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LUCOEX PROJECT

D 2.1 WORK PLAN

Large Underground Concept Experiments
"LUCOEX"

Work Package 2:
Full-Scale Emplacement Experiment (FE) at Mont Terri

Keywords: LUCOEX, FE, FP7, EURATOM, EC, deliverable, work plan, tunnel construction, emplacement, engineered barrier system, bentonite, heater experiment, Full-Scale Emplacement, Mont Terri

Revision log

Revision	Date	Changed sections

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1 Introduction

1.1 General

The overall objective of the LUCOEX Project (FP7 EURATOM) Work Package 2 (WP2) "Full-Scale Emplacement Experiment (FE) in Mont Terri" is to demonstrate on a 1:1 scale the Swiss repository concept for the disposal of SF and HLW in Opalinus Clay. The key elements of the experiment will be conducted at the Mont Terri rock laboratory. The following activities are supported by, and form part of, the LUCOEX Project: tunnel construction and support, selection and modification of the tunnelling machine, manufacturing of the buffer material, development of emplacement equipment and emplacement activities. The integration activities linked to WP1 will focus on networking for new scientists through the secondment of employees of the project partners to Nagra.

The Work Package 2 to be performed at the Mont Terri rock laboratory consists of the following tasks:

- Task 2.1 Experiment planning – this report
- Task 2.2 Tunnel construction and support
- Task 2.3 Preparation for emplacement
- Task 2.4 Emplacement activities
- Task 2.5 Final reporting of WP2
- Task 2.6 Integration

WP2 will be implemented between 1st January 2011 and 31st December 2014.

2 Definitions

This document describes the work plan for Work Package 2 (WP2) of the Large Underground Concept Experiments (LUCOEX) Project (FP7 EURATOM), which is coordinated by SKB (Sweden). The lead beneficiary of WP2 is the NATIONAL COOPERATIVE FOR THE DISPOSAL OF RADIOACTIVE WASTE (Nagra, Switzerland). The project will be implemented in collaboration with a consortium of international participants (also referred to as "partners" in this document):

- SVENSK KÄRNBRÄNSLEHANTERING AB (SKB, Sweden)
- AGENCE NATIONALE POUR LA GESTION DES DECHETS RADIOACTIFS (ANDRA, France)
- POSIVA OY (POSIVA, Finland)

This Work Plan describes the objectives, activities and expected results of WP2, its links to other WPs in LUCOEX and the implementation methods and activities.

3 Objectives of WP2

3.1 Technical development objectives

This experiment has the following objectives:

- Providing confirmation of the suitability of the repository design basis in Nagra's concept or giving a clear insight into how it should be modified;
- Constructing an emplacement tunnel using standard or modified equipment (e.g. modified road header) and adequate support measures (anchors, lining or steel ribs);
- Manufacturing the bentonite buffer in a suitable form and density;
- Designing, manufacturing and testing in situ equipment required for waste and buffer emplacement.

3.2 Objectives related to occupational safety

One objective of WP2 is to provide and maintain safe and healthy conditions for working personnel. The conditions should be free of any hazards causing, or likely to cause, death or serious physical harm to employees and should comply with relevant European legislation and respective national occupational safety and health regulations.

3.3 Objectives related to schedule

The objective is to realise the Work Package respecting the initial schedule agreed with the consortium. The WP was started on 1st January 2011 and will be terminated 48 months later, on 31st December 2014.

The WP overall schedule is presented in the Gantt chart annexed to this Work Plan as Annex A.

3.4 Budget objectives

The WP implementation aims to respect the budget framework of 2,139,500 €.

4 Planning activities for WP2 (Task 2.1)

4.1 Introduction

4.1.1 Requirements

The main goals of the FE Experiment at Mont Terri are to (i) further develop the understanding of THM effects in a full-scale EBS/host rock system and (ii) determine if there are any unexpected interactions or phenomena that need to be examined in greater detail. Within the restrictions imposed by the different conditions in the Mont Terri URL, the understanding developed in the FE Experiment will help to confirm that THM impacts on rock and backfill do not significantly degrade the safety functions of the buffer and the host rock.

The experiment concept has two basic objectives:

- Providing a check of the suitability of the repository design basis (reference thermal load per canister, dimensions, and materials) assumed in Nagra's concept or giving a clear insight into how it should be modified.
- Focusing on understanding of the processes in the buffer and the host rock at full scale and providing partial validation of coupled THM models (and insights into THC models).

These objectives should be met by studying the relevant processes on a 1:1 scale using a tunnel with several heaters that have the reference heat output of disposal canisters and which are surrounded by a reference buffer. In order to achieve this, the experiment will need to provide sufficient heating of the rock such that ΔT impacts on HM processes in the rock can be measured and associated models tested. Instrumentation of the buffer and rock should be sufficient to allow pre-experiment THM model calculations to be tested (validated within certain "boundary conditions") and to confirm satisfactory performance of the design basis.

4.2 Tunnel construction and support (Task 2.2)

4.2.1 Location and geological situation of the FE Experiment

The FE Experiment will be located at the end of the Mine-by Test (MB) tunnel in the shaly facies, far outside the existing laboratory tunnels and experiments in the Mont Terri rock laboratory. The Opalinus Clay, a shale formation, consists mainly of silty and sandy shales with about 66 % sheet silicates (illite, illite/smectite mixed layers, chlorite, kaolinite), 13 % calcite, 3 % siderite, 14 % quartz and about 1 % feldspar and 1 % pyrite (Nagra 2002b).

A simplified geological cross-section is shown below (Fig. 4.2.1).

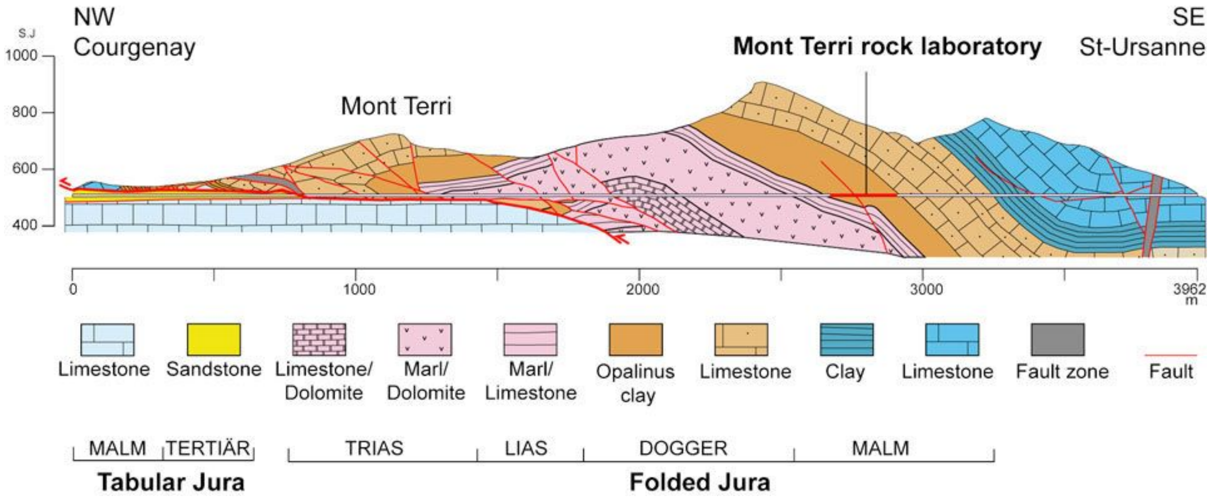


Fig. 4.2.1. Geological cross-section of Mont Terri (Freivogel, M., & Huggenberger, P.,2003).

The main tectonic structure in the area considered is the Mont Terri anticline of the Folded Jura. The orientation of the FE gallery will be parallel to the geological bedding. The bedding planes dip about 30°-40° from horizontal to the south-east.

The gallery will have a length of 50 m, an inner diameter of 2.6 – 2.8 m and an outer diameter of 2.9 – 3.2 m, depending on the type and thickness of the lining and accounting for constructional tolerances.

To ensure sufficient space for the emplacement work and the drilling of monitoring boreholes, a start niche of 8.40 m length, 9.60 m width and 5.30 m height (inner dimensions) was constructed in advance of the tunnelling work between February and June 2011.

4.2.2 General gallery specification

The gallery will be constructed in such a way that the results and data from the long-term experiment can be transferred to the boundary conditions specified in Nagra's disposal feasibility study of 2002 (Nagra 2002a, Nagra 2002b). In addition, the experiment aims to provide information on constructability issues (stability, rock support system, short-term deformation). The gallery construction specifications are outlined as follows:

- The gallery will be horizontal (0 %, for operational safety reasons), following the strike of the sedimentary bedding at Mont Terri;
- Overall gallery length: 50 m;
  - Length of access gallery and plug: 15 m;
  - Length of THM test section: 22.8 m;
  - Length of interjacent / sealing test section: 12.2 m;
- Outer gallery diameter: 3.0 m (taking into account ± 2 × 5 cm of expected tolerances, 2 × 5 cm of convergences and 2 × 16 cm of sprayed concrete liner);
  - Guaranteed minimum clearance (inner diameter): 2.48 m;
  - Maximum clearance (inner diameter): ca. 2.75 m;
- Length of one heater: 4.60 m; diameter of heaters 1.05 m; weight per heater: ca. 5 t;
- Distance between two heaters: 3.0 m. Three heaters will be emplaced;
- Excavation method: point attack header machine (appropriate equipment will be selected by the responsible construction company);
- Assumed maximum achievable excavation advance rate: 1.5 m/d;
- Maximum admissible excavation length: 1.5 m (≅ ½ × outer diameter);

- Ring closure at a distance of maximum 1.5 × outer tunnel diameter (i.e. 4.5 m);
- Rock support in compliance with reference concepts proposed by Nagra (see section 4.2.2.1).

4.2.2.1 Rock mechanical scoping calculations

Scoping calculations were performed to evaluate rock support design options. The aim was to assess design recommendations and rock behaviour. The numerical model set-up, including material laws and modelling sequences, was based on the analysis carried out for the disposal feasibility study of 2002 (Konietzky et al. 2003). The initial and boundary conditions as well as the parameters were derived from the Mont Terri database.

Four different rock support measures – Sprayed Concrete Liner (SCL), steel ribs (TH 29), systematic rock bolting and Thin Spray-on Liner (TSL) – were evaluated and compared with rock mass behaviour without any rock support (Fig. 4.2.2).

The scoping calculations indicated that circumferential supporting liner systems such as SCL and steel ribs have the potential to control short-term deformation and the extent of the EDZ, while providing stability and hence a safe working environment. SCL and steel ribs are therefore the preferred options compared to rock bolts or TSL systems. Field observations indicate that the deformation appears to be underestimated and further analyses and an appropriate liner design are required.

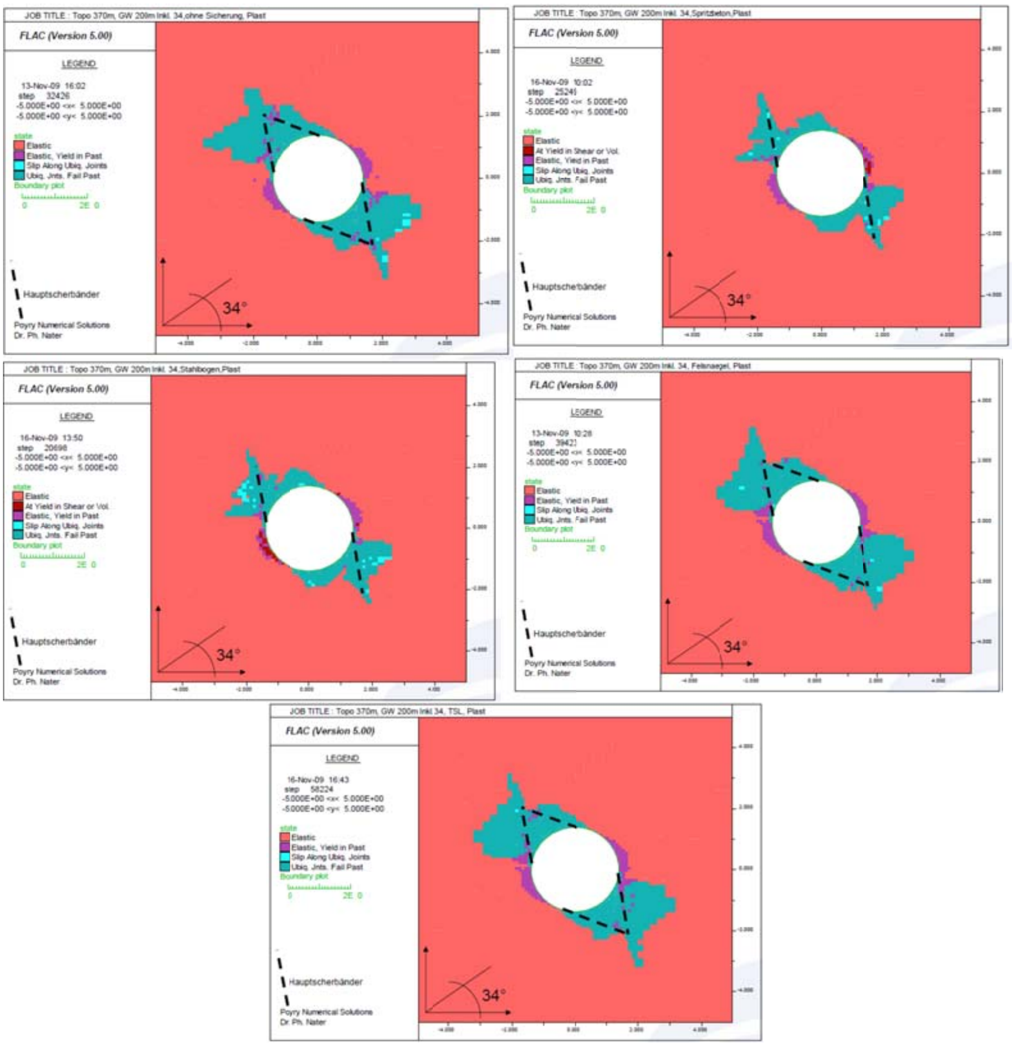


Fig. 4.2.2. Scoping calculations showing the degree of plasticity within the EDZ induced by the bedding (bedding direction indicated with 34°) for various rock support systems. Top left: without any lining; top right: 15 cm shotcrete; middle left: steel ribs; middle right: rock bolts and wire mesh; bottom: TSL.

