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LUCOEX

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Final Report LUCOEX

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EURATOM

Abstract

The four waste management organizations Nagra, Andra, SKB and Posiva have as part of their step-vice development of repository concepts for long-lived radioactive waste come together in the LUCOEX project with the common objective to demonstrate the technical feasibility for a safe and reliable disposal of radioactive waste in geological formations.

This demonstration has been done by executing four parallel experiments at different underground research laboratories, which all are designed for the specific purpose of hosting these kinds of experiments. Each experiment has focused on different concepts and different geological and technical/legal pre-conditions and all experiments have been executed with a focus on openness and willingness to share the knowledge gained to support the development of safe and reliable repositories throughout Europe.

In Switzerland, Nagra has performed the FE-experiment in the Mont Terri underground research laboratory, which is a full-scale, multiple heater test in Opalinus Clay.

In the Bure underground research laboratory in France, Andra has demonstrated the construction feasibility of a complete HLW cell in Callovo-Oxfordian clay with a concept optimized for a possible future retrieval of the waste.

In the Äspö Hard Rock Laboratory in Sweden, SKB has shown the feasibility of the KBS-3H concept in crystalline rock, which is based on horizontal position of canisters in bored tunnels.

In Finland, Posiva has demonstrated the feasibility of emplacing the buffer components in the KBS-3V concept, which is based on horizontal disposal tunnels with vertical disposal positions in crystalline rock.

All objectives have been met and each one of the four LUCOEX partners have shown that construction of galleries, manufacturing of buffer components, installation and sealing of galleries can be made to meet the initial state, i.e. the situation when no more adjusting measures are assumed to be made and further evolution of the repository components are driven by the repository´s THMC environment and geoscientific events.

In addition lots of experience were gained during the excavation, installation and sealing of the four experiments, as several practical problems were experienced, which had to be solved when they appeared. They were all handled to satisfaction and in the final end we concluded that the solutions provided additional knowledge and significant return of experience in the planning of new large underground experiments.

The final component of the LUCOEX project has been the dissemination of our findings. This has been done through a) making it possible to visit the experiments at the underground research facilities, b) presenting results and findings in scientific articles and at conferences, c) producing movies from the different experiments, d) hosting conferences and workshops and e) managing an ambitious scholarship programme to give external parties the possibility to participate both in hosted events and on site during the experiments.

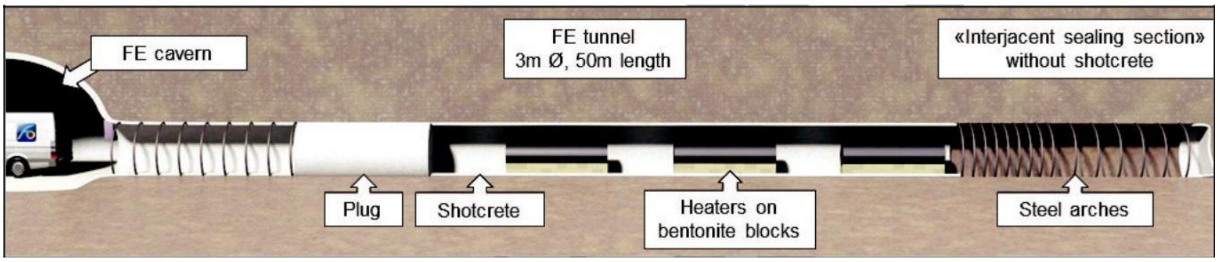
The project also provided additional experience on management and allocation of personnel resources, especially the problems arising when key persons are partly allocated to other tasks. The Expert Group had too many appointed experts (four out of eight had been preferred) and should preferably have focused on the final reporting as now is the case in the DOPAS project.

Contents

EXCECUTIVE SUMMARY

Waste implementers (WMOs) being deeply involved in experiments in underground laboratories (Andra, Nagra, SKB and Posiva) have addressed the European Council´s objective "*Through implementation-oriented RTD establish a sound scientific and technical basis for demonstrating the technologies and safety of disposal of spent fuel and long-lived radioactive wastes in geological formations* by implementing a joint collaboration regarding large underground concept experiments (LUCOEX). The project has focused on four parallel experiments at the WMOs` underground research laboratories, and each one of the experiments has addressed different concepts and different geological and technical/legal pre-conditions. Four key technical areas have been addressed: gallery construction, manufacturing and emplacement of buffer around waste canisters, emplacement of waste packages, and backfilling and sealing of galleries. The work has been conducted based on openness and willingness to broadly disseminate the knowledge obtained.

Nagra has in the Full-Scale Emplacement (FE) experiment at the Mont Terri underground research laboratory in Switzerland performed a full-scale, multiple heater test in Opalinus Clay.



