FINAL REPORT of WORK PACKAGE 2

Grant Agreement number:	**269 905**
Project acronym:	**LUCOEX (WORK PACKAGE 2)**
Project title:	**Large Underground Concept Experiments**
Funding scheme:	**Collaborative projects – CP**
Period covered:	**2010-10-24 to 2015-09-30**
Scientific representative:	**Dr. Hanspeter Weber**
Organisation:	**Nagra**
Tel:	**+41 56 4371 111**
Fax:	**---**
E-mail:	**hanspeter.weber@nagra.ch**
Project website address:	**http://www.lucoex.eu/**

EUROPEAN COMMISSION

Community research

This Project has received funding from the European Union's European Atomic Energy Community's (Euratom) FP7 under grant agreement n°269905, the LUCOEX project.

LUCOEX

(GRANT AGREEMENT: 269905)

DELIVERABLE (D-N°: D2.6)
LUCOEX - Final Report of WP2

Authors (all from Nagra):
Herwig R. Müller, Benoit Garitte, Sven Köhler, Tobias Vogt
Toshihiro Sakaki, Hanspeter Weber, Tim Vietor

Date of issue of this report: **12/06/2015 (draft)**

Start date of project: 01/01/11 Duration: 56 Months

Project co-funded by the European Commission under the Seventh Euratom Framework Programme for Nuclear Research &Training Activities (2007-2011)		
Dissemination Level		
PU	Public	**PU**
RE	Restricted to a group specified by the partners of the LUCOEX project	
CO	Confidential, only for partners of the LUCOEX project	

EURATOM

Summary

Introduction and experimental aims

The Full-Scale Emplacement (FE) Experiment at the Mont Terri underground rock laboratory (URL) is a full-scale multiple heater test in a clay-rich formation (Opalinus Clay). It simulates the construction, waste emplacement, backfilling and early post-closure evolution of a spent fuel (SF) / vitrified high-level waste (HLW) repository tunnel as realistically as possible. The main aim of this experiment is to investigate SF / HLW repository-induced thermo-hydro-mechanical (THM) coupled effects on the host rock at this scale and to validate existing coupled THM models. Further aims are a) the verification of the technical feasibility of constructing a repository tunnel using standard industrial equipment, b) the optimisation of the bentonite buffer material production and c) the investigation of (horizontal) canister and buffer emplacement procedures under underground conditions. Nagra participated in the EU project LUCOEX as Work Package (WP) 2 with the tasks covering these further aims.

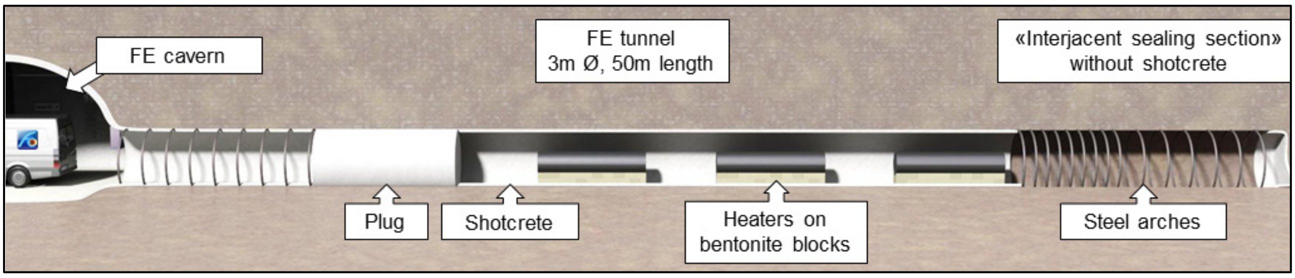

Figure 1: Visualisation of the general experiment layout of the Full-Scale Emplacement (FE) experiment at the Mont Terri URL; sensors and bentonite backfill are not displayed.

Experiment layout

The FE Experiment is based on the Swiss disposal concept for SF / HLW. The construction of the 50 m long experiment tunnel with a diameter of approx. 3 m was completed in September 2012. At the deep end of the tunnel, the so-called 'interjacent sealing section' (ISS) was constructed using only steel arches for rock support, while the rest of the tunnel is supported by shotcrete. In the FE tunnel, three heaters with dimensions similar to those of waste canisters were emplaced on pedestals built of bentonite blocks (see *Figure 1*). The remaining space was backfilled with a highly compacted and granulated bentonite mixture (GBM). Finally, the experiment was sealed off towards the FE cavern with a concrete plug holding the buffer in place and reducing air and water fluxes.

THM instrumentation

The entire experiment implementation as well as the post-closure THM(C) evolution is monitored using several hundred sensors in the geological as well as in the engineered barriers. The rock in the 'far-field' was instrumented with boreholes up to 45 m long drilled from the FE cavern; this instrumentation was completed in April 2012 before the FE tunnel was built and therefore allowed a 'mine-by' observation of the later tunnel construction. Up to February 2014, the 'excavation damage zone' was instrumented with radial boreholes drilled from within the FE tunnel. In June 2014, the instrumentation of the tunnel wall was completed for future monitoring of the bentonite buffer. At this stage, numerous fibre optical cables for distributed temperature and deformation monitoring were also installed. More sensors for the observation of the bentonite buffer in close proximity to the heaters were installed together with the heaters.

The instrumentation allows the THM evolution of the entire system as a whole to be followed. Using various technologies, a dense spatial arrangement and multiple heaters, the instrumentation offers a high degree of redundancy and enables an in-depth observation of the THM interaction of all barrier elements. The technologies used may provide input towards designing a monitoring arrangement in a future pilot repository as foreseen in the Swiss concept.

Bentonite buffer production

After re-assessing the range of possibilities for backfilling materials, only natural (non-activated) sodium bentonite from Wyoming was used for the FE Experiment. First, bentonite block test productions were performed with variation of different production parameters to optimise density and water content and therefore the mechanical stability and long-term integrity of the blocks. Thereafter, approx. 3,000 highly compacted bentonite blocks, each with an average weight of approx. 24.5 kg, an average dry density of approx. 1.78 g/cm^3 and an average water content of approx. 18 %, were produced for filling a 2 m long section in the ISS and for the pedestals below the three heaters. After several parameter optimisation tests, approx. 350 tons of a highly compacted and granulated bentonite mixture (GBM) were produced. With several pre- and mock-up tests and the backfilling of the FE tunnel at the Mont Terri URL, it was possible to demonstrate that, using highly compacted bentonite granules ("pellets") with an average dry "pellet" density of approx. 2.18 g/cm^3 and with a very broad "pellet" size distribution, a so-called Fuller-type distribution and an overall bulk dry emplacement density of at least 1.45 t/m^3 (as targeted in the Swiss concept) can be achieved.

Development of a prototype backfilling machine

One challenge was the design and construction of a prototype machine for backfilling horizontal tunnels with GBM as densely and homogeneously as possible. The machine was designed to fit into the small diameter FE tunnel. It transports, emplaces and compresses the GBM using five auger conveyors simultaneously. All relevant parameters such as the backfilling speed and the backfilling pressure can be controlled. The prototype machine was tested successfully in two full-scale pre-tests in May and August 2014. Finally, it was used successfully to backfill the FE tunnel with approx. 255 tons of GBM at the end of 2014 and the beginning of 2015 where a bulk dry density of up to approx. 1.56 t/m^3 was achieved in segments. In the pre-tests, where the density measurements were performed using different methods and with a better special resolution, a 'local' bulk dry density of up to approx. 1.70 t/m^3 was measured close to some auger outlets.

Heating & monitoring

After the emplacement and the consequent backfilling of the first and deepest heater, the heating was started. With an initial heat output of 1,350 Watt per heater, a temperature of approx. 130 – 150 °C at the heater surface and around 60 °C at the rock surface are expected for the FE experiment at Mont Terri after 3 years. According to current planning, the heating and monitoring phase of the FE experiment at Mont Terri is envisaged to last at least 10 to 15 years.

List of Contents

List of Tables

List of Figures

1 LUCOEX WP2

1.1 Context and Objectives

The Swiss waste disposal programme (Nagra 2008a) as approved by the Swiss Federal Government in 2013 foresees the disposal of spent fuel (SF) / vitrified high-level waste (HLW) in a deep geological repository (DGR). In compliance with the existing legal framework, the repository concept comprises a 1 km x 2 km arrangement of repository tunnels. Within the tunnels, carbon steel waste canisters are emplaced horizontally in a centred position on bentonite pedestals. The tunnels are backfilled with granular bentonite in a stepwise procedure after the emplacement of each canister.

Within the framework of the ongoing safety-driven site selection process, the available candidate host rocks in Switzerland were evaluated. In 2011, the Federal Government approved Nagra's proposal to select the Opalinus Clay as the host rock for the SF / HLW repository (Nagra 2008b).

The overall objective of Nagra's participation in the FP7 EURATOM Project LUCOEX was to demonstrate on a 1:1 scale the Swiss repository concept for the disposal of SF and HLW in Opalinus Clay. This participation constitutes Work Package 2 "Full-Scale Emplacement Experiment (FE) in Mont Terri" of the LUCOEX Project. The key elements of Work Package (WP) 2 were conducted at the Mont Terri underground research laboratory (URL) in Switzerland. As the operation of the Swiss SF / HLW repository starting around 2060 is still far in the future, the demonstration was focused on the elements considered relevant for achieving long-term safety.

The following activities form part of the LUCOEX Project and were therefore supported by the European Union:

- Experiment planning
- Construction of the experiment tunnel at the Mont Terri URL
- Manufacturing of the bentonite buffer (blocks and granulated mixture)
- Planning & construction of the emplacement and backfilling equipment
- Off-site and on-site emplacement and backfilling tests & works
- Sealing the experimental drift with a concrete plug
- Reporting

Integration activities were also performed, such as the organisation of workshops and conferences, which also allowed knowledge exchange and networking for new scientists and the employment of students as interns at Nagra and / or Mont Terri.

As stated in Deliverable D2.1 "WORK PLAN for LUCOEX Work Package 2" (see Weber et al. 2012), Nagra's task had the following objectives:

- Providing confirmation of the suitability of the repository design basis in Nagra's concept
- Constructing an emplacement tunnel using standard (or modified) equipment and adequate support measures (anchors, lining and / or steel ribs)
- Manufacturing the bentonite buffer in a suitable form and density
- Designing, manufacturing & testing the in situ equipment required for waste & buffer emplacement

Because one objective of WP2 was also to provide and maintain safe and healthy conditions for working personnel, a strong focus was put on risk assessment and HSE planning, measures and control. Throughout all WP2-related activities, no serious incidents occurred and no one was injured.

WP2 was implemented between 1st of January 2011 and 31st of August 2015, as indicated in the overview of the project timeline in Figure 2.

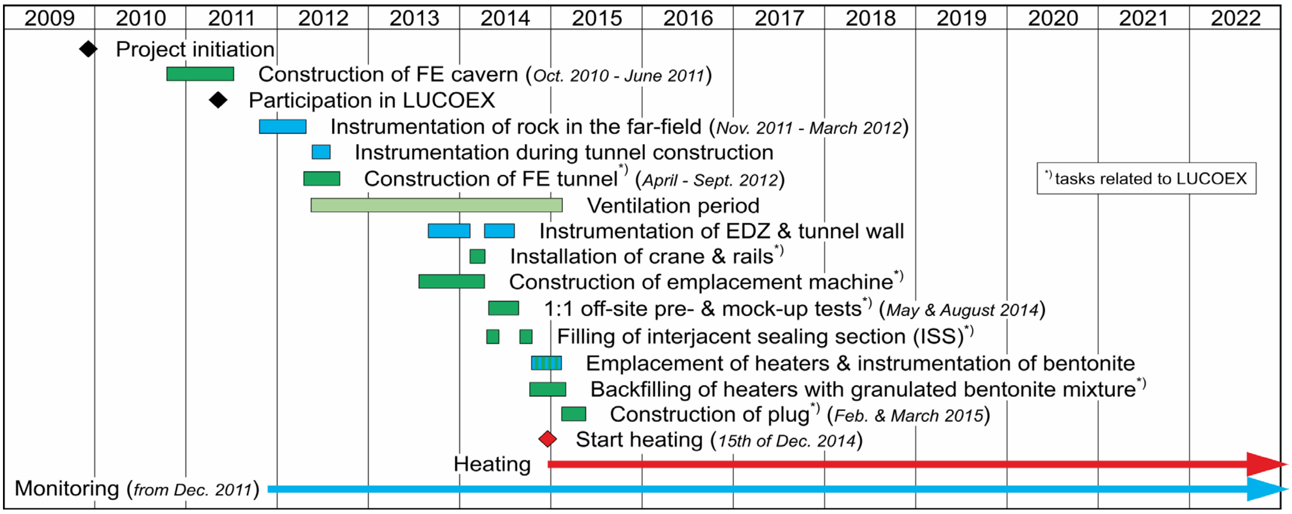

Figure 2: Overview of the implementation timeline of the FE Experiment / LUCOEX WP2.

1.2 Scientific and Technical Results

1.2.1 Geological overview

The underground research laboratory (URL) at Mont Terri is located in the Jurassic fold belt in the north-western corner of Switzerland close to the small town of St-Ursanne. The URL lies in the south-eastern flank of the Mont Terri anticline at a depth of approx. 250 to 300 metres.

The FE tunnel is located in the clay-rich facies of the Opalinus Clay (OPA). The tunnel was constructed parallel to the strike of the bedding, which at this location dips on average with ca. 33° towards SE.

The OPA is an overconsolidated claystone with a uniaxial compressive strength (UCS) of approx. 15 MPa (perpendicular to bedding). At Mont Terri, the rock is partially strongly tectonised and locally even faulted. The FE tunnel encountered such a fault zone around tunnel metre (TM) 15. The core zone of this fault zone had a normal thickness of up to approx. 1 metre. The fault was orientated roughly bedding-parallel and therefore remained within the tunnel cross-section until TM 50.

1.2.2 Instrumentation before the tunnel construction

The rock mass in the 'far-field' was instrumented with 45-metre long boreholes drilled from the FE cavern. This instrumentation was completed in April 2012 before the FE tunnel was built and therefore allowed a 'mine-by' observation of the later tunnel excavation. In two boreholes, drilled sub-parallel to the axis of the FE tunnel, horizontal inclinometer chains were installed. In 3 boreholes drilled parallel to the bedding and in 3 boreholes drilled perpendicular to the bedding, multipacker systems with a total of 36 pore pressure monitoring intervals were implemented.

During construction and up to February 2014, the 'excavation damage zone' (EDZ) was instrumented with radial boreholes drilled from within the tunnel. This instrumentation phase started with five radial extensometers installed already during the excavation of the tunnel (sections E1 and E2 in *Figure 3*).