4.2.2.2 Rock support

Emplacement gallery

The experiment layout coincides with ongoing developments of the liner concepts for HLW emplacement tunnels (Nagra 2009b, Nagra 2010).

In order to test different rock support systems with the framework of LUCOEX, two fundamental liner concepts are envisaged as follows, which can be arranged consecutively or combined:

(1) 16 cm thick sprayed concrete liner (SCL) using low-pH dry mix with one layer of wire mesh. Shotcrete has to be applied circumferentially for every axial advancing step of approx. 1 m to 1.5 m. In order to mitigate overstressing of the SCL due to excessive local strains, open longitudinal slots or yielding elements in the lining are planned ("Sections" or "Tronçons" B-D). Additional rock bolting is envisaged in order to counteract early geomechanical softening.

(2) Circumferential steel support system consisting of TH profiles (steel ribs) and yielding connection elements (clamps) every 1 m, including wire mesh in the crown to avoid rock fall ("Tronçons" E-F). Additional rock bolting is an option.

The gallery will be divided into functional sections, considering the experimental set-up as well as structural elements. Fig. 4.2.3 shows the sectional arrangement of the liner: the first 9 m of the gallery ("Tronçon" A) will be shotcreted and additionally supported by steel ribs, aiming to achieve a very high strength in the vicinity of the start niche. Thus, a combination of both fundamental support systems is envisaged here, which is not an experimental issue but an important structural concern.

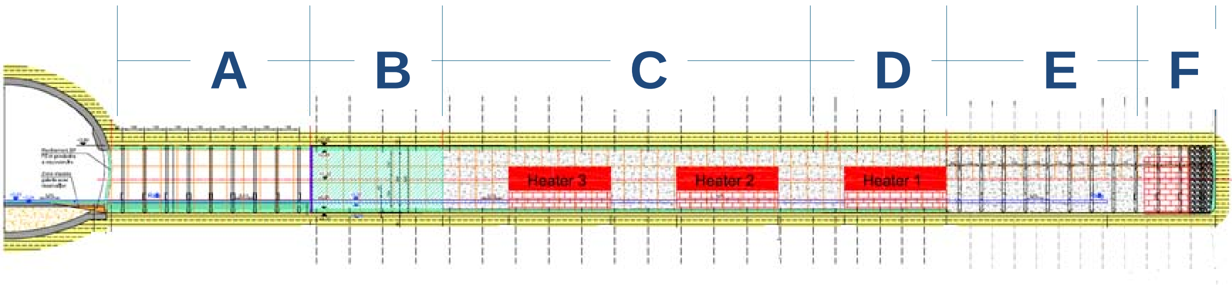


Fig. 4.2.3. Longitudinal section of the test tunnel and liner concept, also showing the experimental layout, i.e. functional sections and the arrangement of the dummy canisters (heater elements), as well as the space provided for the plug.

The following 28.8 m ("Tronçons B-D") will also be shotcreted, but exhibit no steel ribs. This section might additionally be supported by glass fibre rock bolts which behave thermally neutrally in the context of the THM coupled effects to be measured. However, if working conditions prove to be sufficiently secure while advancing, rock bolts could be omitted. Both variants correspond with current design studies for an alternative liner concept for the spent fuel emplacement gallery (Nagra 2010).

The last 12.2 m ("Tronçon E") will be lined with steel ribs only. The intention is to investigate the impact and effectiveness of both preferred liner concepts. Additional rock bolting is an option here in the case of unfavourable / unsecure conditions.

The end tunnel face has to be excavated slightly vaulted and shotcreted.

Different support concepts are shown in Fig. 4.2.4, but the support in all sections will be installed according to the following standards:

- Full rock support and ring closure is required within a distance < 4.5 m from the excavation face at any time (≅ 1.5 × outer diameter);
- Yielding zones within the gallery lining allowing for controlled convergences.

The different sectional specifications are summarized as:

- Tronçon A: steel ribs, shotcrete layer (reinforced) and rock bolts (if required);
- Tronçons B – D: first 7 – 10 cm shotcrete layer (reinforced) and rock bolts in the crown and the wall to be applied after each excavation sequence if necessary in terms of safety (glass fibre rock bolts);
- Tronçons E – F: steel ribs, wire mesh and rock bolts (if required) in the crown and the wall to be applied after each excavation sequence.

The following details will be addressed in future steps:

- For sections A – D, low-pH sprayed concrete (LPC) will be used as a lining material because this will be used in a clay host rock repository. However, since the use of LPC does not influence the main experimental targets, its use will be considered depending on additional costs and time. The suitability of LPC shotcrete using the wet mix methodology has been demonstrated (ESDRED 2009b). However, the wet mix method might result in additional effort and expense due to specific constraints resulting primarily from the small amounts needed per application sequence. Hence, the dry mix methodology is preferred, but suitability tests will have to be carried out in advance.

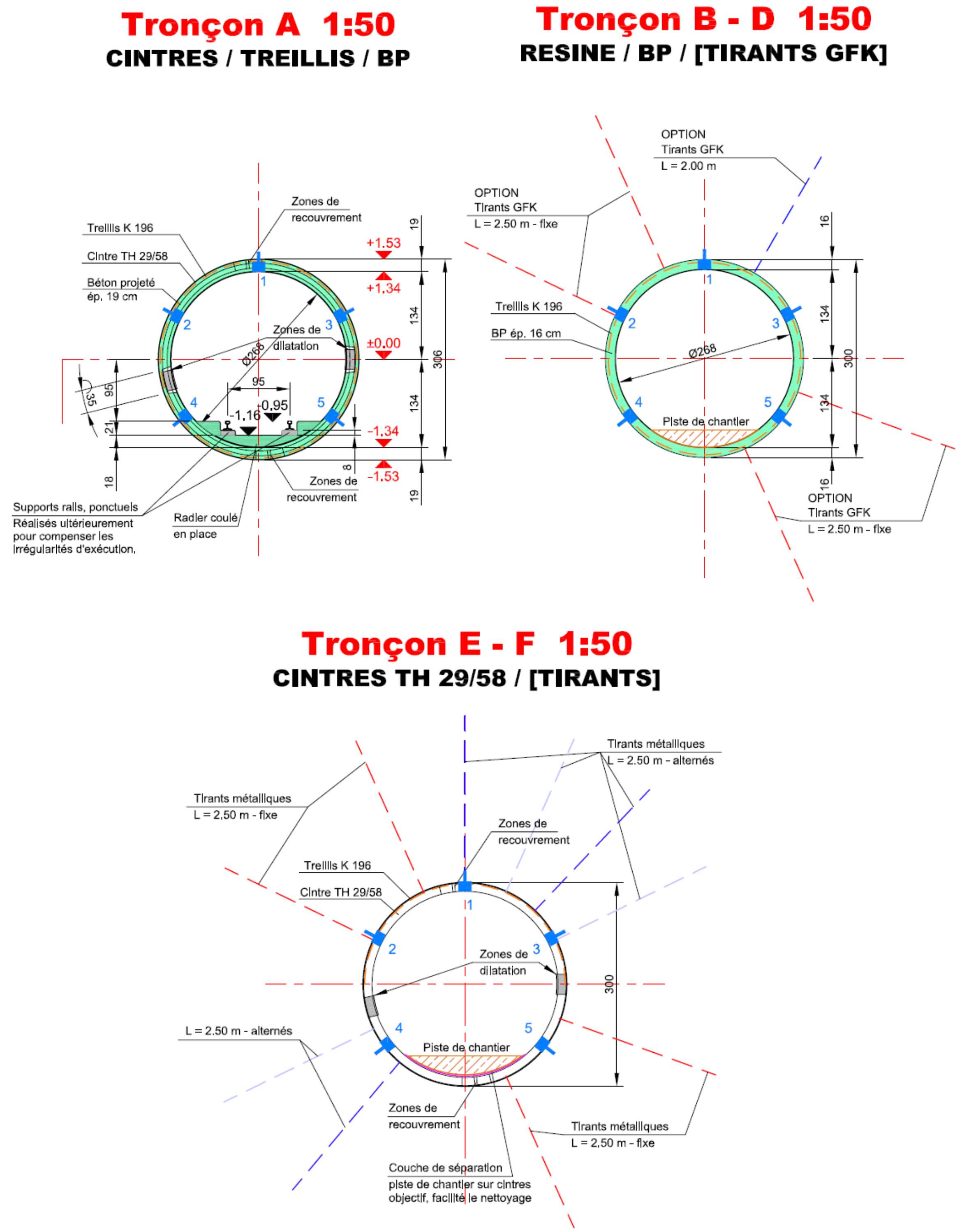


Fig. 4.2.4. Sectional rock support systems for the FE Experiment
(dashed lines: optional bolting; red: fixed bolting positions; blue: alternate positions).

4.2.2.3 Start niche (FE-A)

The purpose of the start niche or monitoring niche is to allow the drilling of exploration and monitoring boreholes. This niche also facilitates the excavation and emplacement work.

The start niche was excavated between February and June 2011. It is located beyond the pre-existing MB niche and has a total width of 9.60 m and a length of 8.40 m (inner dimensions), taking into account the space needed for some of the emplacement equipment operations during the forthcoming backfilling process (see section 4.4). The roof and the floor of the start niche are arched. The maximum height of the structure is 6.70 m (plus concrete wall thickness of 2 × 30 cm resulting in a total excavation height of up to 7.30 m). The backfill of the invert with a gravel-sand mixture up to operational level has a thickness of ca. 1.30 m (including a concrete floor).

Excavation of the start niche was carried out using road headers (a Brokk 260 under restricted working space conditions and a CAT 312 wheel excavator with higher performance, each with a boom-mounted cutting head). Rock support consists of ca. 30 cm of shotcrete reinforced with nine heavy lattice girders (4G-180/34) and two layers of wire mesh (K 196), as well as 3.50 m long rock bolts. Figs. 4.2.5 to 4.2.8 show the construction details of the start niche.

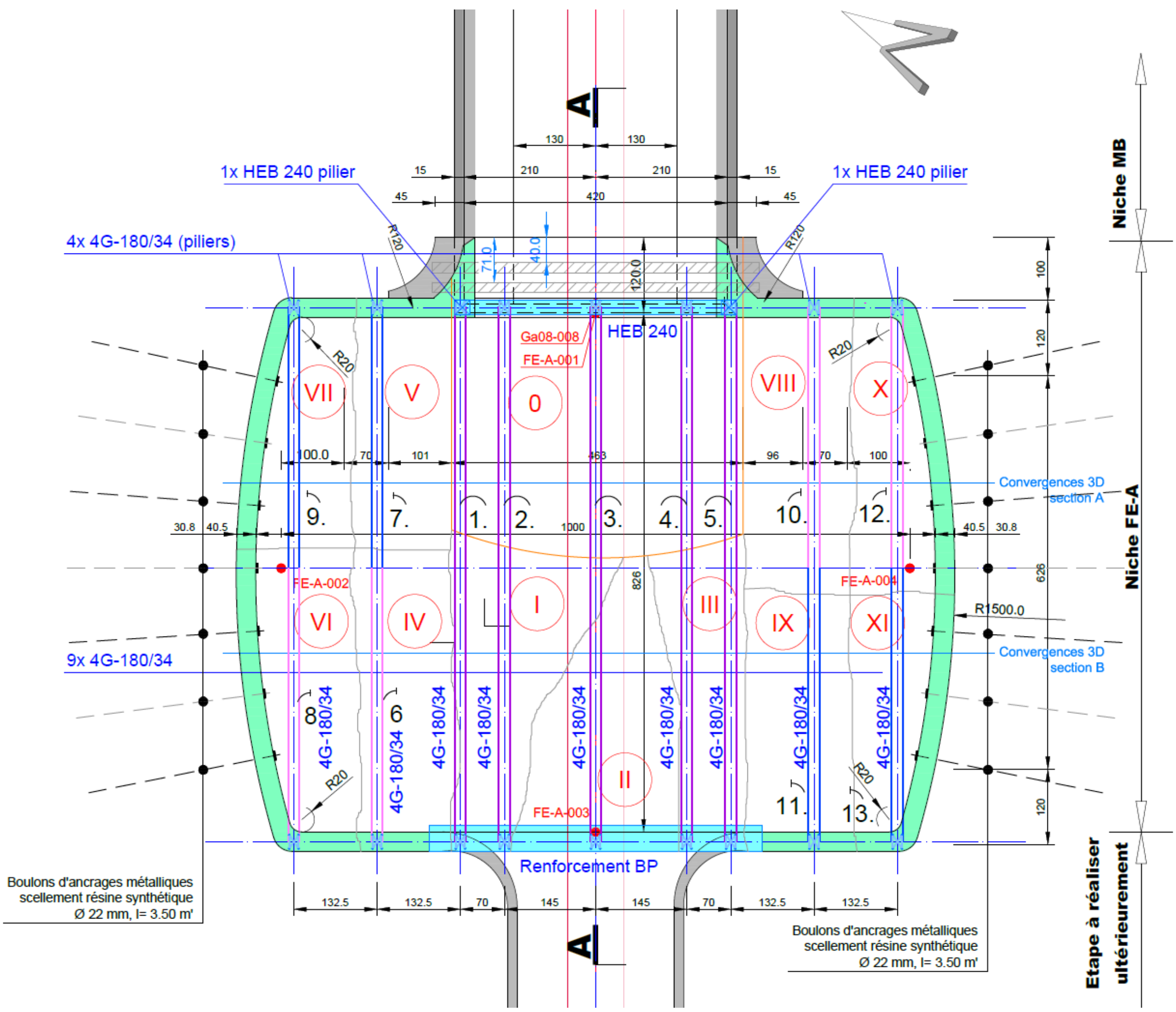


Fig. 4.2.5. Plane view of the start niche (execution plan by GGT S.A.) [cm].