The Full-Scale Emplacement (FE) experiment at Mont Terri.

A 50 m long experimental tunnel with a diameter of approximately 3 m was constructed using conventional equipment. At the far end of the tunnel the so-called interjacent sealing section (ISS) was built using only steel arches for rock support whereas the rest of the tunnel was supported by shotcrete. The construction was surveyed by pre-installed instruments in the surrounding rock. The excavation damage zone (EDZ) was instrumented with radial boreholes during construction.

The backfill in the Swiss concept is based around both highly compacted buffer blocks and a bentonite pellet mixture. Only natural sodium bentonite from Wyoming was used for manufacturing of these components. With optimized density and water content approx. 3,000 highly compacted bentonite and approximately 350 tons of highly compacted and granulated bentonite mixture (GBM) were manufactured.

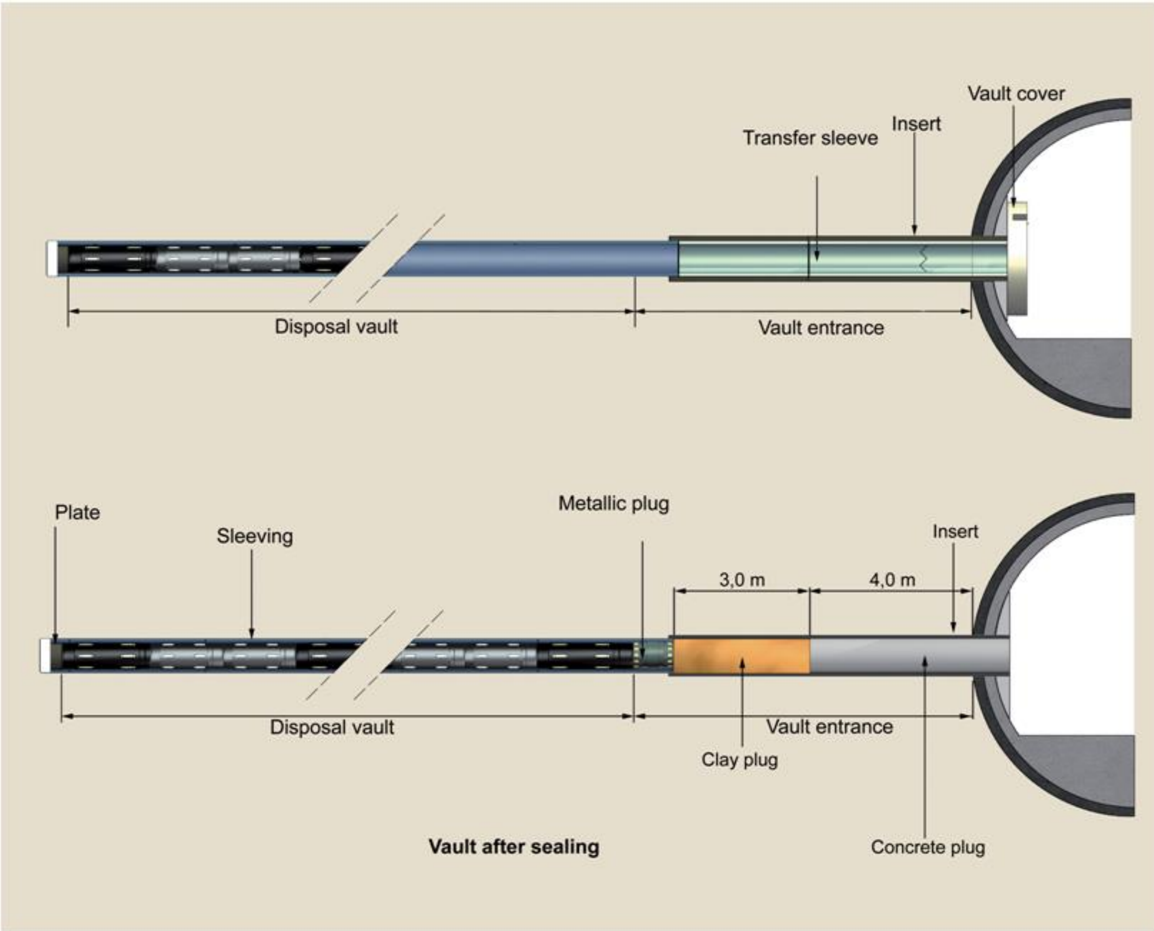
The installation started with the filling of a full 2 m long section with bentonite blocks in the ISS followed by the stepwise construction of the bentonite block pedestals, emplacement of the heaters (with dimensions similar to those of waste canisters) on top of the pedestals and backfilling of the remaining open volume with granulated bentonite mixture. Finally a large amount of sensors were installed for observation of the bentonite buffer in the FE experiment.