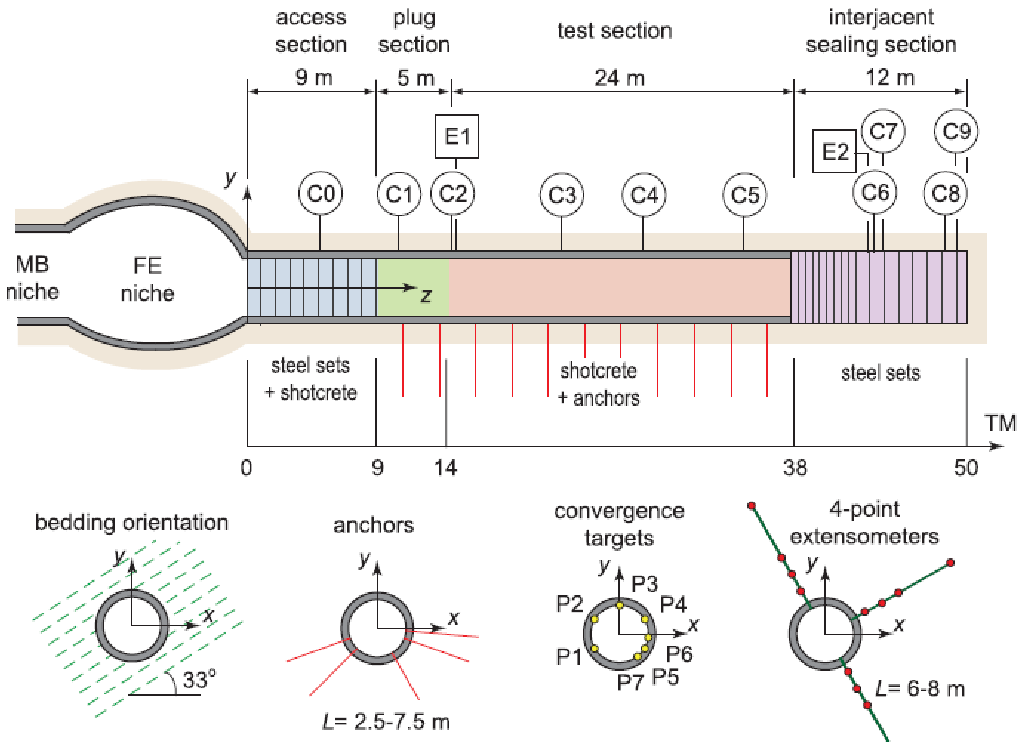

Figure 3: Simplified longitudinal cross-section of the FE tunnel showing the installed support measures, the convergence measuring sections (C0 to C9) and the location of the radial extensometers (E1 and E2) installed during tunnel construction (from Lisjak et al. 2015).

Additionally, the tunnel construction was surveyed with a total of ten convergence measurement sections which were installed with an average spacing of approx. 6 metres during the excavation within the FE tunnel. In measurement sections C1 to C4 (see *Figure 3*), the radial configuration consisted of five observation targets; in measurement sections C5 to C9 the radial configuration consisted of seven observation targets. In total, 55 observation targets were installed. These targets were continuously monitored not only during the tunnel construction but also for a long period thereafter. In fact, the targets were only removed shortly before backfilling the FE tunnel at the end of 2014.

For further details about the instrumentation, see Müller et al. (2015).

1.2.3 Tunnel construction

The 50 metre long FE tunnel was excavated full-face between April and July 2012. The excavated tunnel diameter was approx. 3 metres. The excavation method consisted of a combination of pneumatic hammer and a small road-header which was mainly used for profiling (see *Figure 4*). The excavation speed varied between 1.0 and 1.5 metres per day.

Figure 4: Photo (by COMET) of the small road-header used in the FE tunnel mainly for profiling.

Figure 5: The photo on the left shows the 12 m long shotcrete-free 'interjacent sealing section' (ISS) at the end of the FE tunnel; the photo on the right shows a detail of a steel arch in the ISS.

The steel arches were bedded on flexible grout-injected hoses in order to allow load transfer from the rock onto the support after hardening of the grout. Each steel arch was composed of several pieces with sliding connections which were tightened by bolts.

From TM 0 to TM 38, the support in the tunnel consisted of mesh reinforced shotcrete (see *Figure* 3). Between TM 9 and TM 38, the shotcrete was applied in 2 layers with a total thickness of at least 16 centimetres. The dry application method was used (adding water at the spraying nozzle). 40 % of the Portland cement was substituted by silica fume in order to obtain a shotcrete with a reduced pH value.

The deep end of the FE tunnel (from TM 38 to TM 50) was built using only steel arches and no shotcrete for rock support (see *Figure 5*). With this, the so-called 'interjacent sealing section' (ISS) of a repository tunnel according to the Swiss concept was simulated. In the FE tunnel, the spacing of the steel arches was normally 1 metre (but 0.5 metres close to the end of the shotcrete section). Each steel arch was composed of several pieces with sliding connections which were tightened by bolts with a 300 Nm torque spanner, allowing some movement even after installation (see Daneluzzi et al. 2014).

Whereas the steel arch section showed normal deformation rates and a more or less symmetric tunnel wall convergence, the shotcrete section was initially characterised by asymmetric deformations with a convergence of several centimetres at the lower right side of the tunnel (*Figure 6*).

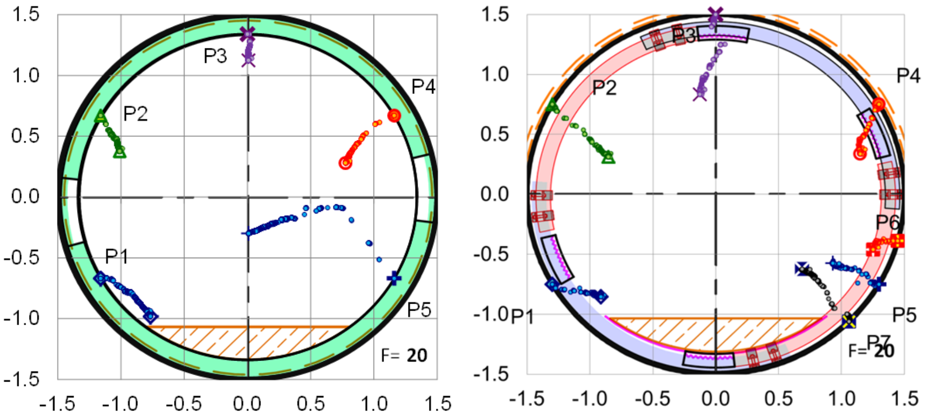

Figure 6: 90-day tunnel wall convergences at two example measurement sections C4 (left graph) and C7 (right graph).

C04 was located in the shotcrete section of the tunnel and C07 in the shotcrete-free section supported only by steel arches. The scale of the displacement vectors is amplified by a factor of 20 with respect to the excavated tunnel represented by a black circle.

Figure 7: Photo from the failed shotcrete invert (right of the dashed white line) before the renovation in September 2012.

Because of the observed deformation rates, 7.5 metre long (steel) rock bolts were installed in the lower right side wall of the shotcrete section. Nevertheless, the shotcrete in the invert failed (see *Figure 7*) and had to be renewed. The renovation of the tunnel section TM 9 to TM 38 was completed in September 2012. The old shotcrete was removed segment by segment and new (mesh reinforced) shotcrete was applied.

During the renovation, extra 7.5 metre long (steel) rock bolts were installed in the right side wall of the FE tunnel. This was done in a pattern which reduced the risk of the interface between the old and the new shotcrete becoming a potential weakness of the tunnel lining. In the tunnel wall on the left side, 2.5 metre long (fibre-reinforced plastic) rock bolts were installed in the same pattern.

The failure of the shotcrete invert was mainly caused by an irregular, not perfectly circular excavation profile and by the resulting shear and bending forces in the lining. An intensive coring and lab testing programme also showed that the shotcrete in the invert did not have the required quality (although the strength[*)] targets were clearly met in the upper part of tunnel). Loose muck and rebound below the invert as well as layering within the shotcrete were detected. The shotcrete in the invert was also partially too unevenly and thinly applied, locally even of crumbling appearance and therefore too weak.

Seemingly these circumstances contributed more to the failure of the invert than the properties of the faulted and tectonically weakened rock mass. This theory is supported by the observation that, although the ISS was built in the same geological setting as the shotcrete section, the steel arch section generally showed a homogeneous tunnel wall convergence and lower deformation rates.

With the renovation work, the deformation rates in the shotcrete section were, if not stopped, greatly reduced. Until the concreting of the plug (between TM 10 and TM 15) in March 2015, no further problems with the tunnel stability were encountered.

The technical feasibility of constructing a repository tunnel in an overconsolidated claystone using standard industrial equipment was successfully verified at the Mont Terri URL.

1.2.4 Test production of bentonite blocks, laboratory and mid-scale testing

One of the objectives of the FE Experiment was to produce bentonite blocks that are capable of resisting the ambient conditions in Mont Terri during the storage and operation phases.

A total of 90 bentonite blocks with three different water contents and three different compaction pressures were produced using a natural sodium bentonite (Gelclay WH2) to investigate the behaviour of the blocks as a function of these production parameters. The resulting dry density for each of the 9 different block groups is shown in *Figure 8* (left). Within the water content range considered, the compaction is on the "wet side" of Proctor (increasing dry density with increasing water content for the same compaction pressure) and the blocks with the highest water content are close to saturation (constant dry density with increasing compaction pressure). The blocks were then isolated in airtight chambers together with a relative humidity (RH) sensor. The equilibrium RH shows a clear correlation with the initial water content with a secondary trend as a function of the compaction pressure (*Figure 8*, right).

---

*) The UCS of "good" shotcrete was on average approx. 42 MPa after 28 days and approx. 50 MPa after 91 days.

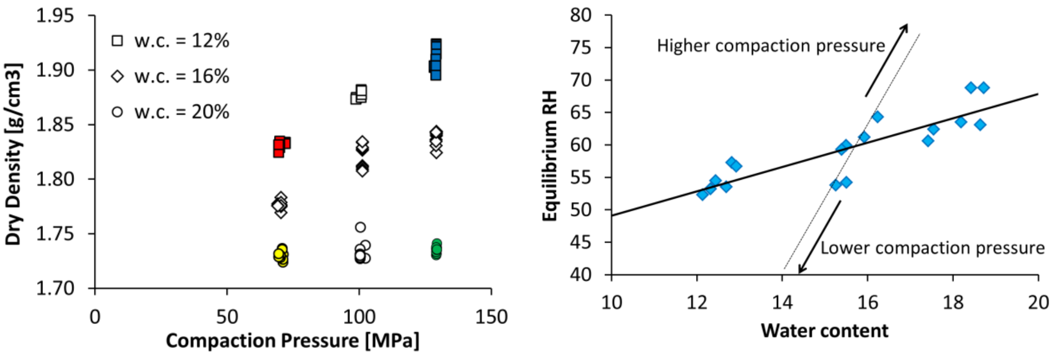

Figure 8: Dry density of the bentonite blocks for the pre-production manufactured with 3 different water contents and 3 different compaction pressures (left) and equilibrium RH of the blocks as a function of their water content.

45 blocks (5 blocks of each of the 9 groups described in *Figure 8*, left) were then submitted to uniaxial compressive strength tests in 5 test series. In the first series, the blocks were tested directly after production and in the next series the blocks were first placed in a climate chamber with a RH of 50 %, 70 %, 90 % and 35 % until the blocks reached equilibrium. The compression test results (*Figure 9*) clearly show that (1) imposing a RH on a bentonite block higher than its natural equilibrium RH drastically reduces its strength. On the other hand, (2) imposing a RH on a block lower than its equilibrium RH leaves the block strength unaffected. Blocks with a high equilibrium RH are thus likely to be more resistant to RH variations and retain their strength.

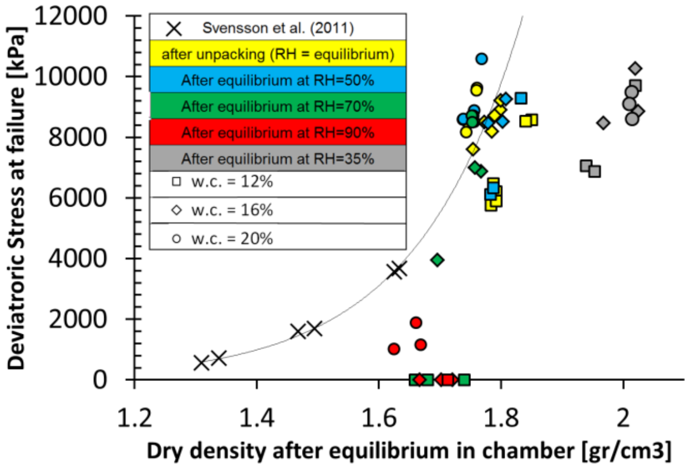

Figure 9: Uniaxial compressive strength (UCS) of the pre-production blocks after equilibrium at different RH values as a function of the dry density after equilibrium.

Values from saturated blocks (Svensson et al. 2011) were added as a reference.

In the Bentonite Long-term Load (BLL) test, 4 groups of 2 blocks with different initial conditions (indicated by coloured dots in *Figure 8*, left) were emplaced in an environment characterised by a varying RH between 50 % and 90 % and were loaded with a similar pressure to that induced by a heater on the bentonite blocks in the FE Experiment. The test was set up (1) to verify the previous laboratory test results and (2) to investigate phenomenologically the mechanisms behind those results. The experiment was installed on 19.09.13 at 11:00 (RH at that time =70 %). Blocks compacted at a low water content disintegrated very quickly: support capability was lost within only one month and the first significant fractures appeared in the first days after emplacement (*Figure 10*). Cameras set up in front of the blocks and recording an image every minute allowed the block disintegration behaviour to be followed. In the low water content blocks, the first fractures appeared in the first hours and the videos (see QR codes in *Figure 10*) clearly showed the link between fracture development and swelling behaviour. The swelling, caused by water absorption by the relatively dry bentonite from relatively wet air, generated cracks that propagated very quickly because the relatively wet air penetrates into the fractures and expands the fracture inside the block. Drying cracks were also observed in the blocks equilibrated at 35 % in the laboratory test, but these were shrinkage cracks and they did not penetrate into the blocks. Blocks produced with a high water content and thus characterised by a higher equilibrium RH took up nearly no water and proved to be very stable over a long time period of approx. 1.5 years.

Figure 10: Resistance of compacted bentonite blocks to exposure time to ambient RH as a function of the production parameters (water content and compaction pressure are indicated at the top of the figure).

The QR codes are linked to time-lapse videos of the block evolution.