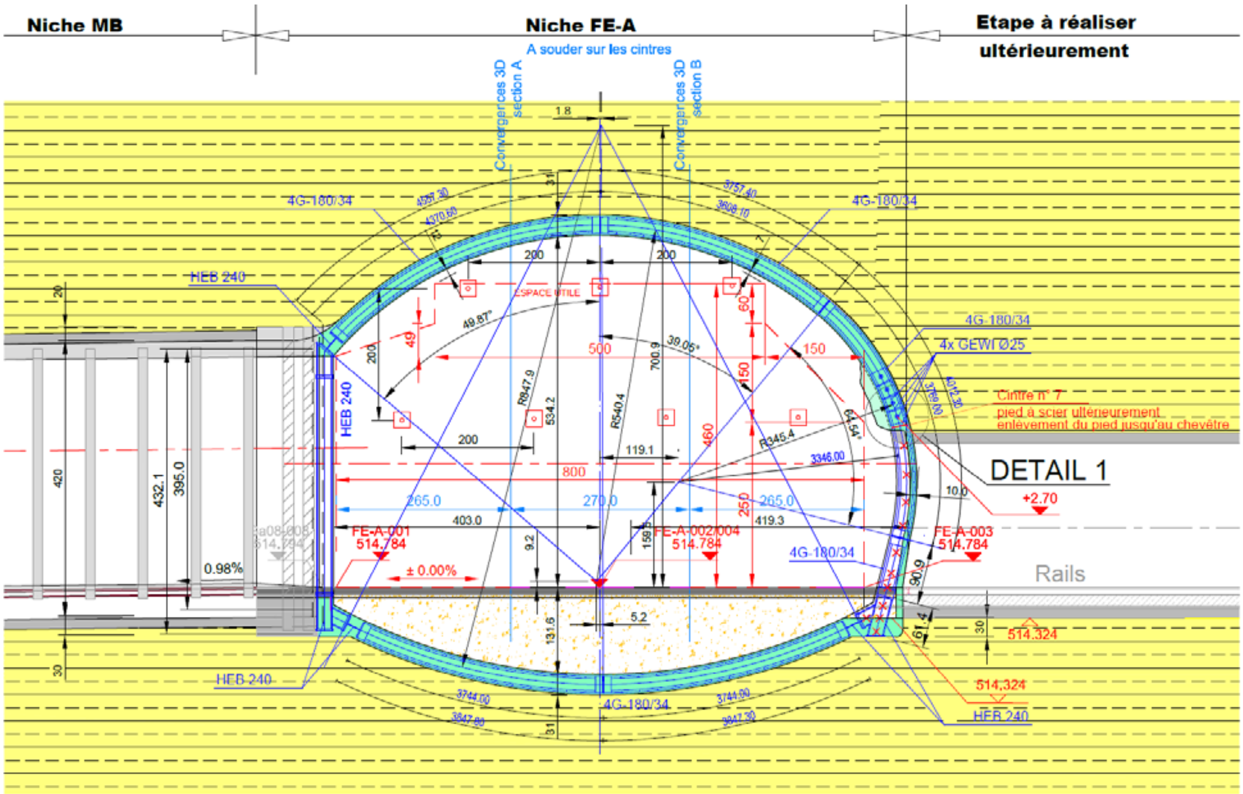


Fig. 4.2.6. Longitudinal section (A-A) of the start niche (execution plan by GGT S.A.) [cm].

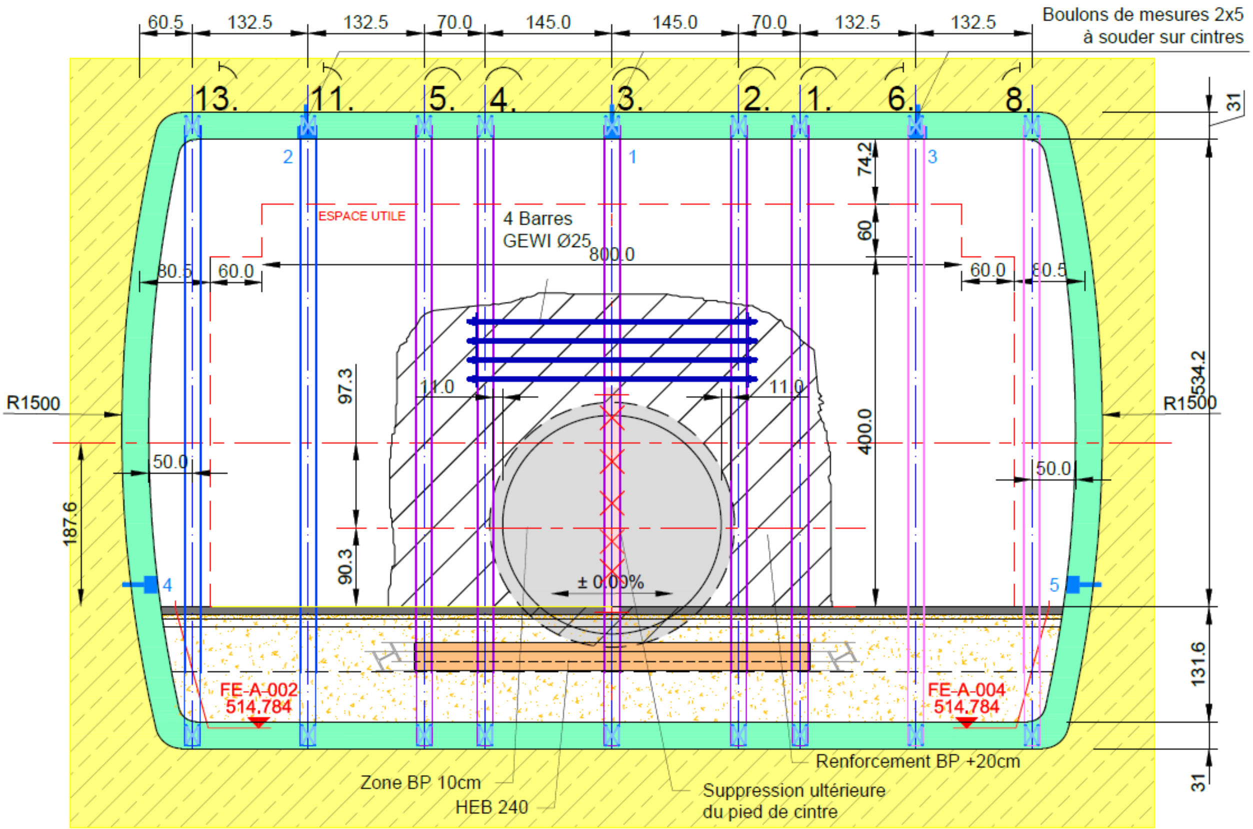


Fig. 4.2.7. Cross-section of the start niche, view towards the future FE gallery (execution plan by GGT S.A.) [cm].

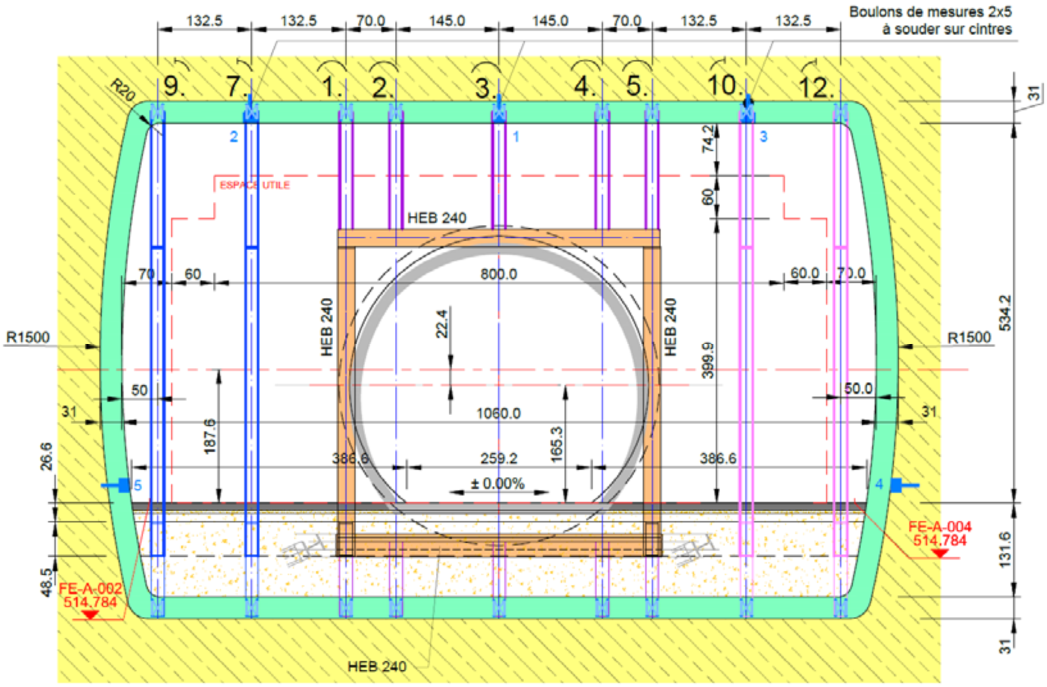


Fig. 4.2.8. Cross-section of the start niche, view towards the MB gallery (execution plan by GGT S.A.) [cm].

4.2.3 Possible modification of the tunnelling machine

The specifications for the tunnel dimensions and support system combined with the restricted space (according to section 4.2.2) are quite challenging with respect to the excavation system. Basically, the specifications were issued together with the tender documents for the gallery construction work and it is up to the construction company to propose and describe an appropriate header device in a technical report submitted with their offer. Nevertheless, some preliminary considerations have been made, which are presented below.

In order to install the rock support circumferentially within 1.5 × excavation diameters behind the tunnel face, a full-face TBM system is not considered as a favourable option. Therefore, road header or pneumatic hammer excavation techniques have been examined in detail. The road header technique is considered to be most suitable for keeping the prescribed tolerances (deviation from ideal profile) and limiting the roughness of the excavated tunnel wall. This will be important for the lining performance in particular.

In principle there are two options for the excavation equipment:

- Existing road header equipment (e.g. Eickhoff ET 120);
- Existing cutting devices (e.g. Erkat ER 600-1 transverse cutter) attached to any basic machine.

The excavation work requires tunnelling equipment with the capacity to carry a heavy cutter and to transmit sufficient normal force to excavate the rock. At the same time, the equipment has to be small enough to work in tight spaces, while providing cutter booms and heads to cover the whole tunnel face. Road headers such as the Eickhoff ET 120 (Eickhoff Bautechnik Bochum) would provide sufficient tractive power for stable performance, but they usually are not capable of excavating circular profiles. Therefore, such equipment needs to be modified by removing the muck loading device and adding a number of struts (e.g. hydraulic press) in order to heave the back and fix the entire equipment. However, despite these modifications this option is still not very flexible and is therefore judged to be unfavourable.

As an alternative, there are basic machines available such as the ITC 120 (Fig. 4.2.9) or the Brokk 260 (Fig. 4.2.10), which may have somewhat reduced power and performance capacity but have the ability to excavate circumferential profiles and are favourable in terms of flexibility. In order to increase the performance, the equipment could be improved by attaching struts against the gallery wall (e.g. by means of hydraulic presses) in order to add more pressure force to the system.

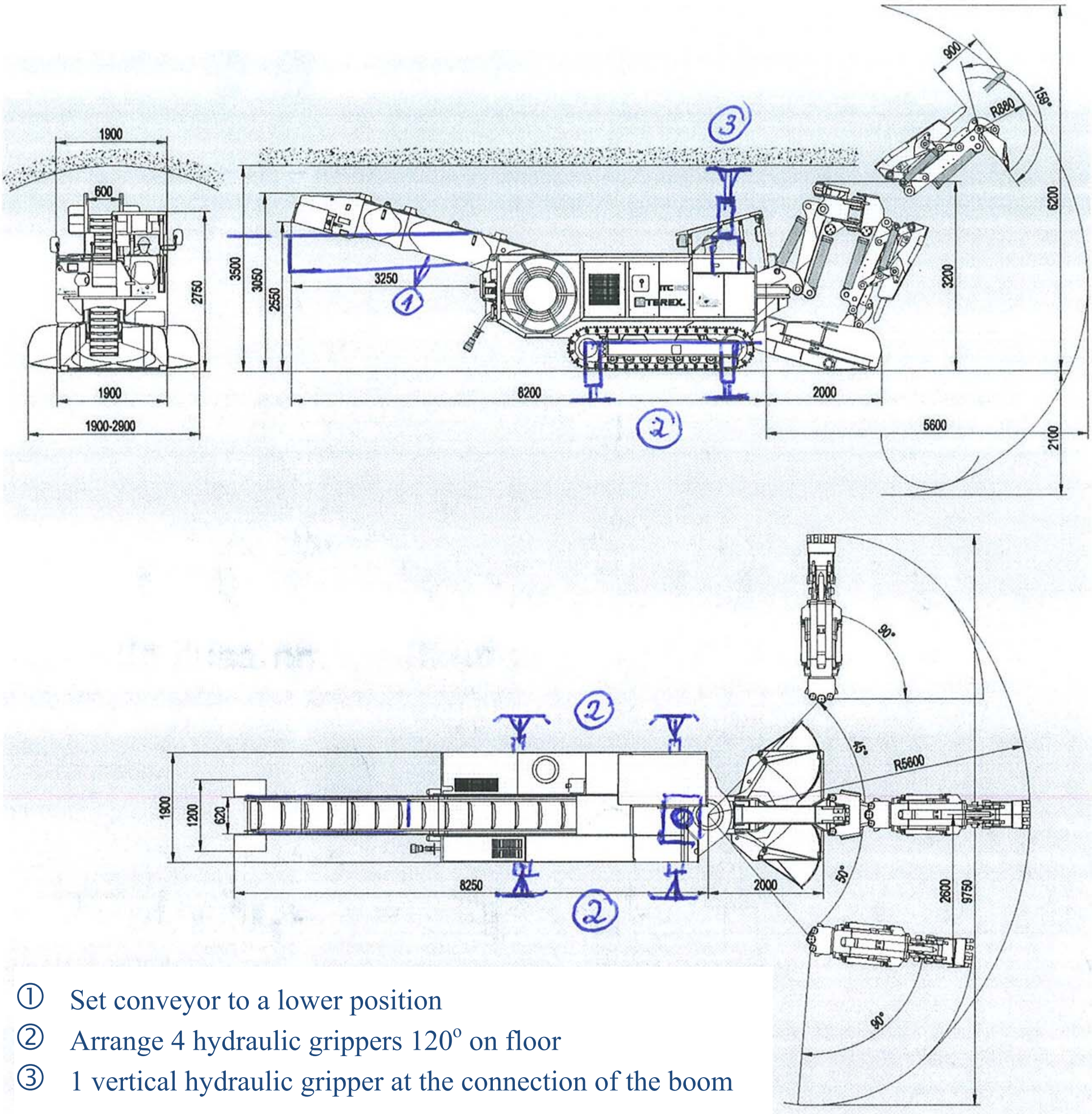


Fig. 4.2.9. Type ITC 120 basic machine. Indicated are potential modifications for improving performance (Original drawing taken from www.alpinecutter.com, modified by Jenni 2011).

