the HFW nodes, which are built within a plastic cylinder of 80 mm in diameter. The position of the different boreholes is consistent with the developed plans, which were slightly modified after "MoDeRn HFW Demonstrator Design Plan" due to operational reason and can be seen in Figure 7.

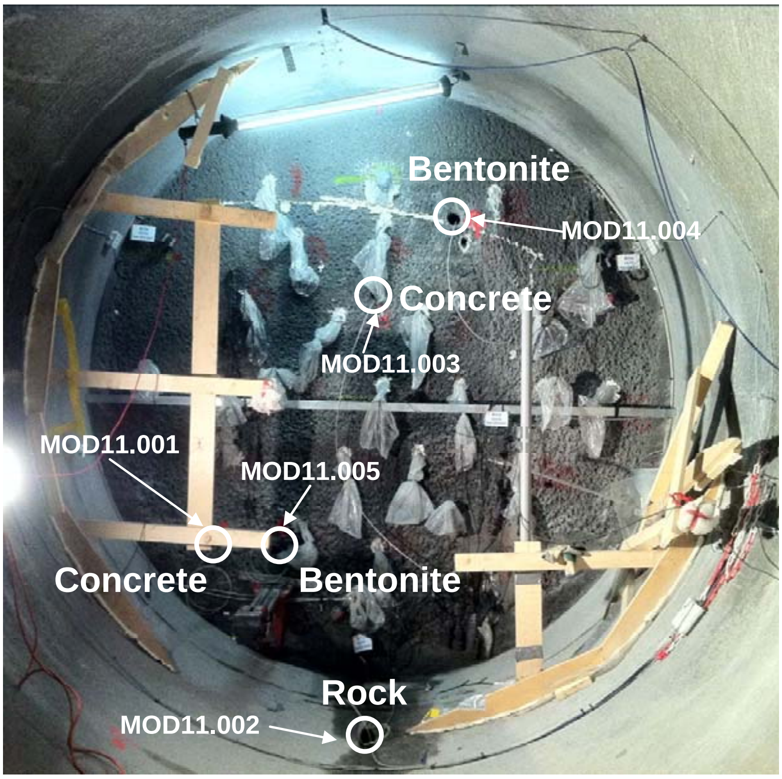

Figure 7: Position of the five different boreholes.

A summary of the boreholes follows:

- MOD11.002 is the only sloped one, it begins by 1 metre in front of the plug and has a length of 4 metres within the rock floor.

- MOD11.001 and MOD11.003 are horizontal boreholes ending in shotcrete, about 3.6 metres long each.

- MOD11.004 and MOD11.005 are also horizontal but reaching the bentonite, with a length of slightly more than 4.0 metres each one.

2.2.2.3 Units installation and tests

After the boreholes were finished, during the first week of November 2011, the HWF nodes were manually installed in them (see Figure 8) and several tests were performed to assess the viability of the system:

Figure 8: Detail of node installation.

- A first set focused on transmission through plug performance (signals' mapping).
- In the next step, a small sensor node network was established, including a receiver and a controller connected to the main DAS. The proper behaviour of intercommunication between devices and data gathering was assessed.

The signals from the five HFW nodes (check layout in next section) are gathered at the open gallery in the reception unit and integrated, via the controller, into the existing AITEMIN data monitoring and control system (SCADA based).

2.2.2.4 Grouting of boreholes

As a final step, the boreholes housing the nodes were filled up with a concrete based filling grout, on March 2012. Data transmission performance was again checked after this final step and no problems were observed.

Figure 9: Detail of node installation.

2.2.3 Final layout of the Monitoring System for the HFW Demonstrator

The demonstration exercise comprised the installation of five HFW based sensing units. Two of them were installed in the bentonite buffer through boreholes drilled in the shotcrete plug. The parameters being measured in these units are: pore pressure, total pressure and water content (relative humidity) The remaining three sensing units were installed in the concrete plug and in the rock mass, two of them to measure pore pressure in the plug and the last one measures pore pressure in the rock around the bentonite buffer (below the plug). A scheme of the overall layout including the precedent instrumentation is shown on Figure 10.