1.2.5 Production of bentonite blocks incl. storage

Around 2,500 rectangular and 500 curved "top layer" blocks were produced in March 2014 (*Figure* 11) using a natural sodium bentonite (trade name Gelclay WH2). The production parameters were set according to the tests described above to obtain stable blocks that are capable of supporting heaters under the expected climatic conditions at Mont Terri:

- Water content of the raw material (18 % ±1 %)
- Compaction pressure (130 MPa)

QC variables (acting as rejection criteria) during production were:

- The block dimensions (required precision: 0.85 mm)
- Geometric density (required precision of 0.02 g/cm^3)
- No visible cracks
- Minimum UCS of 6 MPa

The bentonite blocks were produced at a rate of one block per minute. The average characteristics of the rectangular blocks are given in *Table 1*. The selected compaction pressure and water content resulted in an average dry density of 1.78 g/cm^3. The QC variables measured during production were found to be very stable (*Figure 12*) and mostly within the required limits, resulting in a very small quantity of rejected blocks.

For more details about the production and properties of bentonite blocks see Garitte et al. (2015).

Figure 11: Rectangular blocks after pressing (left); curved blocks before storage (right).

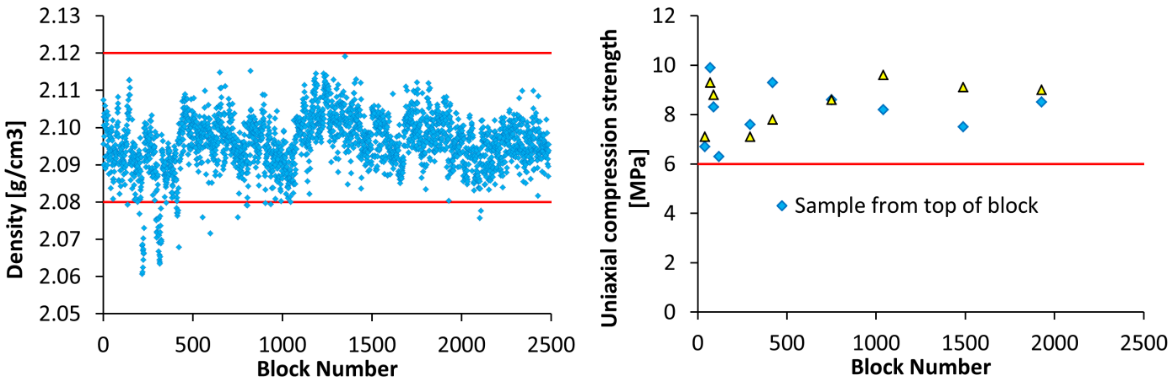

Figure 12: Quality control during block production: geometric density (left) and UCS (right).

Table 1: Average production parameters & characteristics of the 2500 rectangular bentonite blocks.

	Compaction pressure [MPa]	**Weight** [g]	**Length** [mm]	**Width** [mm]	**Height** [mm]	**Bulk Density** [g/cm^3]	**Water content** [%]
Average	129.6	24,517	401.3	200.6	145.3	2.096	18.00
Std. dev.	0.4	93	0.2	0.2	0.3	0.007	0.67
Min	128.7	23,920	400.5	199.9	143.9	2.061	17.27
Max	131.5	25,000	402.1	201.7	146.5	2.119	19.74

After production, the blocks were packed in airtight pallets to prevent water absorption from the environment, which could have caused damage. 5% of the pallets were equipped with a wireless RH sensor to detect potential leakages of the packaging. On-board sensors were found to be unaffected by the RH evolution outside the packaging, proving the tightness of the packaging throughout the storage period (*Figure 13*, left). The QC variables were combined to calculate the degree of saturation in the mould (during compaction) and after unmoulding (*Figure 13*, right). The results suggest that, while in the mould, the bentonite was very close to saturation and the elastic rebound occurring when unmoulding decreased the saturation to about 90%. This suggests that manufacturing blocks with an equilibrium RH higher than 70% might be impossible.

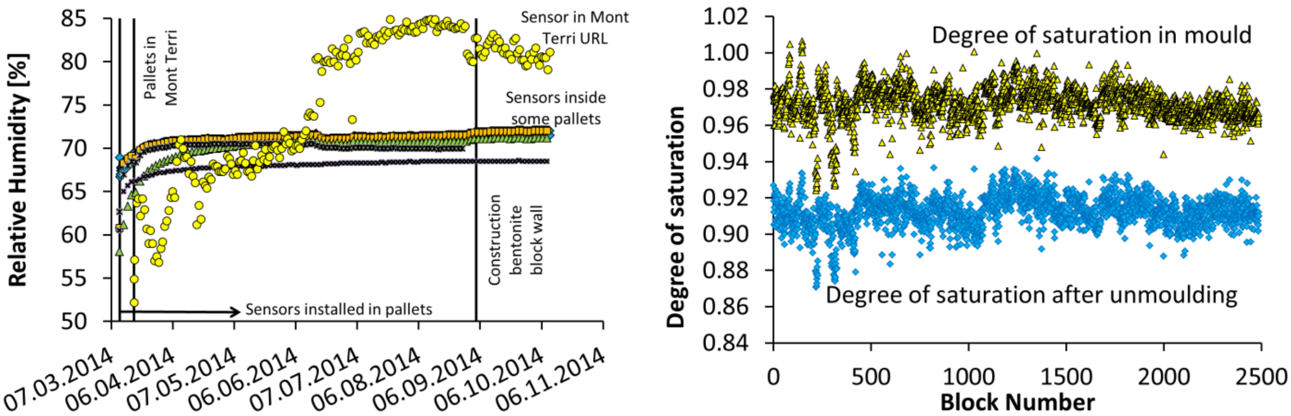

Figure 13: RH inside bentonite block package and ambient RH outside the packages (left) and degree of saturation of the bentonite blocks during and after production (right).

Figure 14: Emplaced bentonite blocks in the FE tunnel: bentonite block wall in the interjacent sealing section and bentonite block pedestal supporting a heater (Photos by COMET).

1.2.6 Emplacement of the blocks in the FE tunnel

The construction of the bentonite block wall (see *Figure 14* left) took place in early September 2014, when the RH in Mont Terri was still relatively high (see *Figure 14*, left). Even under these harsh RH conditions, the blocks survived the 2 weeks of emplacement without any degradation. Each of the three bentonite block pedestals for the heaters survived not only the ambient load but also the 5 tons of the heater.

For more details about the block emplacement in the FE tunnel see Köhler et al. (2015).

1.2.7 Production of granulated bentonite mixture

The delivery of 340 tons of raw bentonite needed for the production of the granulated bentonite mixture (GBM) for backfilling the FE tunnel had to fulfil the minimum technical requirements listed in *Table 2*. The fulfilment of these raw material requirements upon delivery was verified with relevant laboratory measurements in different laboratories (see *Table 3*).

Table 2: Technical requirements on the raw bentonite for the FE Experiment.

Criterion	**Description**
Material	Natural (non-activated) sodium bentonite
Smectite content by dried weight (measured by X-ray diffraction using a dried sample)	> 75 %
Additives (such as magnetite, baryte, etc.)	No additives allowed
CEC (Cation Exchange Capacity) (by Cu(II)- triethylenetetramine method)	> 70 meq/100 g
Water content, meas. acc. to norm ASTM D2216 – 10	< 14 %
Pyrite content by dried weight, measured by X-ray diffraction using a dried sample	< 1 %
Sulphur content by dried weight	< 0.5 % (corresponds to ca. 1 % of pyrite)
Organic carbon by dried weight	< 1 %
Grain size distribution of the delivered raw material acc. to norm ISO 3310-1, BS 410-1	Well distributed between very fine and maximum 2 mm

Table 3: Laboratory measurements on the raw bentonite delivered from CEBO Holland.

Criterion	**Result**
Material	Natural (non-activated) sodium bentonite, confirmed by x-ray diffraction
Smectite content	CEBO: 90 % / ETHZ: 78 % / BGR: 88 – 89 % (see *Table 4*)
CEC	ETHZ: 94.3 meq/100 g
Water content	ETHZ: 11.4 %
Grain size distribution	ETHZ: see *Figure 16*

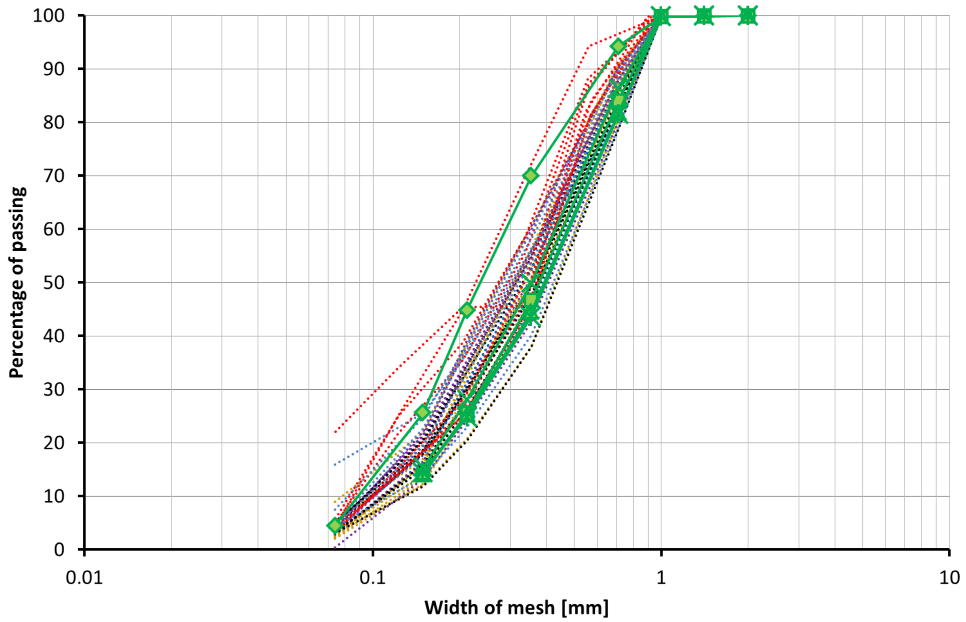

Figure 15: Grain size distribution of National ® Standard WP2 measured 1/3 tons by CEBO during the production of 120 tons.

The required grain size distribution range is indicated by the green lines.

Table 4: Laboratory measurements of mineralogical composition of the bentonite used (analyses by S. Kaufhold & R. Dohrmann from BGR Germany)

Minerals	**Crude national standard** [%]	**Pellet fraction A** [%]	**Pellet fraction C** [%]
Smectite	89.0	88.9	88.5
Muscovite	0.4	0.4	0.4
Quartz	4.0	4.2	4.1
Feldspar	3.7	3.1	3.4
Gypsum	0.8	0.8	0.8
Pyrite	0.3	0.3	0.3
Calcite	0.1	0.5	0.5
Siderite	1.3	1.3	1.3
Cristobalite	0.3	0.4	0.6

To finally reach a high pellet dry density and a high overall emplacement density, the delivered raw bentonite from CEBO Holland had to be dried down from a water content of about 12 % to a lower water content between 4 and 6 %. Laboratory measurements by M. Plötze at ETH Zürich (ETHZ) verified that the water content of the dried raw bentonite was in fact approx. 6%.

The maximum temperature the raw bentonite may be exposed to during the drying process is 80 °C. Exceeding this temperature may lead to mineralogy changes resulting in a non-appropriate material for our use.

The dried raw bentonite then had to be granulated with roller presses; the compacted components had to satisfy the minimum requirements stated in *Table 5*. The bulk material after grinding and mixing had to fulfil the minimum requirements stated in *Table 7*.

Table 5: Technical requirements on the compacted bentonite components after granulation.

Criterion	**Discreption**
Dry density of single component	> 2 g/cm^3
Water content	Between 4 % and 6 %
Max. component size	10 – 15 mm
Mechanical restistance	90 % of 30 components resist 5 drops of 2 m high on concrete floor (or equivalent method)
Temperature	Max. temperature the bentonite may be exposed to during the granulation process: 80 °C

Generally with lower initial water contents, higher component densities can be reached during compaction. With this type of natural sodium Wyoming bentonite material, the optimum Proctor density can be reached with a water content of about 4 to 5 %.

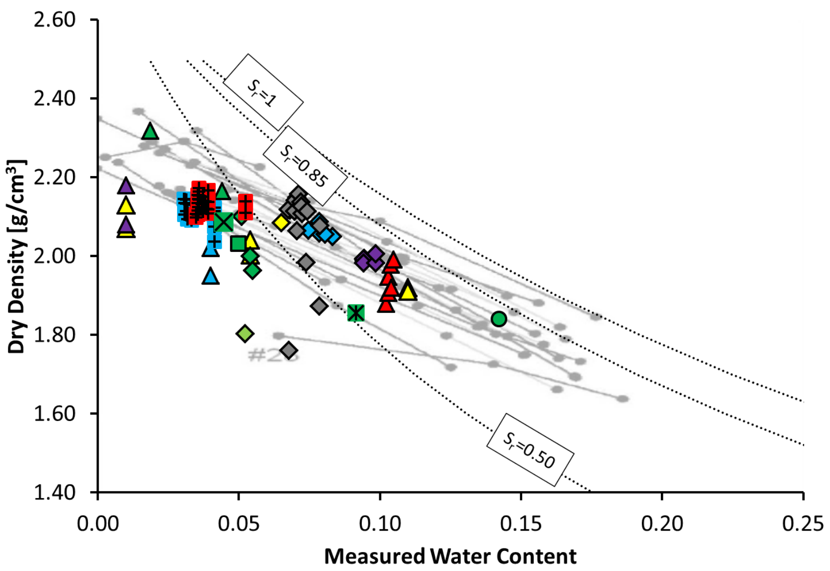

Figure 16: Laboratory measurements on different Wyoming bentonite samples.

Relationship between initial water content and dry density reached after compaction. Data from pellets produced at Rettenmaier in the last 10 years for different Nagra projects with different types of bentonite (dotted lines are water saturation curves).

The properties of the granulated mixture delivered from Rettenmaier (Germany) were checked with different laboratory measurements (see *Table 6*). The grain size distribution of the granulated bentonite mixture (GBM) emplaced in the FE tunnel at the Mont Terri URL is shown in *Figure 19*.

Table 6: Laboratory measurements on the GBM delivered from Rettenmaier (Germany).