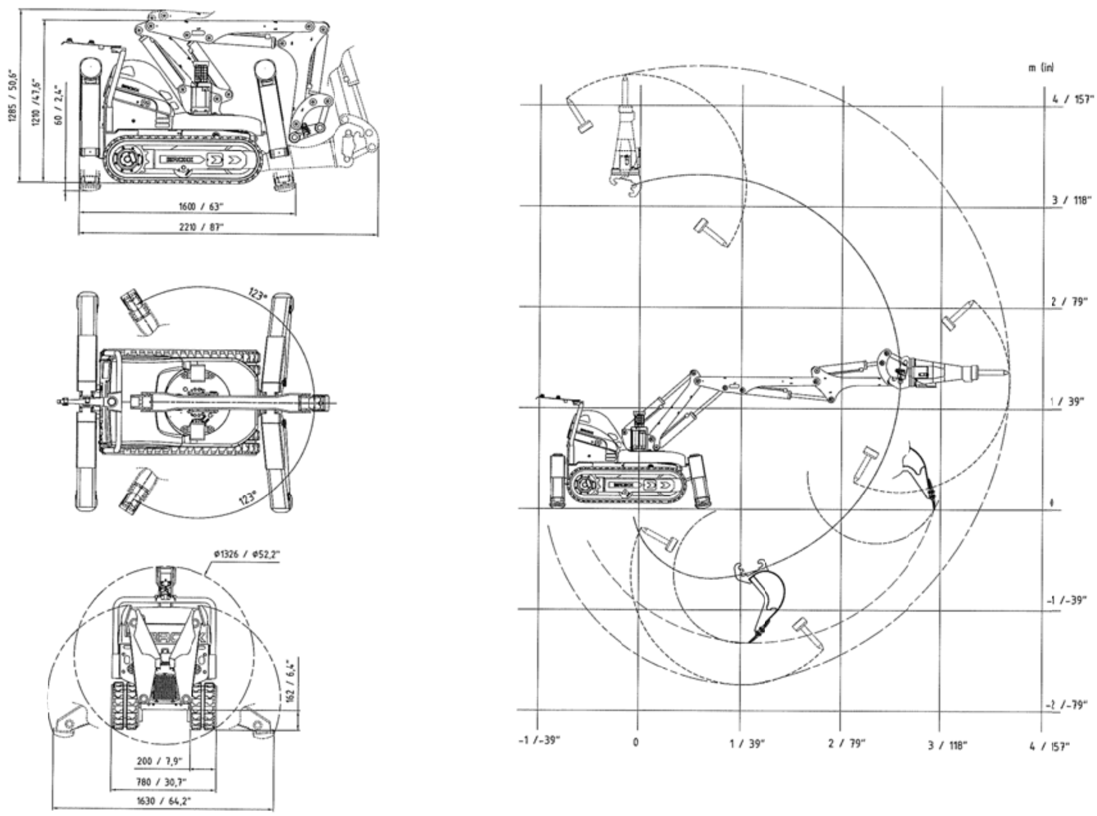


Fig. 4.2.10. Brokk 260, an applicable basic machine designed for tight space. Various tools including rotary cutters and drilling equipment can be modified. This equipment can be remotely controlled (Drawing taken from www.brokk.com).

4.2.4 Gallery construction sequence

The construction sequence for the test gallery excavation is proposed as follows:

1. Full face excavation by cutter on a basic machine (Brokk 260 or similar) of 1 m to 1.5 m;
2. Moving backwards (excavation equipment);
3. Removal of the excavated material, cleaning of the invert;
4. Installation of 2 to 3 rock bolts in the side walls or crown if necessary (drilling rig may be mounted on the basic machine);
5. Placing steel ribs (tronçons A, E, F) and / or application of 5 to 7 cm of sprayed concrete liner (tronçons A, B, C, D) in the tunnel wall and the crown, respectively (section 4.2.2.2);
6. Installation of the wire mesh circumferentially;
7. Tronçons A-D only: application of an additional 5 to 7 cm of sprayed concrete layer in the crown and 10 to 15 cm in the invert, leaving a longitudinal gap to allow for controlled convergence;
8. After a break of more than 7 hours, the invert is backfilled temporarily with excavated material which serves as working surface and protects the invert (this will be removed after excavation is completed).

As before, the tendering construction companies are invited to propose an appropriate gallery construction method and describe it in a technical report submitted with their offer.

4.2.5 Resources/participating organisations and persons

- Financial resources:

Task 2.2 Tunnel construction and support	
Travelling to the tunnel excavation construction company during the modification of the tunnelling machine and to the Mont Terri Site during tunnel construction	4 000 €
Modification of tunnelling machine and tunnelling work	653 000 €
Direct manpower costs	85 000 €
TOTAL	**742 000 €**

- Lead beneficiary (man months allocated): Nagra (5 MM)
    - Key staff: Sven Köhler, Daniel Marti, Sven-Peter Teodori

4.2.6 Schedule

Task 2.2 Tunnel construction and support	Start	End
FE-A Start niche	**April 2010**	**June 2011**
Project development & pre-design	April 2010	May 2010
Tender procedure	June 2010	Sep. 2010
Construction	Jan. 2011	June 2011
FE emplacement gallery	**Nov. 2009**	**Dec. 2011**
2D scoping calculations	Nov. 2009	Dec. 2009
Project development & design	Feb. 2011	May 2011
Production of tender documents	June 2011	Oct. 2011
Tender procedure	Nov. 2011	Feb. 2012
MS 31: Decision on excavation method	March 2012	
MS 32: Start of excavation	April 2012	
Construction	April 2012	July 2012
Convergence measurements	April 2012	July 2012
3D modelling of construction process	Jan. 2012	Aug. 2012
Documentation of construction	March 2012	Oct. 2012
D 2.2 Report on construction of the emplacement tunnel	December 2012	

4.2.7 Milestones

<u>MS 31: Decision on excavation method</u>

- Lead beneficiary: Nagra
- Month: 03/2012 (re-scheduled)
- Method of verification: internal note

<u>MS 32: Start of excavation</u>

- Lead beneficiary: Nagra
- Month: 04/2012 (re-scheduled)
- Method of verification: visual inspection

4.2.8 Deliverables

<u>D 2.2 Report on construction of the emplacement tunnel</u>

- Contents: this report summarises tunnel and support design modification of tunnelling equipment and tunnelling progress
- Lead beneficiary: Nagra
- Nature: report
- Publicity level: public
- Estimated indicative man months: 1
- Delivery date: 12/2012 (re-scheduled)

4.3 Preparation for emplacement (Task 2.3)

4.3.1 Manufacturing of buffer blocks and the granular buffer

The engineered barriers, which comprise large quantities of material with favourable and well-known properties and predictable performance, constitute an important part of the multi-barrier system. After canister failure, i.e. after at least 10,000 years, the bentonite will be a very effective barrier and it is expected that most radionuclides will decay to insignificant levels within the engineered barriers. In the case of SF and vitrified HLW, the canisters are emplaced in tunnels surrounded by a bentonite buffer, which has the following functions:

- to keep the canisters in place and protect them by homogenising the stress field;
- to mechanically stabilise the space between the canisters and the geological barrier;
- to act as a transport barrier for radionuclides and as a barrier for colloids;
- to provide a suitable geochemical environment;
- to ensure low corrosion rates of both the canister and the waste form;
- to limit microbial activity;
- to prevent human intrusion.

For some of these functions, it is necessary for at least a significant part of the bentonite not to be altered in an unacceptable way by temperature or chemical interaction with formation water and rock or corrosion products of the canister.

4.3.1.1 Bentonite blocks as a support structure for the canisters

In earlier large-scale emplacement projects, in which Nagra was involved (FEBEX and EB), the Spanish Serrata bentonite was used for block construction. The (FEBEX) blocks in the EB Project had a dry density of 1.69 g/cm^3 and a water content of about 14 % (12.4 – 15.0 %) and the corresponding emplacement (wet) density was 1.93 g/cm^3. The smectite content of the Serrata bentonite was determined as 88 to 96 %, even higher than the well-known Wyoming bentonite with the commercial name MX-80 (ENRESA 1998; ENRESA 2006; Bossart & Nussbaum 2007).

ANDRA and SKB have used MX-80 bentonite for the production of prefabricated, highly compacted bentonite rings and blocks in numerous projects. Generally, there is considerable knowledge worldwide concerning MX-80 bentonite. Its behaviour and technical parameters are well known from laboratory work, but there are still some open questions regarding its long-term behaviour in a deep repository and particularly questions regarding the interaction between blocks and granular bentonite.

The MX-80 bentonite used by SKB for Swedish projects was delivered by Askania AB and manufactured by Volclay LTD (Merseyside, UK). The material is dominated by mainly natural sodium montmorillonite clay (~ 80 % by weight). Accessory minerals are quartz (~ 4 %), tridymite (~ 4 %), cristobalite (~ 3 %), feldspars (~ 4 %), muscovite/illite (~ 4 %) sulphides (~ 0.2 %) and small amounts of several other minerals and organic carbon (~ 0.4 %). For the LOT and ABM Projects (SKB 2011, Nagra 2011a), a uniaxial compaction device was constructed in order to make it possible to produce blocks with accurate dimensions, density and composition. The bentonite material was compacted without pre-treatment (Fig. 4.3.1). The main target for the production was to achieve a final bulk density of 2,000 kg/m^3 in the test hole after expansion by water uptake, which is the reference KBS-3 bentonite bulk density.

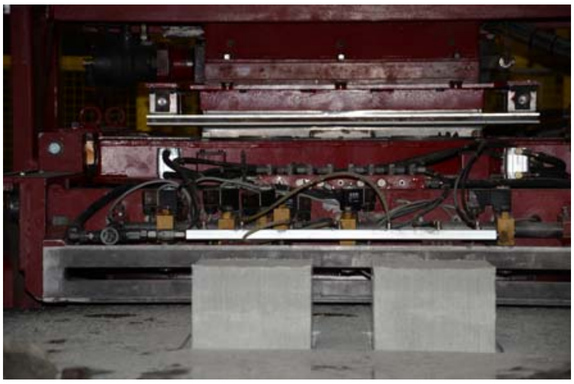



Fig.4.3.1. Uniaxial compaction device and block production (MPC LAVIOSA group, Limay, France).

For the FE Experiment, Nagra will use MX-80 Wyoming bentonite for the block production, the same material as used for the ESDRED Project (Fig. 4.3.2).

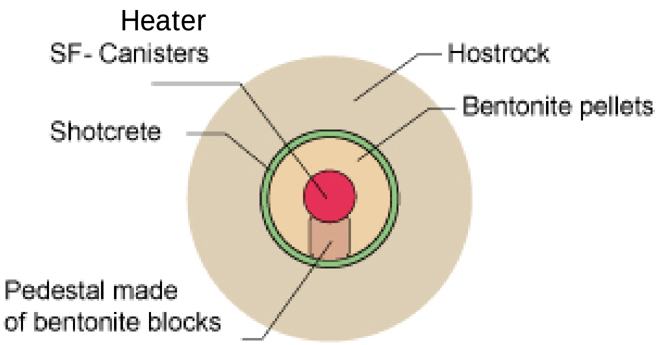


Fig. 4.3.2. Layout of the FE Experiment at Mont Terri.

4.3.1.2 Granular bentonite as backfill

For the EB experiment at Mont Terri, Serrata sodium bentonite from Spain (Almeria) was used for the granular backfill and for the blocks. For the emplacement tests in the ESDRED Project, Nagra used MX-80 Wyoming bentonite from Amcol Speciality Minerals. This bentonite powder was delivered in a conditioned, slightly granulated state to improve the pourability and pelletising behaviour. The measured poured bulk density of the MX-80 Amcol bentonite is 1,100 kg/m^3, corresponding to a dry density of 1,000 kg/m^3 (water content 10.80 %). The chemical and mineralogical properties

(Tab. 4.3.1) of the MX-80 Wyoming bentonite are well known (clay phases, main and accessory minerals).

Mineralogy MX-80 Amcol	**Composition in weight %**
Smectite	85.7 ± 1.2
Muscovite	4.6 ± 0.8
Quartz	3.4 ± 0.5
Feldspar	5.2 ± 0.8
Calcite	1.0 ± 0.2

Tab. 4.3.1. Mineralogical composition (in wt%).