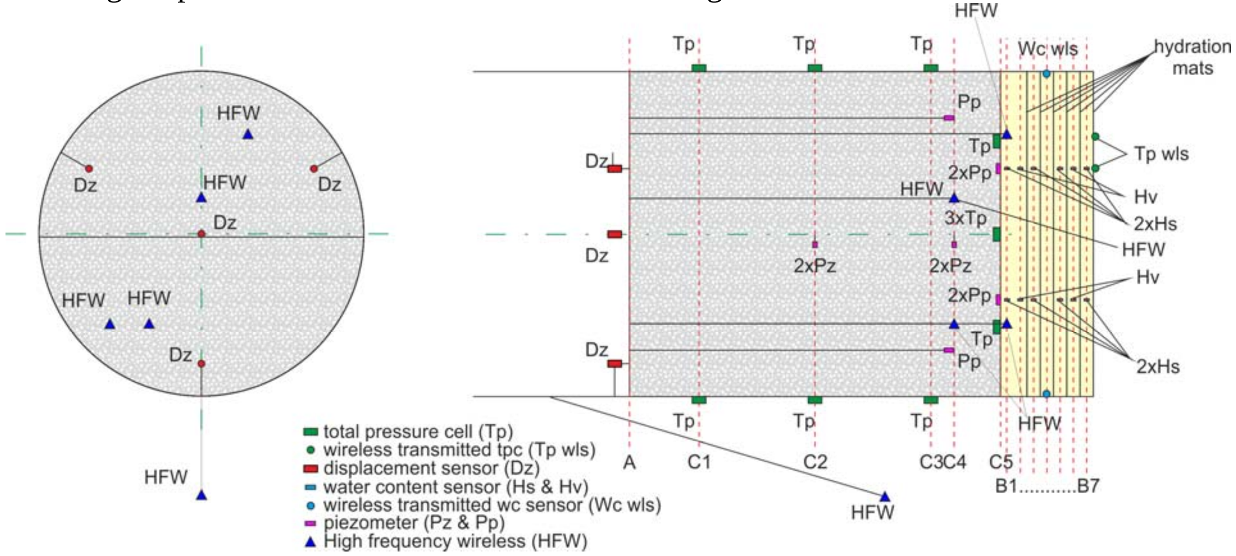

Figure 10: Layout of installed instrumentation (including HFW).

Overall data trends of installed HFW sensors can be obtained and also compared to the other monitoring systems installed in and around the plug. Figure 11 depicts an example of the total pressure values gathered from the HFW nodes until April 2012.

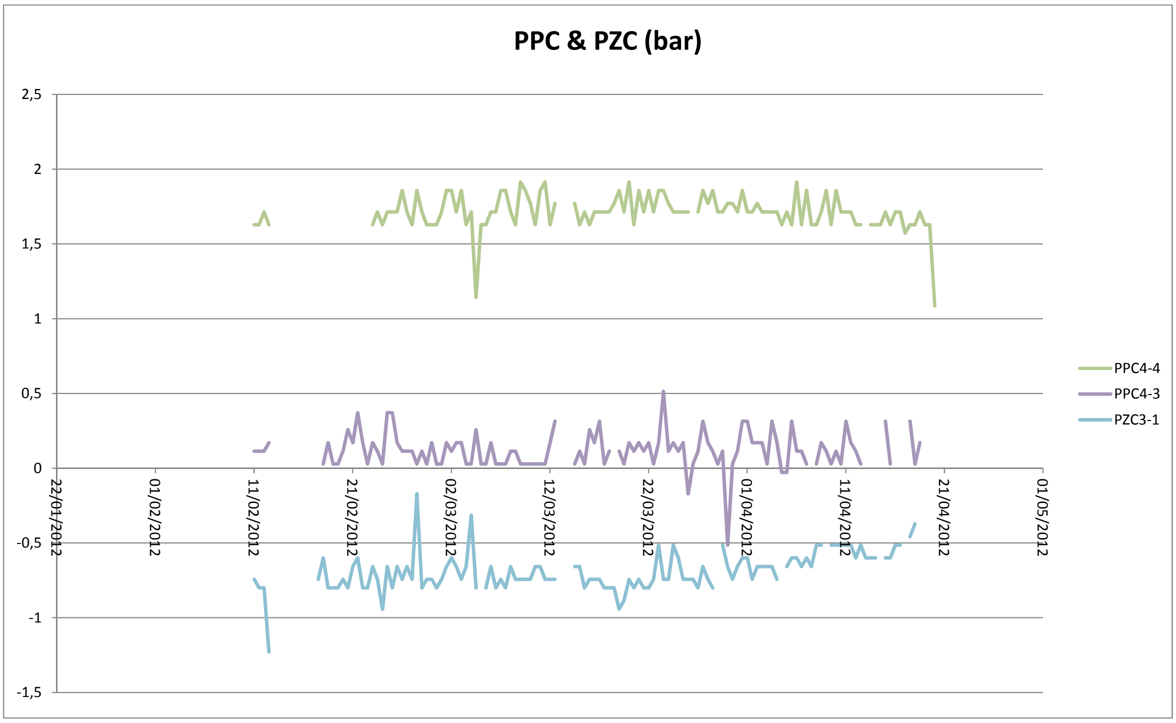

Figure 11: Example of data gathered from HFW nodes.

2.2.4 Evaluation of HFW system performance

The up-to-date performing of the HFW system can be summarized in the following points:

- All nodes installed are transmitting successfully.
- Data is being collected and stored correctly.
- Bentonite is already pressing the HFW nodes.
- Sealing of boreholes has not significantly affected signals' transmission.

It would be appropriate to extend the monitoring time beyond the duration of the MoDeRn Project to assess that the HFW system can continue to perform over long periods of time.

2.3 Conclusions

The following conclusions can be extracted from the behavior of the system so far:

- The HFW network system installation is quick and easier than a wired one.
- It is also easily integrated in proven acquisition systems and/or softwares.
- The system performance/communication capability when installed within a realistic environment (concrete plug) is appropriate.
- The sensing nodes are able to integrate a range of sensors so that different physical effects can be measured in the same emplacement.
- Durability of the system performance seems good but needs to be assessed over longer time periods.

3. References

[1] Bárcena, I. et al. MODERN HFW Demonstrator Design Plan version 1. May 2011.

[2] MoDeRn 'Development Report of Monitoring Technology', MoDeRn Deliverable D2.3.1, 2013.

[3] Grimsel Test Site website: www.grimsel.com

[4] MoDeRn 'Seismic Tomography at Grimsel Test Site', MoDeRn Deliverable D3.2.1, 2012.