Criterion	**Results**
Dry density	ETHZ: 2.15 ± 0.04 % / measurements at Rettenmaier (see *Figure 17*)
Water content	ETHZ: 5.74 ± 0.5 %
Size of pellets	It was difficult to produce pellets with a larger diameter than approx. 10 mm and with an ideal shape close to spherical

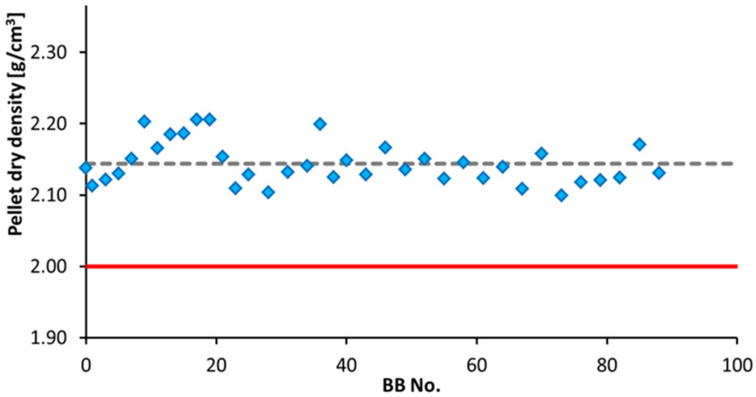

Figure 17: Quality control of the dry density of the produced pellets during compaction with a roller press at Rettenmaier Germany for different bigbags (BB)

Table 7: Technical bulk requirements of the granulated bentonite mixture.

Criterion	**Description**
Component size distribution of bulk mixture	Fuller type, with D_{max} = [10 – 15 mm], n = 0.4 (see *Figure 18*)
Shape of the constituents	Rounded and spherical
Water content	Between 4 % and 6 %
Mixture	Homogeneous

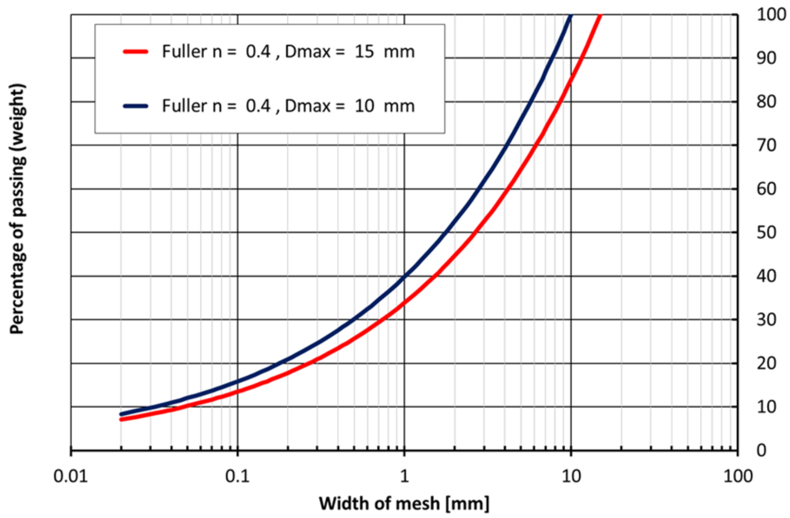

Figure 18: Envisaged Fuller type grain size distribution (Exponent 0.4) with a maximum grain size of 10 mm resp. 15 mm.

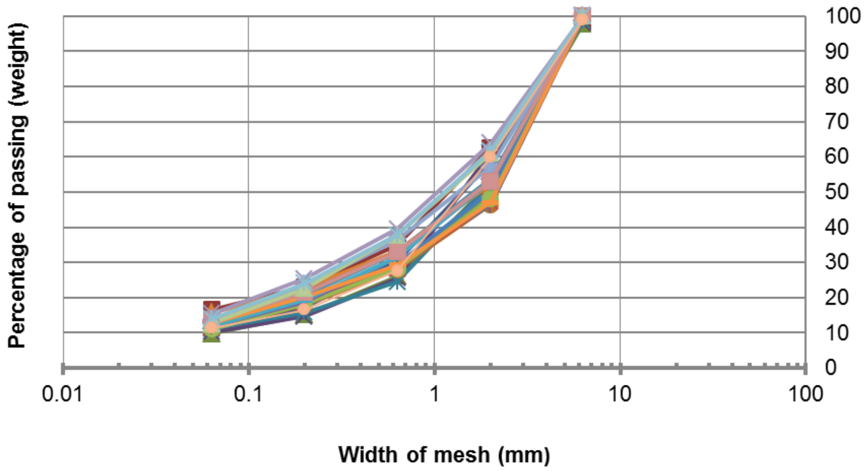

Figure 19: Grain size distribution of the emplaced granulated bentonite mixture at Mont Terri.

Figure 20: Photo of the granulated bentonite mixture produced.

For more details about the production and the properties of the highly compacted and granulated bentonite mixture (GBM) used in in the FE tunnel see Garitte et al. (2015).

1.2.8 Backfilling concept

Based on the experience from the EB experiment (Kennedy & Plötze 2003) and the ESDRED project (Plötze & Weber 2007), the decision was made to design and fabricate a five-arm screw conveyor backfilling machine (see *Figure 21*) that was able to backfill a horizontal tunnel as tightly and homogeneously as possible. This prototype was intended to demonstrate the backfilling process in the FE tunnel (diameter 2.5 to 3 m) with a dry granulated bentonite mixture according to the Swiss reference concept for HLW disposal.

The main requirement for the backfill was an overall bulk dry density of at least 1.45 t/m^3. The aim of using five screw conveyors was to improve the backfilling quality in terms of homogeneity, since segregation effects had been observed during the ESDRED project. A staggered alignment of the screw conveyors was chosen with respect to the expected repose angle of the backfill material. Moreover, an increased compaction was expected as each screw conveyor remained within the material bulk, building up a conveyance pressure. Oblique screw conveyor tips were designed in order to fill up irregular overbreaks in the upper part of the tunnel profile.

The backfilling sequence is shown in *Figure 22*. The backfilling machine drives over the last canister emplaced and starts backfilling from the GBM slope covering the preceding canister.

Figure 21: CAD illustration of the backfilling machine built for the FE Experiment, driving over a dummy canister resting on a pedestal made of bentonite blocks.
Total length of the backfilling machine including the feeding device is 17 m.

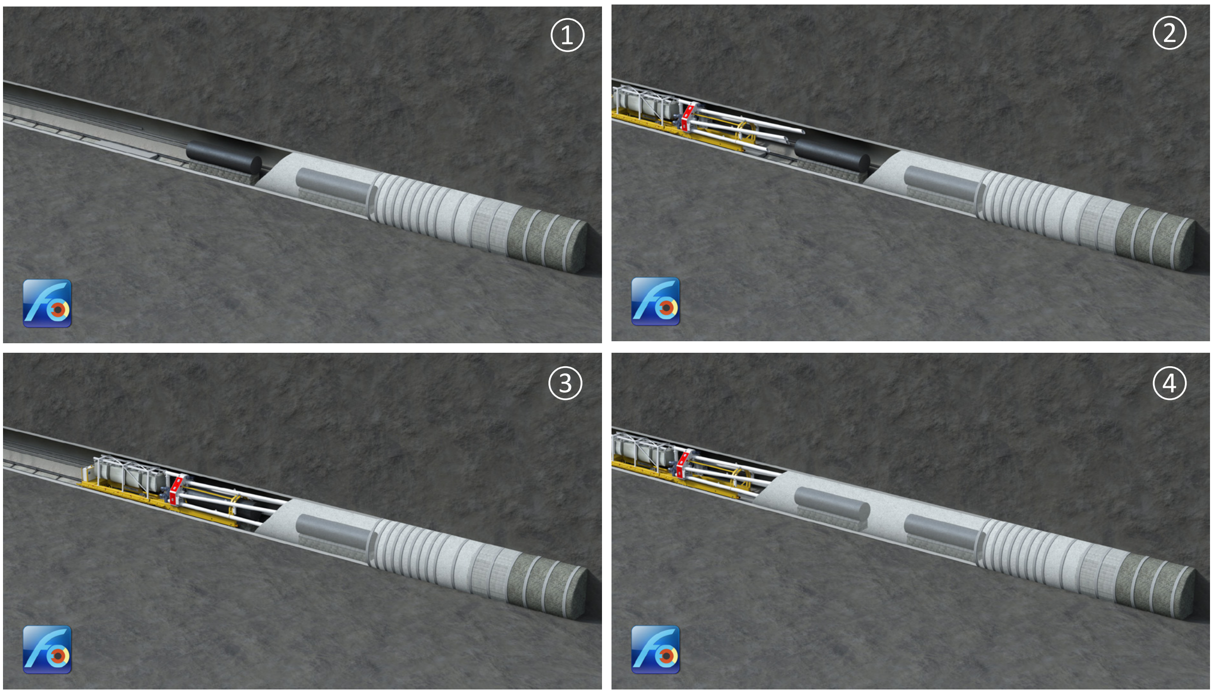

Figure 22: Backfilling sequence for one heater element in the FE tunnel at the Mont Terri URL.

1.2.9 Investigations before backfilling machine construction

Before the backfilling machine was built, two pre-tests were carried out. The first pre-test (see *Figure 23* and *Figure 24*) focused on the coupled effects of material conveyance, the potential to push the bulk material upwards, the resulting backfilling pressure and the corresponding actuation parameters of the screw conveyors.

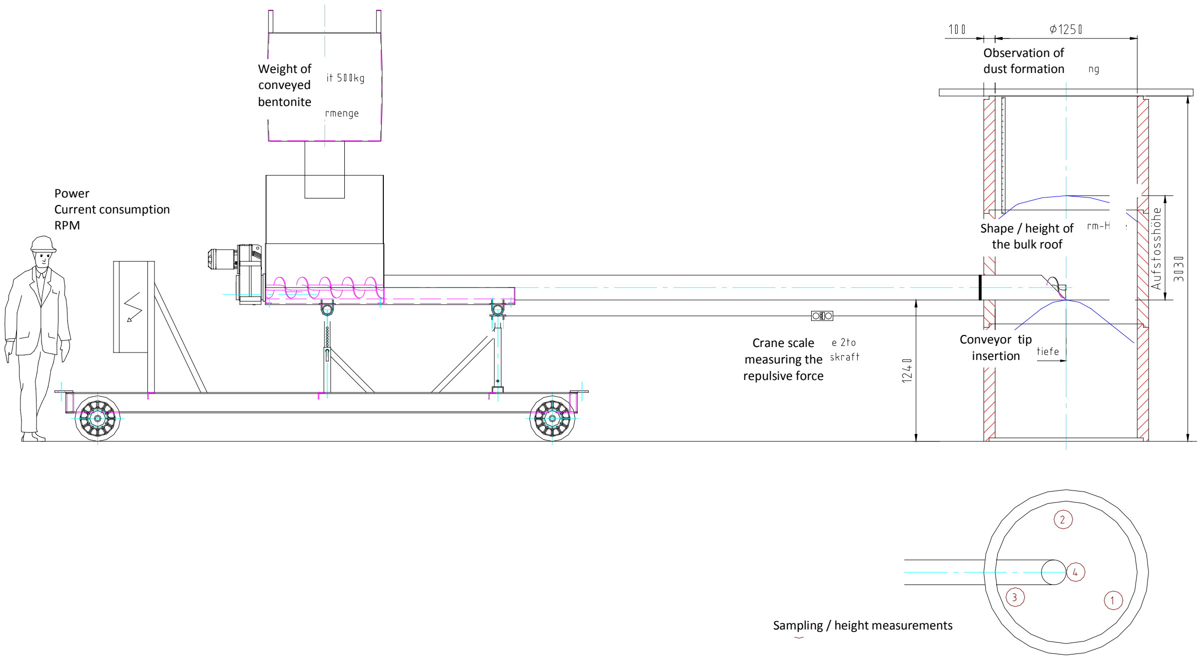

Figure 23: Setup of the first pre-test indicating the observed parameters.

Figure 24: The first pre-test aimed at investigating the potential of pushing the bulk material upwards in a tube of 1.25 m diameter, including corresponding parameters.

The second pre-test (see *Figure 25*) aimed at a better understanding of the bulk material behaviour as dependent on accessory measures such as slope coverage, insertion of a vibration needle, etc., as well as collecting data for optimisation of the backfill material grain size distribution with regard to the required dry density.

Figure 25: The second pre-test visualised the intensity of segregation effects depending on various measures during backfilling (here: no measures in the top pictures, $\rho_d \approx 1.43$ t/m^3 vs. flexible slope coverage and broader grain size distribution in the lower ones, $\rho_d \approx 1.46$ t/m^3).

1.2.10 Backfilling machine construction

According to the Swiss backfilling concept, the backfilling system is rail-bound. It consists of the backfilling machine with the screw conveyance system and the feeding wagon carrying specially designed bigbags. Both devices have their own drive unit. The control unit for the backfilling system is placed at the rear end of the feeding wagon. *Figure 27* shows a photo of the whole backfilling system during test operations.

The feeding wagon is a vehicle carrying four bigbags hanging on rollers to be pushed forward manually as soon as the bigbag in the front becomes empty and is removed. The feeding wagon does not exhibit any demonstration character with regard to the Swiss backfilling concept. It is an economical solution for the non-industrial scale FE Experiment in terms of the relatively small volume to be backfilled.

The feeding hopper attached to the backfilling machine is the interface between the feeding wagon and the backfilling machine.

The core component of the backfilling machine (see *Figure 26*) is the conveyance unit. It consists of a horizontal discharging screw conveyor placed below the feeding hopper and a vertical and a horizontal feeding conveyor towards the distribution box. The latter is equipped with level transmitters to adjust the speed of the discharging screw and thus provide optimum conditions for the bulk material to flow steadily through the distribution box and enter the five horizontal "stuffing" screw conveyors. These are aligned in a staggered manner with respect to the expected bulk material slope in the emplacement tunnel (repose angle of ca. 35^{o}). The tips of the screw conveyor tubes are cut obliquely in order to push the conveyed material upwards. In this way, not only the complete crown area but also gaps and overbreaks resulting from the uneven tunnel wall surface were intended to be filled.

For more details about the planning, production and testing of the emplacement and backfilling equipment see Jenni & Köhler (2015).

Figure 26: The prototype backfilling machine (CAD model) with five screw conveyors developed for backfilling the horizontal FE tunnel with a granulated bentonite mixture as tightly as possible.
The longest screw conveyor is 8.5 m long, total length of the device is 11.5 m.

1.2.11 Testing and commissioning of the machine

Before acceptance of the new backfilling machine, it had to be extensively tested. For this purpose, a test site was set up in a factory building where all relevant processes related to heater emplacement and backfilling could be tested. Temporary rails and a steel tube with a diameter of 2.50 m and a length of 8 m were installed.

Figure 27: The prototype machine with feeding and control unit carrying four bigbags.

The photo was taken during a 1:1 scale mock-up test in an off-site workshop. To the left, a dummy tunnel and a dummy canister resting on a steel pedestal can be seen (photo by COMET).

Figure 28 gives an impression of the test setup (without rails and backfilling machine). The mock-up test comprised two fillings of the steel tube. During mock-up test No. 1, the focus was on technical functionality (e.g. adjustment of the hydraulic brakes to 32 kN horizontal repulsive forces, calibration of force transmitters, etc.) and procedural optimisation (handling, QC methodology, etc.). Before mock-up test No. 2 started, minor technical issues were fixed and the focus was on the backfilling procedure and QC in terms of density verification and sampling.