Numerous pelletising experiments (Wollenberg & Schröder 2006) with pure bentonite material and with admixtures of sand were carried out at the TU Bergakademie Freiberg (Germany) and at Rettenmaier AG (Germany). The pellets produced for the ESDRED experiment were analysed at the IGT ClayLab of ETH-Zürich for their bulk density, water content and porosity. During pelletisation of the bentonite, an increase in the pellet bulk dry density from 1,170 kg/m^3 to 2,100 kg/m^3 was achieved, with simultaneous halving of the porosity. However, the shape of the coarse particles was not ideal. Previous experience had shown that rounding generally improves the flowability, avoids bridging and produces a better-graded grain size distribution and therefore a higher emplacement density. For the ESDRED Project, it proved impossible to find a commercial company that was willing and able to round the granulates in due time and the rounding was therefore carried out in situ by blowing the granular bentonite under air pressure through a 200 m long steel pipe with a conventional shotcrete gun. Tab. 4.3.2 summarises the resulting emplacement bulk densities ("drop densities" in laboratory tests) and water content (Plötze & Weber 2007).

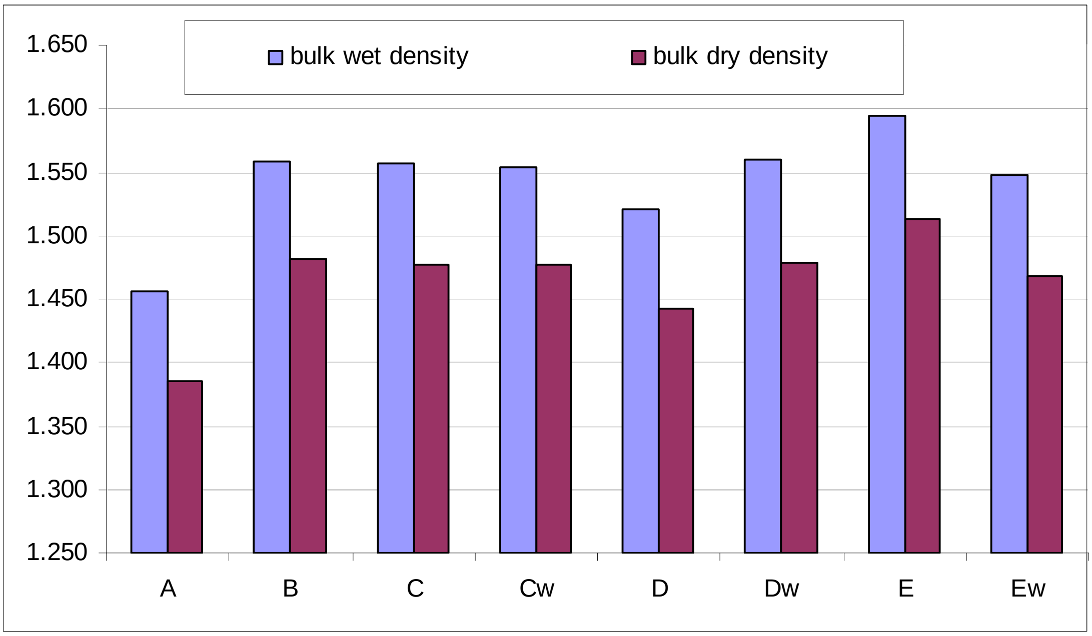
Sample	**bulk wet density ρ**	**bulk dry density ρ_d**	**water content**
	kg/m^3	**kg/m^3**	**%**
ESDRED MX-80 granulate, coarse fraction	1.2	1.15	5.0
Rounded	1.33	1.26	5.2

Tab. 4.3.2. Emplacement bulk densities before and after rounding for the ESDRED Project.

4.3.1.3 Results from previous experiments (ESDRED emplacement tests)

In July 2006, over a period of two weeks, 6 large-scale emplacement tests with granular bentonite were executed using a twin auger system and a steel silo of about 6 m^3 capacity. All the details of these tests are documented in the ESDRED final reports (ESDRED 2009a). Fig. 4.3.3 summarises the measured bulk densities after emplacement.

The bulk densities of the granular bentonite material show only small changes for different admixtures of coarse and fine granular bentonite. The results are very promising in that the required emplacement densities can be reached reliably.



A 100 % coarse rounded granular material, embedded in two layers
B 92 % coarse, 8 % fine, two layers
C 85 % coarse, 15 % fine, two layers
Cw 85 % coarse, 15 % fine, two layers
D 70 % coarse, 30 % fine, two layers
Dw 70 % coarse, 30 % fine, repeat run, two layers
E 64 % coarse, 28 % fine, 8 % briquettes, two layers
Ew 64 % coarse, 28 % fine, 8 % briquettes, repeat run, only one layer

Fig. 4.3.3. Measured bulk densities (g/cm^3) for the ESDRED emplacement tests (ESDRED 2009a).

4.3.1.4 Conclusions, recommendations, open issues

Commercially available granular bentonite products have been shown to meet Nagra's specifications for the backfill material. The production of high density bentonite pellets carried out commercially to date has demonstrated the ability to provide the required properties with regard to agglomeration and compaction. These can subsequently be mixed and rounded to achieve emplacement dry densities of approximately 1500 kg/m^3 using powdered raw material with a water content of 5 %, as was demonstrated in the ESDRED emplacement tests (Plötze & Weber 2007).

In theory, optimal emplacement densities can be reached with a bimodal grain size distribution with diameter differences of 1:10 and a fraction of about 70 % of the coarse material and 30 % of the fine material to fill the finer pore space. The results of the tests performed in the ESDRED Project are shown in Fig. 4.3.3, from A to E. This shows that the resulting emplacement densities satisfy the specified minimum density for the bulk density of the backfill material. Overall, the system for emplacing granular bentonite mixture has been shown to be quite robust, but higher densities can be reached by adding about 20 to 30 % of a coarser fraction with particle diameters of 2 to 3 cm. With these so-called cushions or briquettes, it was possible to increase the emplacement dry densities by approximately 5 %. The technology for producing such high density briquettes is available (Fig. 4.3.4). In addition, further improvements of the overall performance can be achieved with further development of the emplacement equipment (see section 4.3.2).

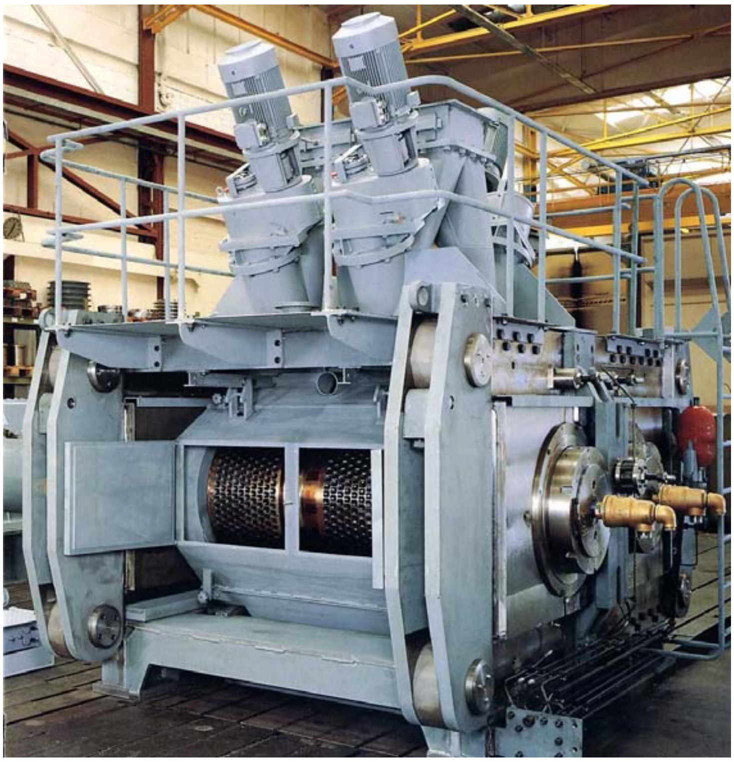


Fig. 4.3.4. Roller press by Koppern Equipment for bentonite briquette production.

4.3.1.5 Resources/participating organisations and persons

- Financial resources:

Task 2.3a Manufacturing of buffer blocks and granular buffer	
Travelling to international producers of bentonite blocks and granulate in Europe and Switzerland for quality control of the products	7 000 €
Cost of bentonite and the manufacturing of blocks and products. It is planned to order the bentonite granular material from the same manufacturer as for ESDRED. Comparisons carried out in 2010 with other producers showed that no other company was able to fulfil the requirements. The blocks will be ordered from the company that is planned to manufacture the PEBS blocks. Costs were estimated from other projects.	214 000 €
Direct personnel costs	59 500 €
TOTAL	**280 500 €**

- Lead beneficiary (man months allocated): Nagra (3.5 MM)
  - Key staff: Hanspeter Weber, Sven Köhler, Sven-Peter Teodori

4.3.1.6 Schedule

Task 2.3a Manufacturing of buffer blocks and the granular buffer	Start	End
Bentonite mock-up test	**Feb. 2012**	**May 2012**
Pre-clearance bentonite	Feb. 2012	March 2012
Contracting bentonite	Feb. 2012	March 2012
Order bentonite for mock-up tests	March 2012	
Bentonite production	March 2012	May 2012
Delivery of bentonite	May 2012	
Bentonite FE Tunnel	**Nov. 2012**	**April 2014**
Planning of bentonite testing	Nov. 2012	Feb. 2013
Characterisation of bentonite pellets and blocks (lab.)	Feb. 2013	May 2013
Clearance bentonite	May 2013	
Contracting bentonite (pellets and blocks)	May 2013	July 2013
Order bentonite (pellets and blocks)	July 2013	
Bentonite production (pellets and blocks)	July 2013	Dec. 2013
MS 33 Delivery of bentonite (pellets and blocks)	Dec. 2013	
D 2.3 Specifications, manufacturing and QC of the buffer components	June 2014	

4.3.1.7 Milestones

MS 33: Production of blocks and granular bentonite completed

- Lead beneficiary: Nagra
- Month: 12/2013 (re-scheduled)
- Method of verification: Visual inspection

4.3.1.8 Deliverables

D 2.3 Specifications, manufacturing and QC of the buffer components

- Contents: This report describes the manufacturing of bentonite blocks and pellets. Specifications will be reported and explained and the quality assurance measures (density, water content, homogeneity) will be documented.
- Lead beneficiary: Nagra
- Nature: Report
- Publicity level: Public
- Estimated indicative man months: 1.5
- Delivery date: 06/2014 (re-scheduled)

4.3.2 Development of emplacement equipment

The "emplacement task" comprises the installation of three dummy spent fuel (SF) canisters (containing only heater elements) and their pedestals in the FE test gallery, as well as the subsequent backfilling of the space around these elements with granular bentonite.

For the emplacement of dummy canisters and their bentonite block pedestals, simple manual techniques have been used in previous experiments (Kennedy 2003, Plötze & Weber 2007, ESDRED 2009b, Nagra 2011b) and are also envisaged for the emplacement in the present experiment. A closer look will be taken at the bearing capacity of the pedestals.

However, the main focus in terms of technical demonstration issues is the development of an emplacement device for the backfilling process with granular bentonite.

In previous tests, three types of equipment have been evaluated for the emplacement of granular bentonite, namely conveyer, pneumatic and auger methods. Based on equipment evaluation tests, the auger technique was identified as the preferred method. As a first optimisation within the ESDRED Project, it was decided to develop a twin auger system instead of the previously used single auger system. For this task, the company "Rowa Tunnelling Logistics AG" (Wangen, Switzerland) was contracted to plan, construct and test this emplacement system (Fig. 4.3.5) (Nagra 2004).

The resulting and currently still existing twin auger has a total length of about 9 m and a weight of 1350 kg. The length of the two auger casings is 7.0 m and the diameter of the tubes is 0.2 m. The feed rate can be controlled by the auger turning speed. The rotating screwing motion of the auger moves the bentonite material to the end of the outer casing tube where it either falls off the end of the auger freely or pushes the material out into the existing bentonite mass. It proved to be useful to leave the augers inserted in the backfilling front in order to build up a backpressure and hence additional compression on the backfilled material. The maximum feed rate was 7 m^3 of granular bentonite material per hour.

The twin auger system reached the specifications regarding overall dry density in a satisfactory way. However, undesired de-mixing of the granular filling material was observed: larger grains roll down the backfilling slope to the bottom and smaller grains tended to aggregate at the gallery roof. This resulted in undesired inhomogeneity with respect to dry bulk density (Plötze & Weber 2007).

The present work on the development of an appropriate emplacement device focuses on advances with respect to the observed de-mixing effects. Specific geometric constraints due to canisters and monitoring instrumentation that have been positioned previously or simultaneously are addressed, as well as QA measures.

Fig. 4.3.5. Twin auger system for the ESDRED Project (Photos: Nagra).

4.3.2.1 Specifications

The major requirement for the emplacement of the canisters and their pedestals is to transfer the bentonite blocks and canisters from the start niche to the designated emplacement position. The transfer of the blocks and canisters can be done consecutively or in a single step.

The requirements for the granular bentonite backfilling procedure are as follows:

- Minimum material dry bulk density after filling the gallery: 1.45 t/m^3 (see section 4.3.1);
- Homogeneous emplacement of the buffer;
- Ability to completely backfill, including the roof, discontinuities and gaps along the gallery walls (e.g. around TH-profile sections, between canisters, etc.) with the required quality;
- Appropriate QA measures to verify the above-mentioned requirements;
- Practicability with particular attention to the canisters positioned previously;
- Practicability with regard to the simultaneous instrumentation[1] of the buffer material.

4.3.2.2 Preliminary design

An appropriate emplacement system for the granular buffer material has to comprise the following functional units:

- An emplacement unit
- A conveyance unit
- Emplacement quality control
- Logistics and material supply

It is planned to develop a new emplacement unit with a multi-auger system or to modify the previously used twin auger system (ESDRED 2009b), in order to reduce the de-mixing effects described above. The other functional units have to meet only practical and site-specific specifications for the experimental set-up without any further demonstration requirements regarding the basic Nagra concept according to the feasibility study in the "Entsorgungsnachweis 2002" Project (Nagra 2002a, Nagra 2002b).