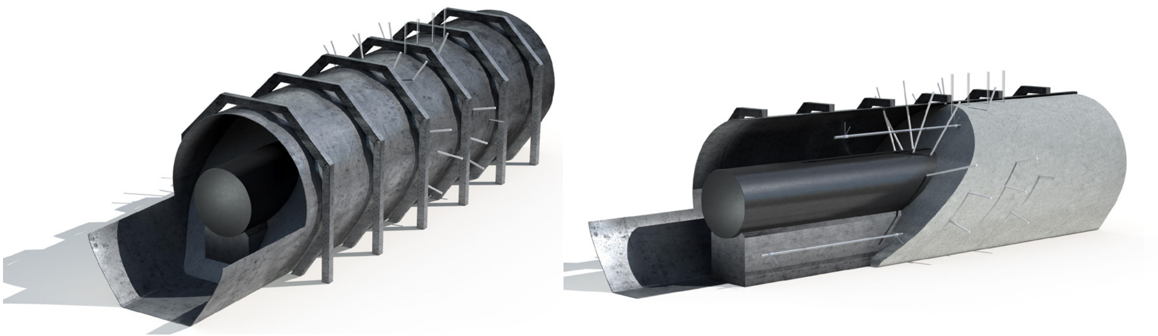

Figure 28: CAD visualisation of the mock-up test tunnel showing pipes for density measurements.

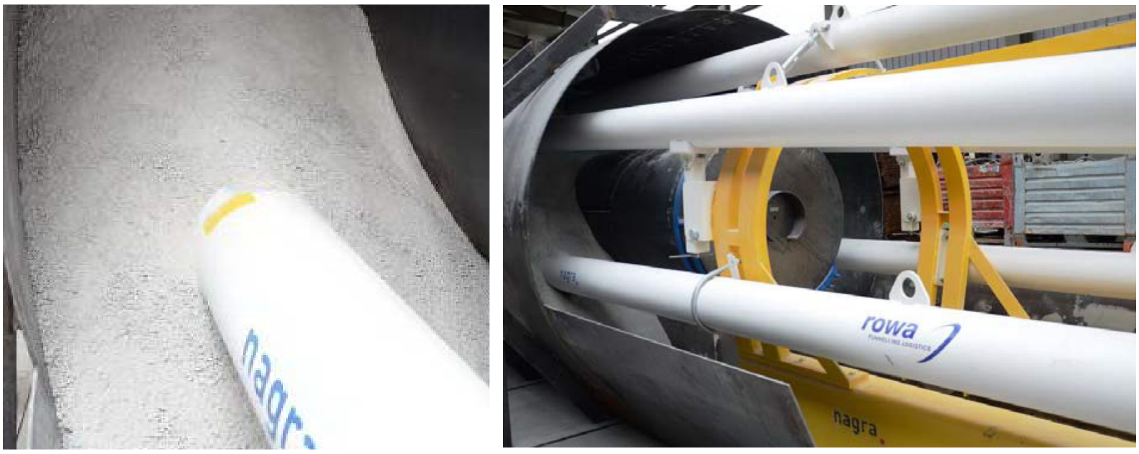

Figure 29: The new backfilling machine being tested in a 1:1-scale tunnel model in an off-site factory. The 1 m diameter dummy heater can be seen in between the screw conveyors.

During backfilling, all screw conveyors are filled and remain in the GBM bulk slope in order to prevent dust formation and to build up a conveyance pressure (see *Figure 29*). This pressure pushes the material bulk upwards, filling overbreaks in the tunnel crown. The backfilling machine is held in place against the repulsive forces by hydraulic brakes, which have to ease off at approximately 32 kN in order to maintain a high conveyance pressure but not to overload the screw actuators. With sophisticated controls, many parameters such as each actuator's power consumption, rotation speed and the hydraulically controlled braking force were controlled and displayed (*Figure 30*).

Figure 30: Touch screen panel for controlling the backfilling machine (photos by COMET).

Regarding QC measures, the mass-volume balance was calculated from the backfilled weight and the backfilled volume. In mock-up test 1 (MUT1), the volume was estimated by combining the known geometry of the steel tube and the application of a 3D camera based on time-of-flight technology to capture the slope geometry. For mock-up test 2 (MUT2), the slope was laser scanned with a geodetic total station. In order to determine the density around the dummy canister and behind it separately, laser scanning was done at two different slope positions (*Figure 31*).

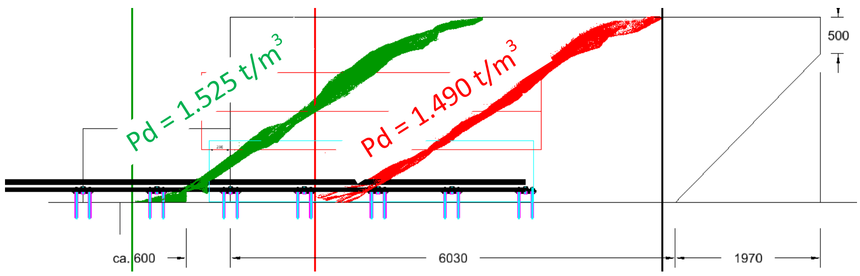

Figure 31: Array of curves from scanning the "start slope" (red) and the "end slope" (green) for separate volume and density determination behind and around the canister.

Moreover, the test setup had the particular advantage that the backfilled bulk material could be accessed not only through the slope, but also radially through the steel tube. Local density was measured using dielectric tools, radioactive logging and horizontal cone penetration testing. In *Figure 28*, small pipes are shown that allow specific probes to be inserted for this purpose.

Dry density results are listed in *Table 8.* The target dry density of 1.45 t/m^3 was clearly reached, especially around the canister where a bulk dry density of approx. 1.53 t/m^3 was reached. At the same time, the required demonstration before using the emplacement technology within the FE Experiment at Mont Terri URL was performed successfully.

Table 8: Dry densities calculated from mass-volume measurements conservatively considering i) 0.35 % due to weighing inaccuracy and 2.5 kg material loss per bigbag, ii) standard deviation in water content measurements (MUT1: 5.54 ± 0.16 % / MUT2: 5.60 ± 0.09 %), iii) inaccuracy in volume estimation (MUT1: 1 % / MUT2: 0.2 %) and iv) inaccuracy in positioning of the survey (± 0.01 m^3).

Values [t/m^3]	**Mock-up 1**	**Mock-up 2 gap**	**Mock-up 2 around canister**	**Mock-up 2 total**
Average dry density	1.498	1.490	1.525	1.502
Deviation	± 0.023	± 0.013	± 0.022	± 0.009

1.2.12 Operation at the Mont Terri URL

Some photo impressions of the backfilling machine driving through the FE tunnel and over a heater resting on a bentonite block pedestal, followed by the backfilling process, are given in *Figure 32 and Figure 33*. For reloading bigbags, the feeding wagon was detached from the backfilling machine and driven to the intersection of the MB niche and Gallery 08 (see *Figure 34 left)*, while the backfilling machine remained in the FE tunnel with the screw conveyors inserted in the bulk material. *Figure 34* (right) shows the control unit on the rear end of the feeding wagon attached to the backfilling machine.

Figure 32: Five screw conveyors on the backfilling machine in the FE tunnel (photo by COMET).

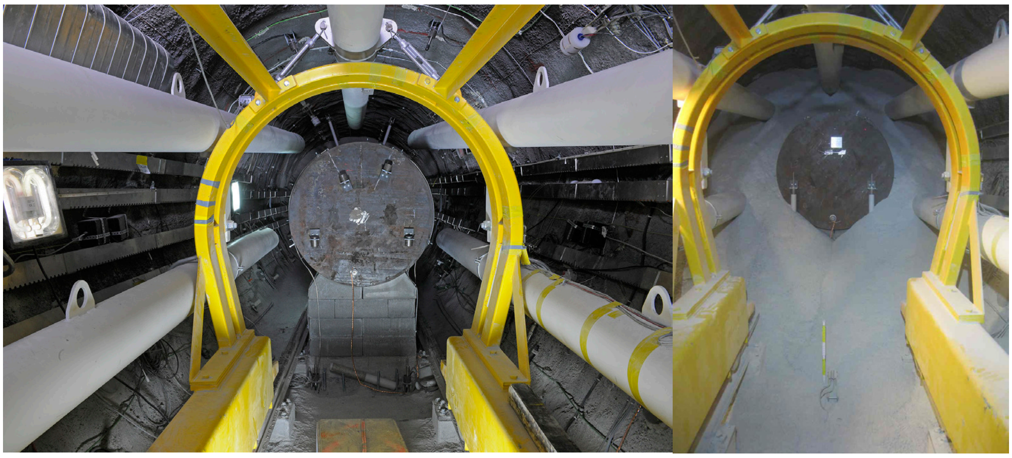

Figure 33: Backfilling machine with screw conveyors driving over the heater and its pedestal (left, photo by COMET) and during backfilling operation (right).

Figure 34: Loading bigbags (left, photo by COMET); rear end of the feeding wagon with control unit visible and brakes attached to the rails (right).

The backfilling at the Mont Terri URL was carried out in four different periods of three days, alternating with periods of several weeks for manual assembly of the three bentonite pedestals and the emplacement of the heaters, including sensor installations. Each backfilling period was suspended by two further interventions for sensor installation (Müller et al. 2015). In total, the backfilling machine was driven out of the FE tunnel eleven times, leaving the slope accessible for QC. Eleven 3D laser scans resulted from these slopes (*Figure 35*), yielding 12 volume determinations in conjunction with a laser scan of the complete tunnel section before backfilling. By mass-volume calculations, this resulted in twelve distinct dry densities along the backfilled tunnel section of 29.6 m length (*Table 9* and *Figure 36*).

Figure 35: Geodetic survey of slopes (left) and sample shapes (right) for differential volume and subsequent density calculations.

Table 9: Dry density results in [t/m^3] per section calculated from mass-volume measurements. Deviation is estimated at 0.007 t/m^3 resulting from the assumption of 0.35% material loss and weighing inaccuracy plus 0.1 % volume estimation inaccuracy.

Slope	TM 15	TM 11	TM 10	TM 9	TM 8	TM 7	TM 6	TM 5	TM 4	TM 3	TM 2	TM 1
Dry density [t/m^3]	1.403	1.477	1.444	1.555	1.530	1.496	1.519	1.494	1.487	1.474	1.495	1.496

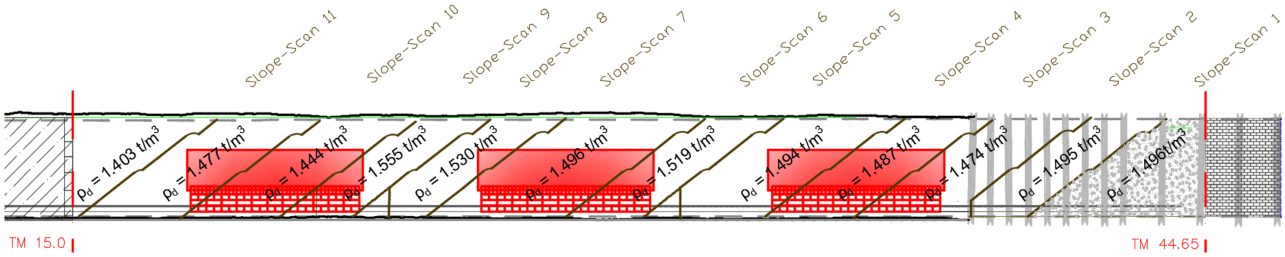

Figure 36: Longitudinal section of the backfilled FE tunnel indicating the measured dry densities.

The overall average dry density was 1.489 ± 0.003 t/m^3. The smaller deviation compared to the sectional values results from the fact that material losses generally occurred along the way to be backfilled within the FE tunnel. This contributes to local inaccuracy, but not to the overall mass balance. Hence, the mass balance is limited to the weighing inaccuracy of 0.1%. Volume inaccuracy is also 0.1 %.

Regarding the notably low value of 1.444 t/m^3 covered by slope 10, lower quality material in a few bigbags happened to be used for backfilling in this section of the FE tunnel. The respective backfill material contains a high proportion of powder instead of the expected Fuller type grain size distribution. The reason for lower backfill material quality is most likely related to the reuse of the granulated bentonite mixture from the mock-up test. Local accumulation of dust had probably not been detected during recycling with a vacuum truck and repacking in bigbags.

Samples for QC measures were taken from every bigbag while pouring into the feeding hopper just before backfilling. Water content, specific pellet density and grain size distribution were analysed systematically (Weber et al. 2015).

An unexpected finding was the observation of wear on the conveyor screws and the respective tubes (*Figure 37*). The reason for this is a significant deflection of the conveyor tube during backfilling due to the vertical component of the repulsive force. This is caused by the oblique tips of the tubes. The wear was more pronounced in some of the screw conveyors. The most intense signs were found in the two middle conveyors which had to provide more mass flux and thus more mechanical work than the top and lower conveyors. Note that the very front part of the screw is not affected. For future screw conveyor designs, this problem should be addressed.

The backfilling at the Mont Terri URL and at other pre-testing sites was achieved without any breakdowns or accidents. All project aims concerning demonstration aspects and backfill quality were reached. New findings such as the signs of wear of the screw conveyors will be analysed and resolved in future developments.

For more details about the pre- and mock-up tests and the backfilling of the FE tunnel at the Mont Terri URL see Köhler et al. (2015).

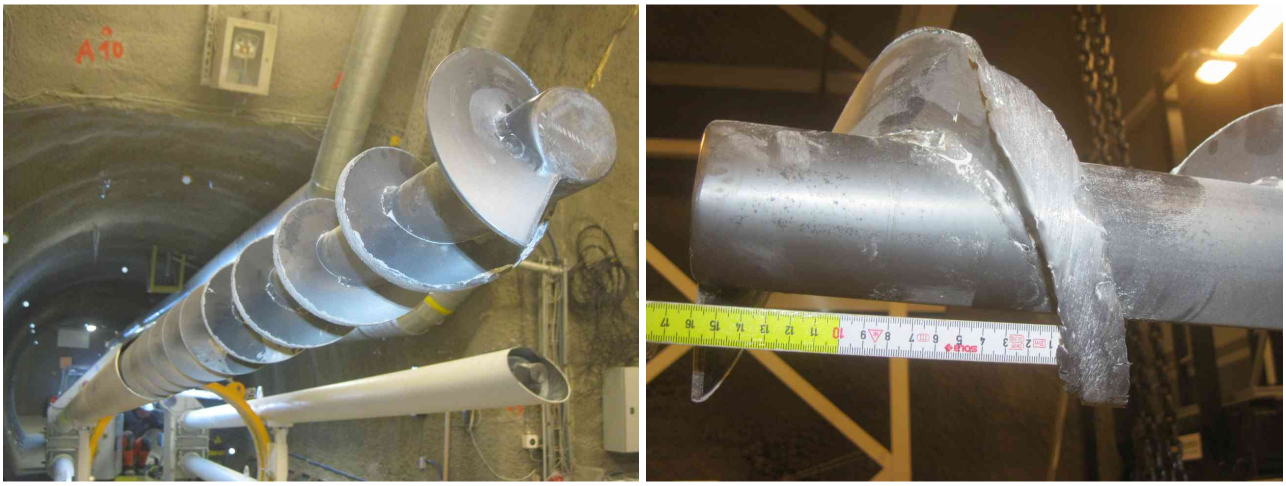

Figure 37: Signs of wear from friction between screw and tube due to bending (see text).

The total emplacement and backfilling sequence at Mont Terri is illustrated in the following graphic.

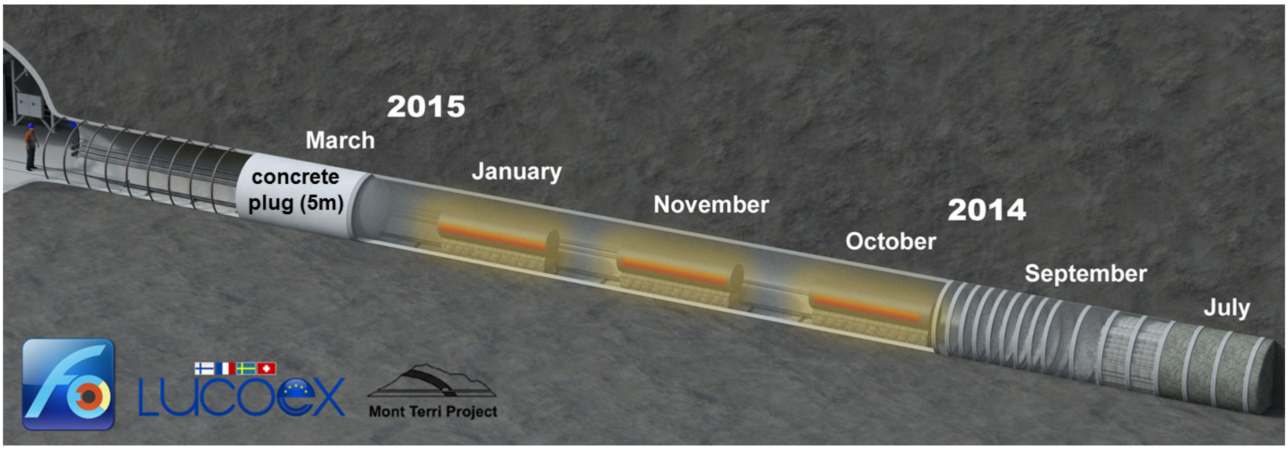

Figure 38: Sketch of the emplacement and backfilling sequence in the FE tunnel at Mont Terri.

1.3 Impact

The Full-Scale Emplacement (FE) Experiment at the Mont Terri underground research laboratory (URL) is a full-scale multiple heater test in Opalinus Clay. It simulates the construction, waste emplacement, backfilling and early post-closure evolution of a spent fuel / vitrified high-level waste repository tunnel as realistically as possible. The engineering and demonstration components of the FE Experiment are also part of Nagra's participation in the EU project 'Large Underground COncept Experiments' (LUCOEX).

The FE Experiment and the associated LUCOEX Work Package (WP) 2 are key projects for the deep geological repository programme and concept in Switzerland. This is not only from a technical and scientific perspective, but also for reassuring the scientific community (including the authorities) as well as the public that, with reasonable effort, the horizontal tunnelling, emplacement and backfilling in a shale such as Opalinus Clay can be achieved successfully and reliably. The outcome and findings from the FE Experiment are also relevant for the European and world-wide radioactive waste management community.

One important part of the dissemination process is to allow the public access to the main results documented as EU project reports ("deliverables"), which can be downloaded e.g. from the LUCOEX project webpage www.lucoex.eu. Further visibility for the project was gained with the help of the Mont Terri platform, with its weekly report distributed to a scientific audience and its webpage www.mont-terri.ch. Additionally selected information was shared via the webpage www.nagra.ch and the professional business network service www.linkedin.com.

The scientific community was also involved and informed via several conferences (see Appendix II) and publications (see Appendix I). The main author of the paper by Lisjak et al. (2015) dealing with the construction and deformation behaviour of the FE tunnel for example received the Rocha Medal 2015 from the International Society of Rock Mechanics (ISRM) for his thesis “Investigating the influence of mechanical anisotropy on the fracturing behaviour of brittle clay shales with application to deep geological repositories”, for which he worked as an apprentice at Mont Terri during the construction of the FE tunnel.

One main advantage of European projects – besides all other aspects – is the close collaboration between the different organisations and people involved and therefore the continuous knowledge exchange, which is particularly important for education and training of younger scientists and technicians. In total, 15 apprentices from different European countries worked at Nagra and / or Mont Terri within the framework of the FE Experiment and the associated LUCOEX WP 2.

The hands-on approach from Nagra in implementing and completing such an experiment successfully is recognised positively not only by the scientific community, but also by the public. It is perceived positively when waste management organisations (WMO) test their concepts, ideas and plans on a real scale and when the outcome, including potential difficulties, is discussed openly. This not only makes the WMOs more credible but is also the basis for a continuous improvement process.

In this context, Nagra and other (inter)national partners try to make their work more transparent and understandable by inviting the interested scientific community and the public to visit the Mont Terri URL, which is also run as a scientific exhibition centre. Additionally, Nagra produced a video to explain the FE Experiment / LUCOEX and made it publicly available via youtube/3iuH5NyG53k.

Nagra also published a press release on the FE Experiment / LUCOEX, which was followed by a press conference (see Appendix II). During all these different opportunities, the involvement and funding of the European Union was mentioned whenever possible.

At the press conference in the Mont Terri URL, journalists also had the possibility to visit the on-site backfilling work, which apparently left a very positive impression on the participants. Together with the recent developments and news regarding the site selection process in Switzerland, this resulted in numerous articles in the local and national (and partially even international) newspapers and technical journals. Finally, SRF (the Swiss national television) was intrigued by the topic and showed the experiment, including an interview with the project manager Herwig R. Müller, in the national early evening news.

The dissemination process for WP2 of the LUCOEX project can thus be considered as extremely successful. Nevertheless, the analysis and synthesis of the experimental data and results have just begun. Further dissemination measures (such as publications and presentations at workshops) initiated by Nagra and / or other experimental partners can therefore be expected on a national and international level in the years to come. Wherever possible the LUCOEX project and the European Union will be mentioned.

2 Mandatory EC Questioner

See Appendix IV

3 Acknowledgement

The Full-Scale Emplacement (FE) Experiment was implemented in the Mont Terri underground research laboratory, which is operated by swisstopo, the geological survey of Switzerland. We thank ANDRA (France), BGR (Germany), DOE/LBNL (U.S.A), GRS (Germany) and NWMO (Canada) for participating in the FE Experiment at Mont Terri.

The engineering and demonstration components of the FE Experiment are also part of Nagra's participation in the EU project 'Large Underground COncept Experiments' (LUCOEX). The LUCOEX project has received funding from the European Union's EUROATOM research program (FP7) under grant agreement 269905.

Nagra thanks the European Union for supporting this work. Nagra also thanks the LUCOEX partners ANDRA (France), POSIVA (Finland) and SKB (Sweden) for the continuous discussion and knowledge exchange throughout this EU project and beyond. A further acknowledgement goes to SKB for acting as the LUCOEX project coordinator.

<u>Key people & organisations involved in the FE Experiment / LUCOEX WP2:</u>

Idea, conceptualisation, initiation: Peter Blümling, Lawrence Johnson, Tim Vietor (all Nagra)

LUCOEX Work Package 2 leader: Hanspeter Weber (Nagra)

External experts: Jean-Michel Bosgiraud (Andra), Thomas Fries (Nagra), Stig Pettersson (SKB), Hannu Pihlainen (Posiva), Wilhelm Bollingerfehr (DBE-TECHNOLOGY), Alan Hooper (Consultant, UK), Lumir Nachmilner (Consultant, Czech Republic), Jan Verstricht (SCK/CEN)

Project Manager & Principal Investigator at the Mont Terri URL: Herwig R. Müller (Nagra)

Task leaders during the FE implementation: Benoit Garitte, Tobias Vogt, Sven Köhler, Marian Hertrich, Thomas Spillmann, Jens Becker, Niels Giroud, Sven Teodori, Uschi Züger (all Nagra)

Internal experts: Toshi Sakaki, Nikitas Diomidis, Paul Marschall, Irina Gaus, Piet Zuidema (all Nagra)

Mont Terri URL: Paul Bossart, Christophe Nussbaum, Thierry Theurillat, David Jäggi (all swisstopo)

Photo, film: Jutta Lang, Benedikt Galliker, Patrick Burgert, Bruno Kunz, Dave McKie (all Nagra)

Main contractors (alphabetical listing): Aitemin, Amberg, Belloli, Bfe, Blm, Brugg Cables, Courbat, Ctsm, Flotron, Geomechanica, Geotest, Ggt, Intera, Joliat, Neubrex, Pöyry, Quintessa, Rothpletz+Lienhard, Rowa, Schützeichel, Smartec, Soldata, Solexperts, Terratec, Tfb, Upc, Vsh etc.

4 References

Daneluzzi, R., Burrus, F., Küttel, T., Müller, H.R. & Köhler, S. (2014): LUCOEX Deliverable D2.2 - Report on the construction of the emplacement tunnel. WP2 – Full-Scale Emplacement Experiment (FE) at Mont Terri. EU report downloadable from www.lucoex.eu

Garitte B., Weber, H.P. & Müller, H.R. (2015): LUCOEX Deliverable D2.3 – Requirements, manufacturing and QC of the buffer components. WP2 – Full-Scale Emplacement Experiment (FE) at Mont Terri. EU report downloadable from www.lucoex.eu

Jenni, H. & Köhler, S. (2015): LUCOEX Deliverable D2.4 – Report on the Construction, Testing and Commissioning of the Emplacement Equipment. WP2 – Full-Scale Emplacement Experiment. EU report downloadable from www.lucoex.eu

Kennedy, K. & Plötze, M. (2003): Engineered Barrier Emplacement Experiment in Opalinus Clay (EB). Granular Material Backfill Emplacement Method Evaluation. EC contract FIKW-CT-2000-00017. Project deliverable D4

Köhler, S., Benoit, G., Weber, H.P. & Müller, H.R. (2015): LUCOEX Deliverable D2.5 – Emplacement report. WP2 – Full-Scale Emplacement Experiment (FE) at Mont Terri. EU report downloadable from www.lucoex.eu

Lisjak, A., Garitte, B., Grasselli, G., Müller, H.R. & Vietor, T. (2015): The excavation of a circular tunnel in a bedded argillaceous rock (Opalinus Clay): Short-term rock mass response and FDEM numerical analysis. Tunnelling and Underground Space Technology 45, January 2015, Pages 227-248, http://dx.doi.org/10.1016/j.tust.2014.09.014

Müller, H.R., Vogt, T., Garitte, B., Sakaki, T., Spillmann, T., Hertrich, M. & Giroud, N. (2015): Instrumenting, monitoring and heating the Full-Scale Emplacement (FE) Experiment at the Mont Terri URL. LUCOEX Conference & Workshop, Oskarshamn, Sweden, 2-4 June 2015

Nagra (2008a): Entsorgungsprogramm 2008 der Entsorgungspflichtigen [Waste Management Programme 2008 of the Waste Producers]. Nagra Tech. Report NTB 08-01. Nagra, Wettingen. [report in German]

Nagra (2008b): Vorschlag geologischer Standortgebiete für das SMA- und das HAA-Lager: Darlegung der Anforderungen, des Vorgehens und der Ergebnisse. Nagra Tech. Report NTB 08-03. Nagra, Wettingen. [report in German]

Plötze, M. & Weber, H.P. (2007): ESDRED Emplacement tests with granular bentonite MX-80 – Laboratory results from ETH Zürich. Nagra Arbeitsber. NAB 07-24. Nagra, Wettingen

Svensson, D., Dueck, A., Nilsson, U., Olsson, S., Sandén, T., Lydmark, S., Jägerwall, S., Pedersen, K. & Hansen, S. (2011): Alternative buffer material: Status of the ongoing laboratory investigation of reference materials and test package 1. SKB TR-11-06. SKB, Stockholm

Weber, H.P., Köhler, S., Teodori, S., Müller, H. & Vietor, T. (2012): LUCOEX Deliverable D2.1 – Work plan LUCOEX Work Package 2: Full Scale Emplacement Experiment (FE) at Mont Terri. EU report downloadable from www.lucoex.eu

Weber, H.P., Garitte, B., Köhler, S. & Müller, H. (2015): LUCOEX: QA/QC during bentonite material production & emplacement in the framework of the FE Experiment. LUCOEX Conference & Workshop, Oskarshamn, Sweden, 2-4 June 2015

Appendix I – Scientific publications

- List of all scientific (peer reviewed) publications relating to the foreground of the project.

These tables are cumulative, which means that they should always show all publications and activities from the beginning until after the end of the project.

TEMPLATE A1: LIST OF SCIENTIFIC (PEER REVIEWED) PUBLICATIONS, STARTING WITH THE MOST IMPORTANT ONES										
NO	Title	Main author	Title of the periodical or the series	Number, date or fre-quency	Pub-lisher	Place of publi-cation	Year of publi-cation	Relevant pages	Permanent identifiers[1] (if available)	Open access[2] pro-vided?
1	The excavation of a circular tunnel in a bedded argillaceous rock (Opalinus Clay): Short-term rock mass response and FDEM numerical analysis.	Lisjak A.; Garitte B.; Grasselli G.; Müller H.R.; Vietor T.	Tunnelling and Underground Space Technology, 2015, Bd. 45, S. 227–248.					**22**		**no**
2	Nagra's activities at the Grimsel Test Site and the Mont Terri Project: Update and outlook	Vomvoris S., Blechschmidt I., Vietor T., Mueller H.R.	Proceedings of the International High-Level Radioactive Waste Management Conference, April 12-16, 2015, Charleston, South Carolina.					**11**		**no**
3	The Swiss radioactive waste management program - Brief history, status and outlook	Vomvoris S., Claudel A., Blechschmidt I., Müller H.R.	Journal of Nuclear Fuel Cycle and Waste Technology 10/2013; 1(1):9-27.					**19**		**no**
4	FE/LUCOEX: Design criteria for bentonite block manufacturing and emplacement in an underground facility	Garitte B., Müller H.R., Weber H.P.	Proceedings of the LUCOEX Conference and Workshop: Full-scale demonstration tests in technology development of repositories for disposal of radioactive waste. Oskarshamn, 2.-4. June 2015, 155-160.					**6**	**www.lucoex.eu**	**yes**
5	Backfilling a Horizontal Tunnel with Granular Bentonite – Machine Development, Pre- & Mock-up Tests and Application at the Mont Terri URL	Köhler S., Sakaki t., Weber H.P., Garitte B., Müller H.R.	Proceedings of the LUCOEX Conference and Workshop: Full-scale demonstration tests in technology development of repositories for disposal of radioactive waste. Oskarshamn, 2.-4. June 2015, 35-47.					**18**	**www.lucoex.eu**	**yes**
6	Excavation of the FE tunnel at the Mont Terri URL	Müller H.R., Köhler S., Vogt T.	Proceedings of the LUCOEX Conference and Workshop: Full-scale demonstration tests in technology development of repositories for disposal of radioactive waste. Oskarshamn, 2.-4. June 2015, 129-134.					**6**	**www.lucoex.eu**	**yes**

[1] A permanent identifier should be a persistent link to the published version full text if open access or abstract if article is pay per view) or to the final manuscript accepted for publication.
[2] Open access is defined as free of charge access for anyone via Internet. Please answer "yes" if the open access to the publication is already established and also if the embargo period for open access is not yet over but you intend to establish open access afterwards.