In this context, the company "Rowa Tunnelling Logistics AG" (Wangen, Switzerland) was contracted to develop a conceptual design for the experiment equipment, taking into account the test site boundary conditions and the experience from the previous tests. In addition to a multi-auger emplacement unit, the mandate comprised the conceptual development of an integrated emplacement concept, not only for bentonite granules but also for the canisters and the pedestals of bentonite blocks. Furthermore, the necessary logistics and auxiliary devices are to be taken into account, i.e. transfer and reloading equipment for continuous feeding of homogeneous granular material plus installations for rails (side note: rails are considered necessary for accurate positioning and to avoid uncontrollable sideways shifting of the vehicles within the gallery, taking into account the various rock support measures envisaged in the invert).

The conceptual experimental set-up is shown in Fig. 4.2.3. The dummy canisters are 4.6 m in length and 1.05 m in diameter. The space between two canisters is 3.0 m. These given geometries are a determining factor for the emplacement process described below.

[1] Not part of the LUCOEX Project, but part of the overriding goals of the FE Experiment.

Emplacement system for canisters and bentonite blocks

A technical solution for transposing the bentonite blocks and canisters from the start niche to the respective emplacement position has to be found. The transfer of the blocks and canisters will be done consecutively using appropriate devices, e.g. trolley wagons. Fig. 4.3.6 shows a trolley wagon concept for carrying a canister and the bentonite blocks separately.

For material transfers and / or vehicle re-railing, a small gantry crane has to be mounted in the start niche (Fig. 4.3.7).

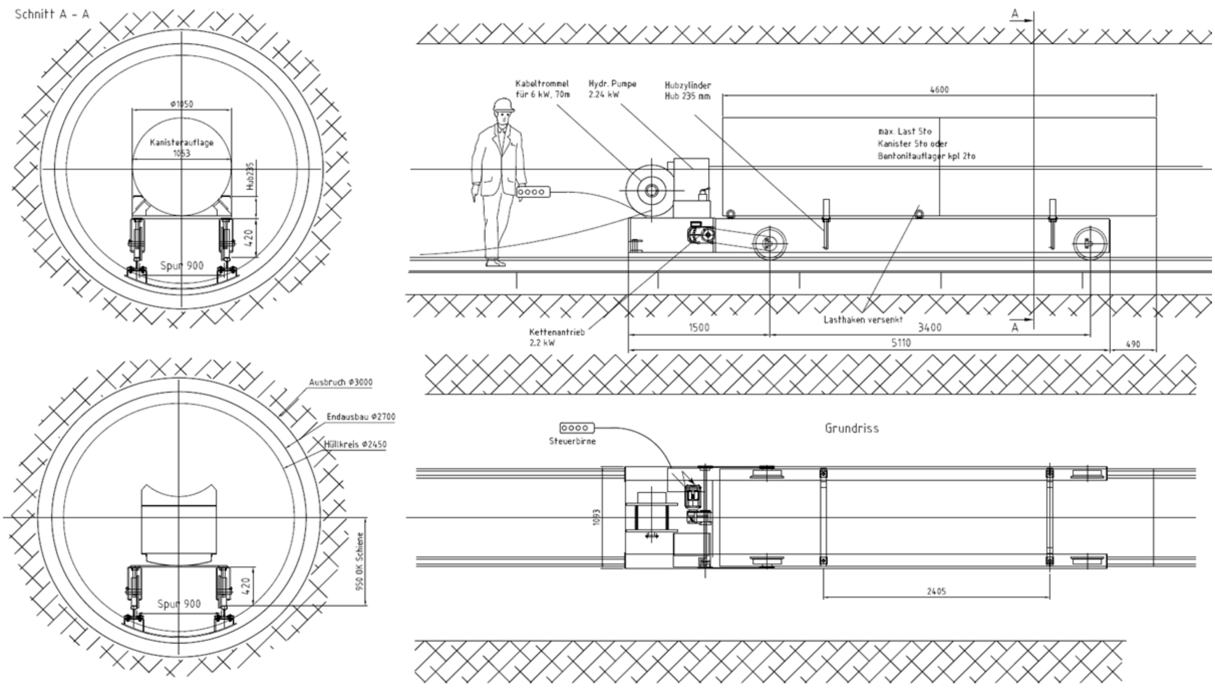


Fig. 4.3.6. Trolley wagon concept for carrying a canister and its pedestal (bentonite blocks) separately [mm].

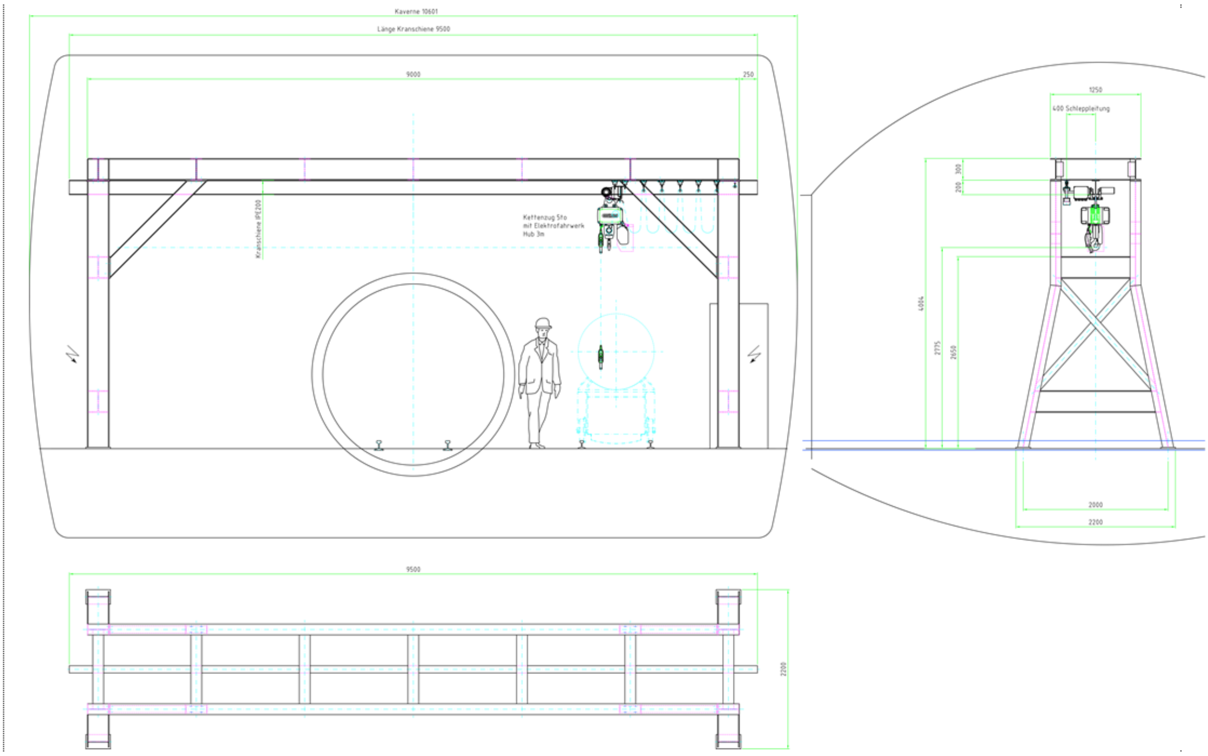


Fig. 4.3.7. Gantry crane to be mounted in the start niche (FE-A) for material transfers and / or vehicle re-railing [mm].

Emplacement system for granular material

A conceptual design for the emplacement unit containing five augers is shown in Fig. 4.3.8. The undesired aggregation of mono-sized grains at the base and top of the gallery is mitigated by a staggered alignment of the augers in accordance with the slope angle. Two augers at the bottom fill the base, another two on either side cover the canister and fill parts of the crown. The fifth auger is the longest one, filling the remaining part of the crown. The auger positions are adjustable within a limited tolerance, in order to optimise filling performance (e.g. to compensate for local structural discontinuities of the excavated cross-section).

Figs. 4.3.9 and 4.3.10 show an appropriate conveyance unit that can be connected to the emplacement unit. For this task, the basic chassis of the trolley wagon mentioned above will be used. A supporting frame will be attached to the chassis to carry up to four large big bags (i.e. 4 m^3) of granular bentonite for feeding into the loading hopper of the emplacement unit.

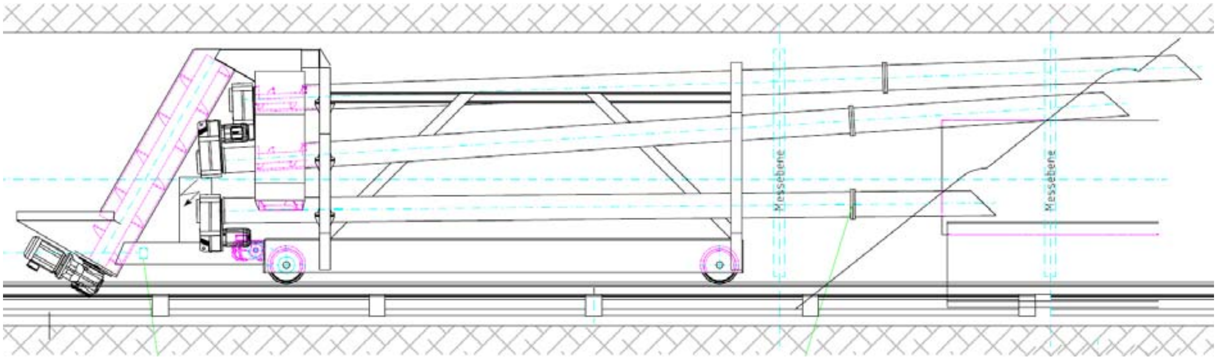


Fig. 4.3.8. Longitudinal section of the emplacement unit for granular bentonite.

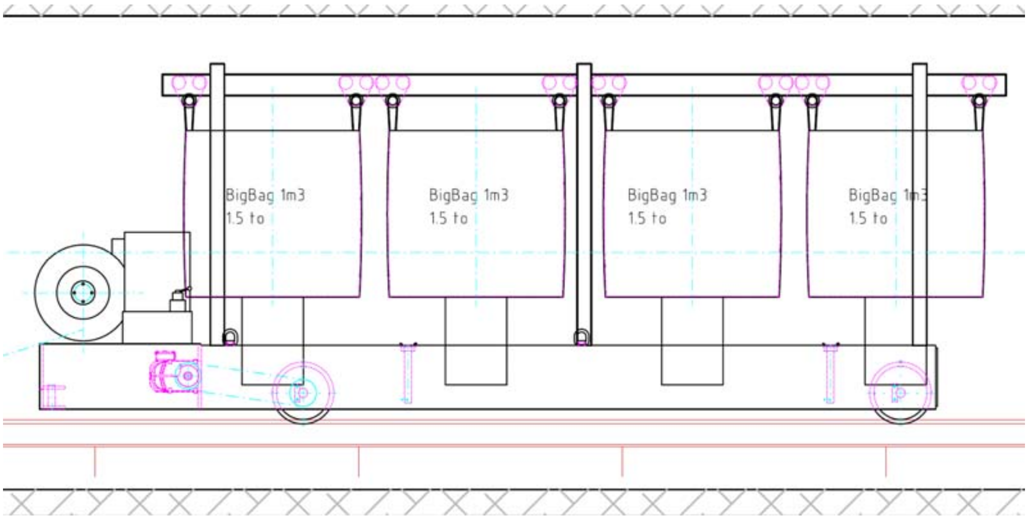


Fig. 4.3.9. Longitudinal section of the conveyance unit for granular material supply of the emplacement unit (basic chassis of the trolley wagon).

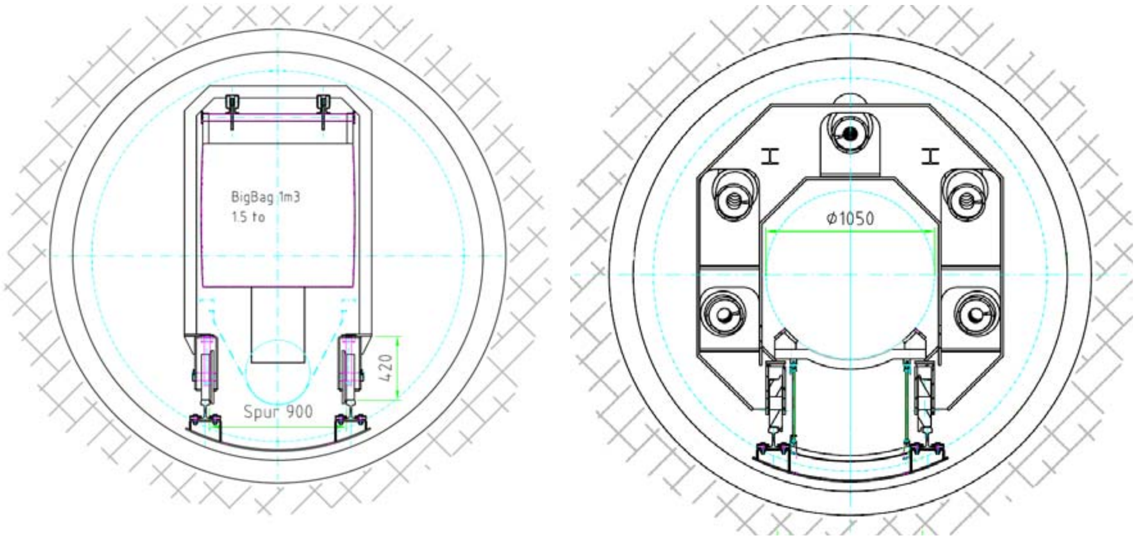


Fig. 4.3.10. Cross-sections of the emplacement device. Left: conveyance unit (trolley wagon); right: emplacement unit.

4.3.2.3 Further developments, quality control and prototype testing

In order to control the parameters "material dry bulk density" and "homogeneity", it will be necessary to measure the backfilled gallery volume and correlate it with the emplaced material mass per time unit. This will ensure the emplaced density of the backfill material. One method for determining the filled tunnel volume is to scan its profile prior to emplacement.

Ideally, the volume currently being filled and the filling rate are controlled automatically. Redundant control measures are currently being evaluated.