7	Instrumenting, monitoring and heating the Full-Scale Emplacement (FE) Experiment at the Mont Terri URL	Müller H.R., Vogt T., Garitte B., Sakaki T., Spillmann T., Hertrich M., Giroud N.	Proceedings of the LUCOEX Conference and Workshop: Full-scale demonstration tests in technology development of repositories for disposal of radioactive waste. Oskarshamn, 2.-4. June 2015, 49-53.	**5**	**www.lucoex.eu**	**yes**
8	LUCOEX: QA/QC during bentonite material production and emplacement in the framework of the FE Experiment.	Weber H.P.; Garitte B.; Köhler S.; Müller H.	Proceedings of the LUCOEX Conference and Workshop: Full-scale demonstration tests in technology development of repositories for disposal of radioactive waste. Oskarshamn, 2.-4. June 2015, 185-193.	**9**	**www.lucoex.eu**	**yes**
9	Structural geological analysis during excavations in the Mont Terri Rock Lab: Influences of pre-existing fractures on tunnel stability and EDZ characteristics.	Becker J.K.; Jaeggi D.; Lisjak A.; Madritsch H.; Müller H.R.; Schefer S.	Clays in Natural and Engineered Barriers for Radioactive Waste Confinement, 6th international conference, Brussels, March 23-26, 2015	**2**	**www.clayconferencebrussels2015.com**	**yes**
10	Stability of compacted bentonite blocks and block pedestals under changing climatic conditions in tunnels and long-term loads	Garitte B., Kober F., Müller H.R., Köhler S., Weber H.P., Blechschmidt I.	Clays in Natural and Engineered Barriers for Radioactive Waste Confinement, 6th international conference, Brussels, March 23-26, 2015	**2**	**www.clayconferencebrussels2015.com**	**yes**
11	FE experiment / LUCOEX: Production of bentonite based backfill materials.	Garitte B.; Müller H.R.; Weber HP.	Clays in Natural and Engineered Barriers for Radioactive Waste Confinement, 6th international conference, Brussels, March 23-26, 2015	**2**	**www.clayconferencebrussels2015.com**	**yes**
12	FE experiment: THM modelling, predictions, observations and interpretation.	Garitte B.; Thatcher K.; Vogt T.; Müller H.R.; Vietor T.	Clays in Natural and Engineered Barriers for Radioactive Waste Confinement, 6th international conference, Brussels, March 23-26, 2015	**2**	**www.clayconferencebrussels2015.com**	**yes**
13	FE experiment / LUCOEX: Development of a prototype machine for backfilling horizontal emplacement tunnels with granulated bentonite.	Jenni H.; Köhler S.; Müller H.R.	Clays in Natural and Engineered Barriers for Radioactive Waste Confinement, 6th international conference, Brussels, March 23-26, 2015	**2**	**www.clayconferencebrussels2015.com**	**yes**
14	High resolution fiber optic monitoring system for the FE experiment at the Mont Terri URL.	Kishida K.; Vogt T.; Guzik A.; Müller H.R.; Frieg B.; Knüpfer B.	Clays in Natural and Engineered Barriers for Radioactive Waste Confinement, 6th international conference, Brussels, March 23-26, 2015	**2**	**www.clayconferencebrussels2015.com**	**yes**
15	Swiss backfilling concept – Requirements and Approaches for Optimization of the Bentonite Barrier around SF/HLW Disposal Canisters.	Köhler S., Fries T., Müller H.R., Gaus I.	Clays in Natural and Engineered Barriers for Radioactive Waste Confinement, 6th international conference, Brussels, March 23-26, 2015	**2**	**www.clayconferencebrussels2015.com**	**yes**
16	The Full-Scale Emplacement Experiment – Implementation of a multiple heater experiment at the Mont Terri URL	Müller H.R.; Vogt T.; Garitte B.; Köhler S.; Sakaki T.; Weber HP.; Vietor T.:	Clays in Natural and Engineered Barriers for Radioactive Waste Confinement, 6th international conference, Brussels, March 23-26, 2015	**2**	**www.clayconferencebrussels2015.com**	**yes**
17	Numerical pre- and post-construction models of the geomechanical behaviour in the FE experiment at the Mont Terri URL.	Nater P.; Garitte B.; Köhler S.; Müller H.R.:	Clays in Natural and Engineered Barriers for Radioactive Waste Confinement, 6th international conference, Brussels, March 23-26, 2015	**2**	**www.clayconferencebrussels2015.com**	**yes**
18	Evaluation of gas transport phenomena in support of the Full-Scale Emplacement Experiment at the Mont Terri URL	Pappafotiou A., Senger R., Marschall P., Garitte B., Müller H.R.	Clays in Natural and Engineered Barriers for Radioactive Waste Confinement, 6th international conference, Brussels, March 23-26, 2015	**2**	**www.clayconferencebrussels2015.com**	**yes**
19	FE Experiment: Density measurement of granulated bentonite mixture in a 3D 1:1 scale mockup test using dielectric tools.	Sakaki T.; Köhler S.; Hertrich M.; Müller H.R.:	Clays in Natural and Engineered Barriers for Radioactive Waste Confinement, 6th international conference, Brussels, March 23-26, 2015	**2**	**www.clayconferencebrussels2015.com**	**yes**
20	FE Experiment: Density measurement of granulated bentonite mixture in a 2D pre-test using a dielectric moisture profile probe.	Sakaki T.; Köhler S.; Müller H.R.:	Clays in Natural and Engineered Barriers for Radioactive Waste Confinement, 6th international conference, Brussels, March 23-26, 2015	**2**	**www.clayconferencebrussels2015.com**	**yes**
21	FE Experiment: Monitoring of water content in Opalinus Clay using a moisture profile probe and a customized TDR sonde.	Sakaki T.; Vogt T.; Müller H.R.; Wörsching H.:	Clays in Natural and Engineered Barriers for Radioactive Waste Confinement, 6th international conference, Brussels, March 23-26, 2015	**2**	**www.clayconferencebrussels2015.com**	**yes**

22	Geomechanical characterization of the Opalinus Clay from an analysis of the FE Tunnel excavation at the Mont Terri URL	Senger R., Marschall P., Goodarzi S., Walters D., Müller H.R., Vogt T., Garitte B.	Clays in Natural and Engineered Barriers for Radioactive Waste Confinement, 6th international conference, Brussels, March 23-26, 2015	**2**	**www.clayconferencebrussels2015.com**	**yes**
23	Near-field permeability distribution of FE tunnel in the Mont Terri Rock Laboratory - Influence of shotcrete lining on EDZ development	Shao H., Paul B., Wang X., Hesser J., Becker J., Garitte B., Müller H.R.	Clays in Natural and Engineered Barriers for Radioactive Waste Confinement, 6th international conference, Brussels, March 23-26, 2015	**2**	**www.clayconferencebrussels2015.com**	**yes**
24	Fiber optic sensing methods for monitoring temperature and strain implemented in the FE experiment.	Vogt T.; Müller H.; Frieg B.; Vietor T.:	Clays in Natural and Engineered Barriers for Radioactive Waste Confinement, 6th international conference, Brussels, March 23-26, 2015	**2**	**www.clayconferencebrussels2015.com**	**yes**
25	Hydraulic response of Opalinus Clay during excavation and ventilation phases of the 1:1 scale FE experiment.	Vogt T.; Müller H.; Garitte B.; Sakaki T.; Giroud N.; Vietor T.:	Clays in Natural and Engineered Barriers for Radioactive Waste Confinement, 6th international conference, Brussels, March 23-26, 2015	**2**	**www.clayconferencebrussels2015.com**	**yes**
26	FE experiment: The instrumentation and monitoring concept of a 1:1 scale heater experiment at the Mont Terri URL.	Vogt T.; Müller H.; Sakaki T.; Hertrich M.; Spillmann T.; Garitte B.; Giroud N.; Vietor T.	Clays in Natural and Engineered Barriers for Radioactive Waste Confinement, 6th international conference, Brussels, March 23-26, 2015	**2**	**www.clayconferencebrussels2015.com**	**yes**
27	Development of TDR probes for monitoring water content in Opalinus Clay in the FE experiment at Mont Terri Rock Laboratory. [in Japanese]	Sakaki T.; Vogt T.; Müller H.R.; Wörsching H.; Vrzba M.	Japan Society for Civil Engineers Annual Meeting 2014, 2014, S.2.			
28	Scoping computations for the full-scale emplacement (FE) experiment at the Mont Terri underground research laboratory.	Garitte B.; Müller H.; Vogt T.; Vietor T.; Thatcher K.; Senger R.	PEBS - International conference on the Performance of Engineered Barriers: Backfill, Plugs & Seals, February 6-7, 2014, BGR, Hannover, Germany, 2014, S. 507-510.	**4**	**www.pebs-eu.de**	**yes**
29	Bentonite buffer material production and emplacement during the Full-Scale Emplacement (FE) Experiment at the Mont Terri URL.	Müller H.R.; Garitte B.; Weber H.P.; Köhler S.; Plötze M.	PEBS - International conference on the Performance of Engineered Barriers: Backfill, Plugs & Seals, February 6-7, 2014, BGR, Hannover, Germany, 2014, S. 75-78.	**4**	**www.pebs-eu.de**	**yes**
30	Monitoring water content in Opalinus Clay within the FE-Experiment: Test application of dielectric water content sensors.	Sakaki T.; Vogt T.; Komatsu M.; Müller H.	Fall Meeting American Geophysical Union AGU, 09.-13. December 2013, San Francisco, 2013	**1**		**yes**
31	Excavation induced hydraulic response of Opalinus Clay - Investigations of the FE-Experiment at the Mont Terri URL in Switzerland.	Vogt T.; Müller H.; Garitte B.; Sakaki T.; Vietor T.	Fall Meeting American Geophysical Union AGU, 09.-13. December 2013, San Francisco, 2013	**1**		**yes**
32	Monitoring THM effects in a full scale EBS/host rock system - first experiences of the FE-Experiment in the Mont Terri URL during construction and ventilation phase.	Vogt T.; Müller H.; Sakaki T.; Vietor T.	Extended Abstract.- MoDeRn Monitoring in geological disposal of radioactive waste: Objectives, strategies, technologies and public involvement, proceedings of an international conference and workshop, Luxembourg 19-21 March 2013, Deliverable D-N°: 5.4.1, 2013, S. 326-334.	**9**		**yes**
33	The Full-scale Emplacement (FE) Experiment at the Mont Terri URL.	Müller H.R.; Weber H.P.; Köhler S.; Vogt T.; Vietor T.	Clays in Natural and Engineered Barriers for Radioactive Waste Confinement, 5th international meeting, Montpellier, October 22-25, 2012, 2012, S. 200-201.	**2**	**www.montpellier2012.com**	**yes**
34	Granular bentonite production as buffer material for a full-scale emplacement ("FE") experiment.	Teodori S.P.; Weber H.P.; Köhler S.; Plötze M.; Holl M.; Müller H.R.	Clays in Natural and Engineered Barriers for Radioactive Waste Confinement, 5th international meeting, Montpellier, October 22-25, 2012, 2012, S. 336-337.	**2**	**www.montpellier2012.com**	**yes**

Appendix II – Dissemination activities

List of all dissemination activities (publications, conferences, workshops, websites/applications, press releases, flyers, articles published in the popular press, videos, media briefings, presentations, exhibitions, thesis, interviews, films, TV clips, posters).

These tables are cumulative, which means that they show all publications and activities from the beginning until after the end of the project.

TEMPLATE A2: LIST OF DISSEMINATION ACTIVITIES

No	Type of activities[3]	Main leader	Title	Date / Period	Place	Type of audience[4]	Size of audience	Countries addressed
1	*Exhibition*	*SWT+Nagra*	Mont Terri URL	ongoing	St.Ursanne, Switzerland	Civil Society & Scientific Comm.		
2	*Press release*	*Nagra*	The FE Experiment/ LUCOEX	14.11.2014	St.Ursanne, Switzerland	Media	*20*	Switzerland
3	*Press conf.*	*Nagra*	The FE Experiment/ LUCOEX	21.11.2014	St.Ursanne, Switzerland	Media	*20*	Switzerland
4	*Articles*	*various*	Various articles about the FE	Nov. 2014	Various newspapers	Civil Society		Switzerland
5	*Interview*	*Nagra*	The FE Experiment/ LUCOEX	*26.1.2015*	SRF Swiss National TV	Civil Society		Switzerland
6	*Video*	*Nagra*	The FE Experiment/ LUCOEX	May 2015	youtu.be/3iuH5NyG53k	Civil Society & Media	*Youtube*	
7	*Conference*	*Swisstopo*	*Mont Terri Technical Meeting 30*	*8.-9.2.2012*	St.Ursanne, Switzerland	Scientific Community & Industry	*Ca. 100*	
8	*Conference*	*Andra*	Clay Conference	23.-25.10.2012	Montpellier, *France*	Scientific Community & Industry	*Ca. 400*	
9	*Conference*	*SKB*	LUCOEX midterm Conference	25.-26.10.2012	Montpellier, *France*	Scientific Community & Industry	*Ca. 60*	
10	*Conference*	*Swisstopo*	*Mont Terri Technical Meeting 31*	*13.-14.2.2013*	St.Ursanne, Switzerland	Scientific Community & Industry	*Ca. 120*	
11	*Conference*	*BGR*	PEBS Bentonite Workshop	6.-7.2.2014	Hannover, Germany	Scientific Community & Industry	*Ca. 200*	
12	*Conference*	*Swisstopo*	*Mont Terri Technical Meeting 32*	*12.-13.2.2014*	St.Ursanne, Switzerland	Scientific Community & Industry	*Ca. 120*	
13	*Workshop*	*Nagra*	*Backfilling Machine / Bentonite*	*19.-20.5.2014*	Grono, Switzerland	Scientific Community & Industry	*Ca. 50*	
14	*Conference*	*IGD-TP*	*Geodisposal 2014*	*24.-26.6.2014*	Manchester, UK	Scientific Community & Industry		
15	*Conference*	*Swisstopo*	*Mont Terri Technical Meeting 33*	*11.-12.2.2015*	Porrentruy, Switzerland	Scientific Community & Industry	*Ca. 150*	
16	*Conference*	*ONDRAF*	Clay Conference	23.-26.3.2015	Brussels*, Belgium*	Scientific Community & Industry	*Ca. 400*	
17	*Conference*	*SKB*	*LUCOEX end conference*	*2.-4.6.2015*	*Oskashamn, Sweden*	Scientific Community & Industry	*Ca. 80*	

3 publications, conferences, workshops, web, press releases, flyers, articles, videos, media briefings, presentations, exhibitions, thesis, interviews, films, TV clips, posters, other.

4 Scientific community (higher education, research), industry, civil society, policy-makers, media, other ('multiple choice' is possible).

Appendix III – Confidential information

The applications for patents, trademarks, registered designs, etc. shall be listed according to the template B1 provided hereafter.

The list should specify at least one unique identifier e.g. European Patent application reference. For patent applications, only if applicable, contributions to standards should be specified. This table is cumulative, which means that it should always show all applications from the beginning until after the end of the project.

TEMPLATE B1: LIST OF APPLICATIONS FOR PATENTS, TRADEMARKS, REGISTERED DESIGNS, ETC.					
Type of IP Rights[5]:	Confidential Click on YES/NO	Foreseen embargo date	Application reference(s)	Subject or title of application	Applicant (s) (as on the application)
---					

[5] A drop-down list allows selection of the type of IP rights: Patents, Trademarks, Registered designs, Utility models, Others.

Part B2

Please complete the following table:

Type of Exploitable Foreground[6]	Description of exploitable foreground	Confidential Click on YES/NO	Foreseen embargo date	Exploitable product(s) or measure(s)	Sector(s) of application[7]	Timetable, commercial or any other use	Patents or other IPR exploitation (licences)	Owner & Other Beneficiary(s) involved
---								

In addition to the table, please provide text to explain the exploitable foreground, in particular:

- Its purpose
- How the foreground might be exploited, when and by whom
- IPR exploitable measures taken or intended
- Further research necessary, if any
- Potential/expected impact (quantify where possible)

[6] General advancement of knowledge, commercial exploitation of R&D results, exploitation of R&D results via standards, exploitation of results through EU policies, exploitation of results through (social) innovation.

[7] NACE nomenclature: http://ec.europa.eu/competition/mergers/cases/index/nace_all.html

Appendix IV – EC questionnaire

The following questions will assist the Commission in obtaining statistics and indicators on societal and socio-economic issues addressed by projects. The questions are arranged in a number of key themes. As well as producing certain statistics, the replies will also help to identify those projects that have shown a real engagement with wider societal issues, and thereby identify interesting approaches to these issues and best practices. The replies for individual projects will not be made public.

A General Information	
Grant Agreement Number:	**269905**
Title of Project:	**LUCOEX**
Name and Title of Coordinator:	**Jan Gugala, Project Manager SKB AB**

B Ethics	
1. Did your WP undergo an Ethics Review (and/or Screening)? • If Yes: have you described the progress of compliance with the relevant Ethics Review/Screening Requirements in the frame of the periodic/final work package reports? Special Reminder: the progress of compliance with the Ethics Review/Screening Requirements should be described in the Period/Final Work package Reports under the Section 3.2.2 *'Work Progress and Achievements'*	*No*
2. Please indicate whether your WP involved any of the following issues (tick box) :	***No***
RESEARCH ON HUMANS	
• Did the work package involve children?	
• Did the work package involve patients?	
• Did the work package involve persons not able to give consent?	
• Did the work package involve adult healthy volunteers?	
• Did the work package involve Human genetic material?	
• Did the work package involve Human biological samples?	
• Did the work package involve Human data collection?	
RESEARCH ON HUMAN EMBRYO/FOETUS	
• Did the work package involve Human Embryos?	
• Did the work package involve Human Foetal Tissue / Cells?	
• Did the work package involve Human Embryonic Stem Cells (hESCs)?	
• Did the work package on human Embryonic Stem Cells involve cells in culture?	
• Did the work package on human Embryonic Stem Cells involve the derivation of cells from Embryos?	
PRIVACY	
• Did the work package involve processing of genetic information or personal data (eg. health, sexual lifestyle, ethnicity, political opinion, religious or philosophical conviction)?	
• Did the work package involve tracking the location or observation of people?	
RESEARCH ON ANIMALS	
• Did the work package involve research on animals?	
• Were those animals transgenic small laboratory animals?	
• Were those animals transgenic farm animals?	
• Were those animals cloned farm animals?	
• Were those animals non-human primates?	
RESEARCH INVOLVING DEVELOPING COUNTRIES	
• Did the work package involve the use of local resources (genetic, animal, plant etc)?	
• Was the work package of benefit to local community (capacity building, access to healthcare, education etc)?	
DUAL USE	
• Research having direct military use	
• Research having the potential for terrorist abuse	

C	Workforce Statistics	
3.	**Workforce statistics for the work package: Please indicate in the table below the number of people who worked on the work package (on a headcount basis).**	

Type of Position	Number of Women	Number of Men
Scientific Coordinator		
Work package leader WP2	0	1
Experienced researchers (i.e. PhD holders) within Nagra	1	14
PhD Students & scientific apprentices	4	5
Other		

4. How many additional researchers (in companies and universities) were recruited specifically for this work package?	
Of which, indicate the number of men:	

D Gender Aspects

5. Did you carry out specific Gender Equality Actions under the work package?	○ ●	Yes No

6. Which of the following actions did you carry out and how effective were they?

	Not at all effective				Very effectiv e
❑ Design and implement an equal opportunity policy	○	○	○	○	○
❑ Set targets to achieve a gender balance in the workforce	○	○	○	○	○
❑ Organise conferences and workshops on gender	○	○	○	○	○
❑ Actions to improve work-life balance	○	○	○	○	○
○ Other:					

7. Was there a gender dimension associated with the research content – i.e. wherever people were the focus of the research as, for example, consumers, users, patients or in trials, was the issue of gender considered and addressed?

○ Yes- please specify

● No

E	Synergies with Science Education
8.	**Did your work package involve working with students and/or school pupils (e.g. open days, participation in science festivals and events, prizes/competitions or joint work packages)?** ◉ Yes- please specify: University students were working as "scientific apprentices" for WP2 ○ No
9.	**Did the work package generate any science education material (e.g. kits, websites, explanatory booklets, DVDs)?** ○ Yes- please specify ◉ No

F	Interdisciplinarity
10.	**Which disciplines (see list below) are involved in your work package?** ◉ Main discipline: 1.4 & 2.1 & 2.3 ○ Associated discipline: ○ Associated discipline:

CLASSIFICATION OF SCIENTIFIC DISCIPLINES ACCORDING TO THE FRASCATI MANUAL

1. NATURAL SCIENCES

1.1 Mathematics and computer sciences [mathematics and other allied fields: computer sciences and other allied subjects (software development only; hardware development should be classified in the engineering fields)]

1.2 Physical sciences (astronomy and space sciences, physics and other allied subjects)

1.3 Chemical sciences (chemistry, other allied subjects)

1.4 Earth and related environmental sciences (geology, geophysics, mineralogy, physical geography and other geosciences, meteorology and other atmospheric sciences including climatic research, oceanography, vulcanology, palaeoecology, other allied sciences)

1.5 Biological sciences (biology, botany, bacteriology, microbiology, zoology, entomology, genetics, biochemistry, biophysics, other allied sciences, excluding clinical and veterinary sciences)

2 ENGINEERING AND TECHNOLOGY

2.1 Civil engineering (architecture engineering, building science and engineering, construction engineering, municipal and structural engineering and other allied subjects)

2.2 Electrical engineering, electronics [electrical engineering, electronics, communication engineering and systems, computer engineering (hardware only) and other allied subjects]

2.3. Other engineering sciences (such as chemical, aeronautical and space, mechanical, metallurgical and materials engineering, and their specialised subdivisions; forest products; applied sciences such as geodesy, industrial chemistry, etc.; the science and technology of food production; specialised technologies of interdisciplinary fields, e.g. systems analysis, metallurgy, mining, textile technology and other applied subjects)

3. MEDICAL SCIENCES

3.1 Basic medicine (anatomy, cytology, physiology, genetics, pharmacy, pharmacology, toxicology, immunology and immunohaematology, clinical chemistry, clinical microbiology, pathology)

3.2 Clinical medicine (anaesthesiology, paediatrics, obstetrics and gynaecology, internal medicine, surgery, dentistry, neurology, psychiatry, radiology, therapeutics, otorhinolaryngology, ophthalmology)

3.3 Health sciences (public health services, social medicine, hygiene, nursing, epidemiology)

4. AGRICULTURAL SCIENCES

4.1 Agriculture, forestry, fisheries and allied sciences (agronomy, animal husbandry, fisheries, forestry, horticulture, other allied subjects)

4.2 Veterinary medicine

5. SOCIAL SCIENCES

5.1 Psychology

5.2 Economics

5.3 Educational sciences (education and training and other allied subjects)

5.4 Other social sciences [anthropology (social and cultural) and ethnology, demography, geography (human, economic and social), town and country planning, management, law, linguistics, political sciences, sociology, organisation and methods, miscellaneous social sciences and interdisciplinary , methodological and historical S1T activities relating to subjects in this group. Physical anthropology, physical geography and psychophysiology should normally be classified with the natural sciences].

6. HUMANITIES

6.1 History (history, prehistory and history, together with auxiliary historical disciplines such as archaeology, numismatics, palaeography, genealogy, etc.)

6.2 Languages and literature (ancient and modern)

6.3 Other humanities [philosophy (including the history of science and technology) arts, history of art, art criticism, painting, sculpture, musicology, dramatic art excluding artistic "research" of any kind, religion, theology, other fields and subjects pertaining to the humanities, methodological, historical and other S1T activities relating to the subjects in this group]

G	Engaging with Civil society and policy makers		
11a	**Did your work package engage with societal actors beyond the research community?** *(if 'No', go to Question 14)*	● ○	Yes No

11b If yes, did you engage with citizens (citizens' panels / juries) or organised civil society (NGOs, patients' groups etc.)?

- ○ No
- ○ Yes- in determining what research should be performed
- ○ Yes - in implementing the research
- ● Yes, in communicating /disseminating / using the results of the work package

11c	**In doing so, did your work package involve actors whose role is mainly to organise the dialogue with citizens and organised civil society (e.g. professional mediator; communication company, science museums)?**	● ○	Yes No

12. Did you engage with government / public bodies or policy makers (including international organisations)

- ○ No
- ○ Yes- in framing the research agenda
- ○ Yes - in implementing the research agenda
- ● Yes, in communicating /disseminating / using the results of the work package

13a Will the work package generate outputs (expertise or scientific advice) which could be used by policy makers?

- ○ Yes – as a **primary** objective (please indicate areas below- multiple answers possible)
- ● Yes – as a **secondary** objective (please indicate areas below - multiple answer possible)
- ○ No

13b If Yes, in which fields?

Agriculture	Energy	Human rights
Audiovisual and Media	Enlargement	Information Society
Budget	Enterprise	Institutional affairs
Competition	Environment	Internal Market
Consumers	External Relations	Justice, freedom and security
Culture	External Trade	Public Health
Customs	Fisheries and Maritime Affairs	Regional Policy
Development Economic and Monetary Affairs	Food Safety	Research and Innovation
Education, Training, Youth	Foreign and Security Policy	Space
Employment and Social Affairs	Fraud	Taxation
	Humanitarian aid	Transport

13c If Yes, at which level?

- ○ Local / regional levels
- ● National level
- ○ European level
- ○ International level

H	Use and dissemination		
14. How many Articles were published/accepted for publication in peer-reviewed journals?			34
To how many of these is open access[8] provided?			31
How many of these are published in open access journals?			0
How many of these are published in open repositories?			31
To how many of these is open access not provided?			3
Please check all applicable reasons for not providing open access:			
✓ publisher's licensing agreement would not permit publishing in a repository ❑ no suitable repository available ❑ no suitable open access journal available ❑ no funds available to publish in an open access journal ❑ lack of time and resources ❑ lack of information on open access ❑ other[9]: ……………			
15. How many new patent applications ('priority filings') have been made? *("Technologically unique": multiple applications for the same invention in different jurisdictions should be counted as just one application of grant).*			0
16. Indicate how many of the following Intellectual Property Rights were applied for (give number in each box).	Trademark		0
	Registered design		0
	Other		0
17. How many spin-off companies were created / are planned as a direct result of the work package?			0
Indicate the approximate number of additional jobs in these companies:			

18. Please indicate whether your work package has a potential impact on employment, in comparison with the situation before your work package:

❑	Increase in employment, or	❑	In small & medium-sized enterprises
❑	Safeguard employment, or	❑	In large companies
❑	Decrease in employment,	❑	None of the above / not relevant to the work package
✓	Difficult to estimate / not possible to quantify		

19. For your work package partnership please estimate the employment effect resulting directly from your participation in Full Time Equivalent (*FTE = one person working fulltime for a year*) jobs:	*Indicate figure:*
Difficult to estimate / not possible to quantify	✓

[8] Open Access is defined as free of charge access for anyone via Internet.
[9] For instance: classification for security project.

I	Media and Communication to the general public
20.	**As part of the work package, were any of the beneficiaries professionals in communication or media relations?** ◉ Yes ○ No
21.	**As part of the work package, have any beneficiaries received professional media / communication training / advice to improve communication with the general public?** ◉ Yes ○ No

22 Which of the following have been used to communicate information about your work package to the general public, or have resulted from your work package?

✓	Press Release	✓	Coverage in specialist press
✓	Media briefing	❑	Coverage in general (non-specialist) press
✓	TV coverage / report	✓	Coverage in national press
❑	Radio coverage / report	❑	Coverage in international press
❑	Brochures /posters / flyers	✓	Website for the general public / internet
✓	DVD /Film /Multimedia	✓	Event targeting general public (festival, conference, exhibition, science café)

23 In which languages are the information products for the general public produced?

❑	Language of the coordinator	✓	English
❑	Other language(s)	✓	German