Preliminary off-site tests are planned in order to study the immersion of the augers in the filling material in relation to pressure head and material dry density. The off-site tests will also provide information for fundamental machinery design purposes and final approval of the fully assembled emplacement system prior to application at Mont Terri. It is planned to perform two subsequent mock-up tests, the first one focusing on basic machinery design parameters prior to the detailed design work and the second one addressing QA measures in terms of material density and homogeneity, as well as optimisation of the entire emplacement process, including the simultaneous instrumentation work.

4.3.2.4 Resources/participating organisations and persons

- Financial resources:

Task 2.3b Development of emplacement equipment	
Construction and testing of emplacement equipment (auger system and electronic control unit)	422 000 €
Direct personnel costs	59 500 €
TOTAL	**481 500 €**

- Lead beneficiary (man months allocated): Nagra (3.5 MM)
  - Key staff: Sven Köhler, Hanspeter Weber, Sven-Peter Teodori

4.3.2.5 Schedule

Task 2.3b Development of emplacement equipment	Start	End
Concept report including cost study	April 2011	Feb. 2012
Planning, preparation, material procurement for mock-up test 1	March 2012	April 2012
Realisation of off-site mock-up test 1	May 2012	May 2012
Analysis of mock-up test 1	June 2012	June 2012
Contracting detailed machinery design	July 2012	July 2012
Coordination with instrumentation fixation	Aug. 2012	Aug. 2012
Detailed design of emplacement devices	Sep. 2012	Nov. 2012
Contracting manufacturing of emplacement devices	Dec. 2012	Dec. 2012
Manufacturing of emplacement devices, assembly & factory test runs	Jan. 2013	June 2013
Contracting mock-up test 2	March 2013	March 2013
Planning, preparation, material procurement for mock-up test 2	April 2013	June 2013
Realisation of off-site mock-up test 2	July 2013	Sep. 2013
Analysis of mock-up test 2	Sep. 2013	Oct. 2013
Modification, optimisation	Oct. 2013	Oct. 2013
Transport to Mont Terri URL and assembly on-site	Nov. 2013	Nov. 2013
MS 34 Prototypes of emplacement equipment tested and ready for use	Dec. 2013	
Documentation emplacement equipment	Dec. 2013	May 2014
D 2.4 Construction of emplacement equipment	June 2014	

4.3.2.6 Milestones

MS 34: Prototypes of emplacement equipment tested and ready for use

- Lead beneficiary: Nagra
- Month: 12/2013 (re-scheduled)
- Method of verification: Visual inspection

4.3.2.7 Deliverables

D 2.4 Construction of emplacement equipment

- Contents: This report describes the construction of the emplacement equipment and tests documenting the functionality
- Lead beneficiary: Nagra
- Nature: Report
- Publicity level: Public
- Estimated indicative man months: 1.5
- Delivery date: 06/2014 (re-scheduled)

4.4 Emplacement activities (Task 2.4)

4.4.1 Ventilation period

According to the reference concept, a period of up to two years should pass between the gallery excavation and the emplacement of canisters with subsequent backfilling (Nagra 2002a). During this time, the gallery walls are ventilated, which will affect the water content and hence the geomechanical characteristics of the near-field of the surrounding rock, as well as the subsequent re-saturation time of the gallery and the buffer material, respectively.

In order to generate realistic boundary conditions, the experiment schedule includes a ventilation period of 1 ½ years between gallery construction and emplacement activities.

4.4.2 Structural and technical preparations at the Mont Terri URL

A delivery and storage area has to be provided at the Mont Terri URL. Delivered materials include the emplacement devices, bentonite material (blocks on pallets and granulate in big bags), dummy canisters (heater elements), construction machines and construction materials (rails, etc.), the gantry crane and other tools and components. Additionally, for the emplacement devices, an adequate assembly area is required, which will be the start niche FE-A.

An electrical power supply is also an important issue. The power demand of an emplacement device has been preliminarily calculated to be around 100 A.

Ventilation and de-dusting facilities also have to be installed for the emplacement work. All of this has to be arranged with the operator of the Mont Terri URL.

4.4.3 Installation of rails

After excavation of the gallery, rails will be installed manually in order to ensure accurate working processes. Removal of the rails after or simultaneously with the emplacement process is not envisaged as this would be fairly effort-intensive, time-consuming and might cause loss of quality of the density of the bentonite buffer.

4.4.4 Emplacement process

The overall experimental set-up is shown in Fig. 4.2.3. The emplacement cycle is envisaged as follows:

1. Installation of a sand-gravel filter and bentonite block wall as formwork for the sand-gravel filter
2. Backfilling with granular bentonite to the position of the first canister (heater)
3. Transfer and positioning of the first pedestal
4. Transfer and positioning of the first canister
5. Backfilling with granular bentonite for the first canister (heater)

6. – 11. Repetition of procedure steps 3 – 5 for the second and third canisters

12. Construction of the plug
13. Simultaneous backfilling of the upper part next to the plug with granular bentonite (formwork needed)

The installation of the sand-gravel filter and the bentonite blocks at the far end of the FE gallery will be done manually (step 1). The trolley wagon will serve as a simple, rail-bound transport device (with a plate lying on top of the bifurcated chassis). It can also be used for transportation of the bentonite blocks for the pedestal of the dummy canisters to their destination point where they are assembled manually (steps 3, 6 and 9). An alternative procedure would be to provide a lowering mechanism for a plate between the fork branches of the trolley wagon. Through this, each bentonite pedestal could be assembled in the start niche into its final shape, transferred to the destination point and deposited. This would mean that the plate – or open mesh flooring – would remain permanently in the FE gallery.

The chassis of the trolley wagon is bifurcated in order to allow it to pass over the previously assembled bentonite pedestal and deposit a canister onto it with a lowering mechanism.

For backfilling the FE gallery using granular bentonite (steps 2, 5, 8, 11), the newly developed emplacement device will be used. It has a staggered alignment of five augers in accordance with the slope angle of the granular material. The design allows the device to pass over the previously positioned canister in order to continue backfilling from the current material slope, which is beyond the canister (section 4.3.2.2).

The material supply will be done by reconfiguring the trolley wagon. A supporting frame will be mounted on the wagon, which will allow up to four big bags of granular material to be hung up (section 4.3.2.2). The big bags will be lifted up and attached to the supporting frame in Gallery 08 ("Ga 08") using a fork lift, while the emplacement unit remains at its position in the FE gallery during the whole emplacement cycle.

The trolley wagon reconfigured and loaded in this way functions as a conveyance and feeding unit. It will move into the FE gallery and be attached to the emplacement unit, where the first big bag is positioned above the loading hopper of the emplacement unit. The supporting frame will be equipped with roller rails and the big bags will be suspended on sliding bars so that they can be moved forward over the loading hopper after the previous big bag has been emptied and removed.

Four big bags loaded with 1 m^3 of granular bentonite are equivalent to a backfilling range of ca. 0.7 m in the FE gallery at positions where no components are installed. Around the canister positions, the backfilling range will be approximately 1 m. After each feeding cycle, the trolley wagon has to be moved back to Ga 08 for reloading until the whole backfilling cycle is completed.

The activation of both the trolley wagon and the emplacement unit will be controlled manually via teach pendants.

QC measures in terms of the density and homogeneity of the backfilled granular bentonite are envisaged using pressure controlling sensors attached to each auger. Additionally, an automatic mass balance system is planned for each auger. Knowing the current position in relation to the exact geometry and cross-sectional area of the gallery allows permanent control and regulation. In this context, the previously conducted off-site mock-up tests play an important role in terms of operating experience as well as relating data from pressure measurements and mass balance devices to manually determined densities (section 4.3.2.3).

4.4.5 Gantry crane in the start niche

For the backfilling procedure, the trolley wagon operates behind the emplacement unit, but, for the transportation and emplacement of bentonite blocks and canisters, it has to operate in front of the emplacement unit. For this reason, when changing from emplacement to backfilling steps, the trolley wagon has to be lifted off the rails to allow the emplacement unit to pass by.

For lifting operations like this, a small gantry crane is envisaged in the start niche. It will also be needed for the final assembly of the emplacement unit, especially for lifting the augers.

4.4.6 Plug

After complete backfilling of the emplacement gallery, the entrance zone will be sealed with a plug. For planning this closure plug, valuable experience from the GAST and FEBEX experiments at the Grimsel URL and the EB experiment at the Mont Terri URL can be used. For the GAST and FEBEX experiments, a specific formulation of concrete was used for the plug which ensures low shrinkage (Nagra 2011c, ENRESA 1998, Bossart & Nussbaum 2007). Further valuable information is provided by SKB (2009a, b, and c).

The plug at the front end of the FE gallery will serve the following purposes:

- Mechanical support to keep the backfill material in place;
- Insulation function against heat conduction;
- Barrier function against gas and water flow.

Further aspects that will be considered during plug design include:

- The plug should not contain steel reinforcements or anchors of any kind, to facilitate future dismantling.
- The specific concrete formulation will consider the following:
  - Low production of hydration heat to avoid disturbing the main experimental conditions controlled by accurately regulated heat production of the canisters;
  - Shrinkage should be minimal to avoid cracks and thus preserve the best possible sealing effect. In addition, separation from the adjacent rock can be minimised;
  - Use of low-pH concrete, at least at the interface zone between the seal and the bentonite buffer material to prevent clay mineralogy alterations.

More practical requirements relate to the pass-through of cables for energy supply and measurement data transfer and preserving the required sealing properties in the PVC or PE cable channels. At the FEBEX test site, the use of hot PU resin for sealing the plastic tubes showed the most satisfactory results. Experience generally shows that large bundles of cables should be avoided, e.g. by using spacers between distinct cable strings.

4.4.7 Resources/participating organisations and persons

- Financial resources:

Task 2.4 Emplacement activities	
Travelling to Mont Terri during the emplacement of the bentonite for QC and to coordinate the field work	4 000 €
Emplacement work and plug construction	234 000 €
Direct personnel costs	110 500 €
TOTAL	**348 500 €**

- Lead beneficiary (man months allocated): Nagra (6.5 MM)
  - Key staff: Sven Köhler, Hanspeter Weber, Sven-Peter Teodori

4.4.8 Schedule

Task 2.4 Emplacement activities	**Start**	**End**
Ventilation	July 2013	Jan. 2014
Transport and assembly of emplacement devices at Mont Terri URL	Nov. 2013	Nov. 2013
MS 35: Start of emplacement	Jan. 2014	
Emplacement of sealing section with bentonite blocks ("Tronçon" F)	Jan. 2014	Jan. 2014
Emplacement of sealing section with granular bentonite ("Tronçon" E)	Jan. 2014	Feb. 2014
Emplacement of dummy canister sections ("Tronçons" C and D)	Feb. 2014	June 2014
Documentation of emplacement activities	July 2014	Dec. 2014
Construction of plug	June 2014	Aug. 2014
MS 36: Construction of plug completed	Aug. 2014	
Documentation of plug construction	Sep. 2014	Oct. 2014
D 2.5 Emplacement report	Oct. 2014	

4.4.9 Milestones

MS 35: Start of emplacement

- Lead beneficiary: Nagra
- Month: 01/2014 (re-scheduled)
- Method of verification: Visual inspection

MS 36: Construction of plug

- Lead beneficiary: Nagra
- Month: 08/2014 (re-scheduled)
- Method of verification: Visual inspection

4.4.10 Deliverables

D 2.5 Emplacement report

- Contents: This report documents the on-site emplacement of the dummy waste canisters, the bentonite blocks and the tunnel backfilling process
- Lead beneficiary: Nagra
- Nature: Report
- Publicity level: Public
- Estimated indicative man months: 1.5
- Delivery date: 10/2014 (re-scheduled)

4.5 Final reporting of WP2 (Task 2.5)

This task involves the compilation of all WP2 results in a final WP report (deliverable), which may be summarised in a peer-reviewed scientific paper.

4.5.1 Resources/participating organisations and persons

- Financial resources:

Task 2.5 Final reporting of WP2	
Direct personnel costs	25 500 €
TOTAL	**25 500 €**

- Lead beneficiary (man months allocated): Nagra (1.5 MM)
    - Key staff: Hanspeter Weber, Tim Vietor, Sven Köhler, Sven-Peter Teodori, Herwig R. Müller

4.5.2 Deliverables

D 2.6 Final report of WP2

- Contents: The final report of WP2 summarises the previous reports and discusses the lessons learned during the Work Package. In the event that visiting scientists or engineers from other organisations are seconded to the Work Package, their reports will be included as an attachment.
- Lead beneficiary: Nagra
- Nature: Report
- Publicity level: Public
- Estimated indicative man months: 1.5
- Delivery date: 12/2014 (not re-scheduled)

4.6 Integration (Task 2.6)

4.6.1 Expert advice

Expert advice from the other participants in the WP2 test planning is desired. In addition, the draft versions of all Nagra deliverables will be sent for review comments to the partners SKB, ANDRA and Posiva.

4.6.2 Invitation to other partners

Invitations will be extended to the other partners SKB, ANDRA and Posiva to participate in meetings and to attend installations and demonstrations during tunnel construction (month 10 – 12) and during emplacement of the heaters and the bentonite (month 25 – 27), with the aim of providing input to the WP.

4.6.3 Review of the WP final report

The review of the WP final report by the other partners SKB, ANDRA and Posiva should verify that the relevant information is complete.

4.6.4 Networking for new scientists

Networking for new scientists will comprise the secondment of an employee of one of the partners to Nagra.

Training of the scientist will comprise EDZ analysis in the vicinity of the FE gallery. The scientist should have a PhD or a Master's degree in geology. The candidate has to deliver a report on his activities and findings (attachment to the final WP2 report).

5 Complete list of overall resources/participating organisations and persons

Task 2.1 – Detailed experiment planning

- Financial resources:

Task 2.1 Detailed experiment planning	
Travel costs	6 000 €
Direct personnel costs	43 000 €
TOTAL	**49 000 €**

- Lead beneficiary (man months allocated): Nagra, 2.5 MM
  - Key staff: Hanspeter Weber, Tim Vietor, Sven Köhler, Herwig R. Müller, Sven-Peter Teodori

Task 2.2 – Tunnel construction and support

- Financial resources:

Task 2.2 Tunnel construction and support	
Travelling to the tunnel excavation construction company during the modification of the tunnelling machine and to the Mont Terri Site during tunnel construction	4 000 €
Modification of tunnelling machine and tunnelling work	653 000 €
Direct manpower costs	85 000 €
TOTAL	**742 000 €**

- Lead beneficiary (man months allocated): Nagra (5 MM)
  - Key staff: Sven Köhler, Daniel Marti, Sven-Peter Teodori

Task 2.3a – Manufacturing of buffer blocks and the granular buffer

- Financial resources:

Task 2.3a Manufacturing of buffer blocks and granular buffer	
Travelling to international producers of bentonite blocks and granulate in Europe and Switzerland for quality control of the products	7 000 €
Cost of bentonite and the manufacturing of blocks and products. It is planned to order the bentonite granular material from the same manufacturer as for ESDRED. Comparisons carried out in 2010 with other producers showed that no other company was able to fulfil the requirements. The blocks will be ordered from the company that is planned to manufacture the PEBS blocks. Costs were estimated from other projects.	214 000 €
Direct personnel costs	59 500 €
TOTAL	**280 500 €**

- Lead beneficiary (man months allocated): Nagra (3.5 MM)
  - Key staff: Hanspeter Weber, Sven Köhler, Sven-Peter Teodori

Task 2.3b – Development of emplacement equipment

- Financial resources:

Task 2.3b Development of emplacement equipment	
Construction and testing of emplacement equipment (auger system and electronic control unit)	422 000 €
Direct personnel costs	59 500 €
TOTAL	**481 500 €**

- Lead beneficiary (man months allocated): Nagra (3.5 MM)
  - Key staff: Sven Köhler, Hanspeter Weber, Sven-Peter Teodori

Task 2.4 – Emplacement activities

- Financial resources:

Task 2.4 Emplacement activities	
Travelling to Mont Terri during the emplacement of the bentonite for QC and to coordinate the field work	4 000 €
Emplacement work and plug construction	234 000 €
Direct personnel costs	110 500 €
TOTAL	**348 500 €**

- Lead beneficiary (man months allocated): Nagra (6.5 MM)
  - Key staff: Sven Köhler, Hanspeter Weber, Sven-Peter Teodori

Task 2.5 – Final reporting of WP2

- Financial resources:

Task 2.5 Final reporting of WP2	
Direct personnel costs	25 500 €
TOTAL	**25 500 €**

- Lead beneficiary (man months allocated): Nagra (1.5 MM)
  - Key staff: Hanspeter Weber, Tim Vietor, Sven Köhler, Sven-Peter Teodori, Herwig R. Müller

6 Complete list of milestones

MS 30: Final version of work plan

- Lead beneficiary: Nagra
- Month: 03/2012 (re-scheduled)
- Method of verification: Report

MS 31: Decision on excavation method

- Lead beneficiary: Nagra
- Month: 03/2012 (re-scheduled)
- Method of verification: internal note

MS 32: Start of excavation

- Lead beneficiary: Nagra
- Month: 04/2012 (re-scheduled)
- Method of verification: visual inspection

MS 33: Production of blocks and granular bentonite completed

- Lead beneficiary: Nagra
- Month: 12/2013 (re-scheduled)
- Method of verification: Visual inspection

MS 34: Prototypes of emplacement equipment tested and ready for use

- Lead beneficiary: Nagra
- Month: 12/2013 (re-scheduled)
- Method of verification: Visual inspection

MS 35: Start of emplacement

- Lead beneficiary: Nagra
- Month: 01/2014 (re-scheduled)
- Method of verification: Visual inspection

MS 36: Construction of plug

- Lead beneficiary: Nagra
- Month: 08/2014 (re-scheduled)
- Method of verification: Visual inspection

7 Complete list of deliverables

D 2.1 Work plan

- Contents: This document describes the detailed work on Nagra's emplacement concept, including functional requirements of designed equipment and tunnelling procedures.
- Lead beneficiary: Nagra
- Nature: report
- Publicity level: Restricted to a group specified by the consortium (including the Commission Services)
- Estimated indicative man months: 2.5
- Delivery date: 03/2012 (re-scheduled)

D 2.2 Report on construction of the emplacement tunnel

- Contents: this report summarises tunnel and support design modification of tunnelling equipment and tunnelling progress
- Lead beneficiary: Nagra
- Nature: report
- Publicity level: public
- Estimated indicative man months: 1
- Delivery date: 12/2012 (re-scheduled)

D 2.3 Specifications, manufacturing and QC of the buffer components

- Contents: This report describes the manufacturing of bentonite blocks and pellets. Specifications will be reported and explained and the quality assurance measures (density, water content, homogeneity) will be documented.
- Lead beneficiary: Nagra
- Nature: report
- Publicity level: public
- Estimated indicative man months: 1.5
- Delivery date: 06/2014 (re-scheduled)

D 2.4 Construction of emplacement equipment

- Contents: This report describes the construction of the emplacement equipment and tests documenting the functionality
- Lead beneficiary: Nagra
- Nature: Report
- Publicity level: Public
- Estimated indicative man months: 1.5
- Delivery date: 06/2014 (re-scheduled)

D 2.5 Emplacement report

- Contents: This report documents the on-site emplacement of the dummy waste canisters, the bentonite blocks and the tunnel backfilling process
- Lead beneficiary: Nagra
- Nature: Report
- Publicity level: Public
- Estimated indicative man months: 1.5
- Delivery date: 10/2014 (re-scheduled)

D 2.6 Final report of WP2

- Contents: The final report of WP2 summarises the previous reports and discusses the lessons learned during the Work Package. In the event that visiting scientists or engineers from other organisations are seconded to the Work Package, their reports will be included as an attachment.
- Lead beneficiary: Nagra
- Nature: Report
- Publicity level: Public
- Estimated indicative man months: 1.5
- Delivery date: 12/2014 (not re-scheduled)

8 Risks / constraints

The risks and constraints of this project have been identified and are shown in descending order of importance (Tab. 8.1).

ID	Risk Description of the risk and its potential consequence.	Risk analysis P	C	R	Preventive action Description of the preventive action which is planned to diminish the probability of the risk or mitigate its consequence	Responsible person (within LUCOEX)	Deadline for preventive action	Status (will be yellow if deadline in danger and red if deadline missed)	Risk identified / updated Date for entry of risk and latest update	Comment
Nagra 1	Original time schedule for WP 2 too optimistic.	4	4	**16**	Walk through of time schedule Identifying uncertainties	WP2 and task leaders	01.07.2011		01.04.2011	
Nagra 2	Lack of key personel causes delay in project work.	1	4	**4**	Negotiate high priority for Lucoex aims in yearly planning with management	WP2 leader	01.07.2011		01.04.2011	
Nagra 3	Difficulties in realising width and magnitude of problem in the early phase of an activity may cause delay.	4	3	**12**	Identify possible problems and find solutions within the WP	WP2 leader	01.07.2011		01.04.2011	
Nagra 4	Changes in project directives	2	4	**8**	Communication between stakeholders in LUCOEX project in order to early share the concern generating consideration of changes of project directives	WP2 leader	Continuous risk management		01.04.2011	
Nagra 5	Changes in requirement in a late stage of the work may cause delay or reduced quality of results	2	3	**6**	Communication with participants in LUCOEX in order to introduce necessary changes in prerequisites as early as possible	WP2 and task leaders	Continuous risk management		01.04.2011	
Nagra 6	Unexpected results may cause rethinking of concepts	1	5	**5**	Awareness of the need of fast action	WP2 and task leaders	Continuous risk management.		01.04.2011	
Nagra 7	Lack of important information from participants and subcontarctors results in delay	2	4	**8**	Establisment of an efficient inter-WP contact Implementation of a procedure for using all necessary and available information	WP2 leader	Continuous risk management		01.04.2011	
Nagra 8	Geotechnical / rock mechanics risk during tunnel excavation	2	2	**4**	Prepare monitoring concept with intervention level and intervention support measures in the framework of the technical pre-project	WP2 and task leaders	30.10.2011		01.04.2011	
Nagra 9	Bentonite blocks (pedestal) do not meet required mechanical properties	1	4	**4**	Early pre-testing and - at best - modification of compacted bentonite blocks	WP2 and task leaders	30.10.2011		01.04.2011	
Nagra 10	Emplacement technique cannot be reconciled with THM monitoring	**2**	4	**8**	Mock-up tests to show feasiblity	WP2 and task leaders	28.02.2013		01.04.2011	
Nagra 11	Emplacement density and homogeneity of granular bentonite possibly insufficient	1	2	**2**	Mock-up tests to optimize procedure	WP2 and task leaders	28.02.2013		01.04.2011	

Tab. 8.1. Risks and constraints of the project.

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9 Connections to other WPs

NAGRA's involvement in the LUCOEX Project work packages has the following connections:

- WP 1 – Coordination and integration;
- WP 3, Task 3.4 – Integration;
- WP 4, Task 4.3 – Upgrading of the deposition machine;
- WP 5, Task 5.3 – Quality assurance and problem handling.

NAGRA's own development initiatives are summarised as follows:

- Further development of the emplacement equipment: additional supporting equipment (e.g. rails, crane, transport wagon) and additional equipment tests necessary to carry out the emplacement task;
- Emplacement activities: monitoring instruments will be placed in the host rock and buffer to monitor the subsequent heating and saturation of the buffer;
- Heating system design: the experiment requires the installation of three electrical heaters in a horizontal drift, simulating the heat generation of high-level waste, and the observation of the temperature impact on the buffer and host rock properties. The electrical heaters will have a diameter of 1.05 m and a length of 4.6 m, basically the same dimensions as real waste canisters for spent fuel;
- THM-C-related modelling activities: the testing and validation of THM modelling concepts is one of the key objectives of the FE Experiment. In this context, validation is defined as the systematic assessment of the predictive capabilities of THM models, aimed at simulating the evolution of the SF/HLW disposal system in the early re-saturation phase and considering the heat production of the waste. The FE Experiment will provide a comprehensive and reliable dataset for the validation of numerical THM models with realistic environmental conditions.

10 IPR and patents

The IPR (Intellectual Property Rights) were agreed with the consortium participants before the start of the project. The agreement defines the rights to inventions, patents, methods, diagrams, knowledge, experience and findings, both existing and developed during the project.

11 Work Package organisation

The Work Package will be led by the WP Leader under the supervision of the LUCOEX Project Steering Committee and Project Manager. Nagra's delegate in the Project Steering Committee is Tim Vietor. The operational issues in the Work Package will be handled by a Management Group that consists of the Work Package Leaders.

WP Leader

The WP Leader for WP2 is Hanspeter Weber, who represents Nagra in the WP (Fig. 11.1) and is responsible for ensuring that all the project participants and stakeholders are aware of WP2 progress. He has overall responsibility for the day-to-day management and coordination of the WP.

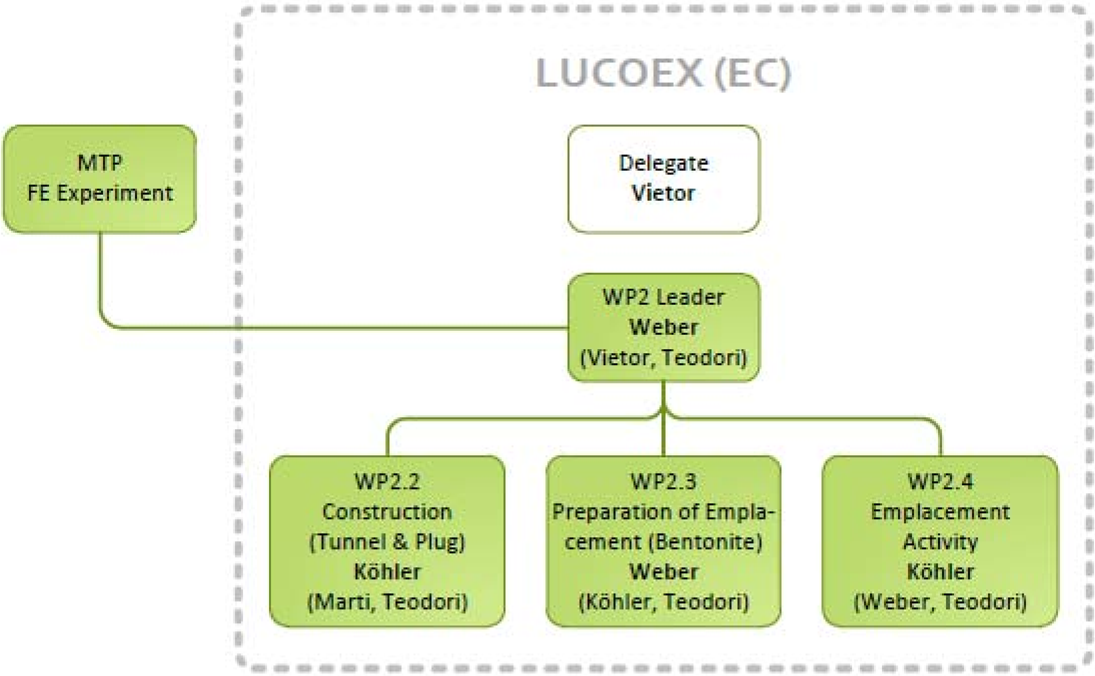

Fig. 11.1. WP organisation.

12 Financial control

12.1 Budget

The total budget for WP2 is 2,139,500 € (requested EC contribution 1,045,000 €).

The WP Leader will be responsible for preparing cost estimates for the tasks to be included in their organisations' budgets.

The costs of the work carried out for WP2 are budgeted for and controlled as part of the LUCOEX Project budgets and the financial control of Nagra.

The contracts with suppliers and sub-contractors are prepared by the Work Package Leaders for the respective tasks. The contracts are prepared and their implementation is controlled according to Nagra's own quality management systems.

12.2 Budget review and reporting

Budget review and reporting will be done according to Nagra's practices and instructions provided by the Steering Committee and the provisions contained in the Consortium Agreement.

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Annex A WP overall schedule