The backfilling part of the project consisted of two parts: the creation of a prototype backfilling machine and the actual backfilling of the tunnel. The prototype machine was based on five screw feeders with which it was judged possible to make a backfill with a high density in the small diameter FE tunnel. And the prototype machine was successfully used to backfill approximately 255 tons of GBM; in some segments with a bulk dry density of up to 1.56 t/m^3. At the pre-tests, where the density measurement were performed with different methods and with a better spatial resolution, a "local"' bulk dry density of up to approximately 1.70 t/m^3 was measured close to some feeder outlets.

The FE experiment was sealed off towards the FE cavern with a concrete plug holding the buffer in place and reducing air and water fluxes.

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 after 3 years. According to current planning, the heating and monitoring phase of the FE experiment is envisaged to last at least 10 to 15 years.

Andra has in the Bure underground research laboratory in France demonstrated the construction feasibility of a complete HLW cell in Callovo-Oxfordian clay with a concept optimized for a possible future retrieval of the waste.



A HLW cell according to the 2009 French benchmark concept.

The HLW cell for the demonstration was excavated in two phases; a 6 m long head section with a 21 mm thick casing having an internal diameter of 767 mm, and a "useful" section with a 20 mm thick casing having an internal diameter of 700 mm. The rig and processes for the drilling had previously been developed within the French national programme. Even though the thrust remained low throughout the drilling there was a minor failure during the last 700 mm requiring adjusting measures by personnel inside the cell.

The installation comprised a base plate, a sleeve head plate, a casing head plate, five heater elements (each 3 m in length and 508 mm in diameter), and more than 150 sensors in the casing.

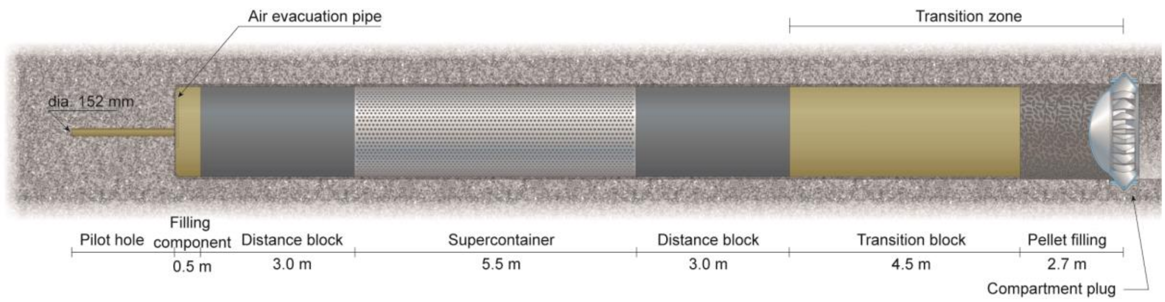
Prior to the excavation of the cell, sensors had been installed in boreholes, drilled from adjacent drifts, to monitor the temperature, the pore pressure and the deformation of the rock.

The sealing and closure of the installation were simplified, as the components for this are investigated in the DOPAS project. In LUCOEX a simple plug was installed at the head of the useful section (representing the radiological protection plug) and a closing plate at the head of the casing.

The installation was followed by the heating phase, which began with a constant 220 W/m power supply for the 15 m occupied by the heater elements, at a depth of between 10 and 25 m into the cell. This power was set to reach a temperature of 90°C at the sleeve wall in 2015.

The hydro-mechanical impact of the cell excavation, monitored on the peripheral boreholes, is consistent with the measurements taken during the excavation of the previous cells parallel to the major horizontal stress. The excavation led to pore pressure increase in the horizontal plane of the cell and to pore pressure drops in the vertical plane. The THM behaviour of the heated cell is developed.

SKB has in the Äspö Hard Rock Laboratory (HRL) demonstrated the construction and installation feasibility of the horizontal disposal concept KBS-3H in crystalline rock.



The Multi-purpose test (MPT) layout.

The construction of the disposal drift has previously been proven through the construction of two deposition drifts at the 220 m level in the Äspö HRL (15 m and 95 m long with a diameter of 1.85 m). The challenge with this construction is the high requirement on the straightness of the drift, i.e. on the pilot hole that is drilled as a first step.

In LUCOEX the ability to make corrective actions down to 0.1° compared to a more normal application of 1° steering corrections have been demonstrated in a 100 m long hole. Testing the full 300 m will be done in the Onkalo URCF.

A new uni-axial mould had to be manufactured as the KBS-3H bentonite blocks are larger than the KBS-3V blocks. Its design is basically the same as that employed for KBS-3V earlier.

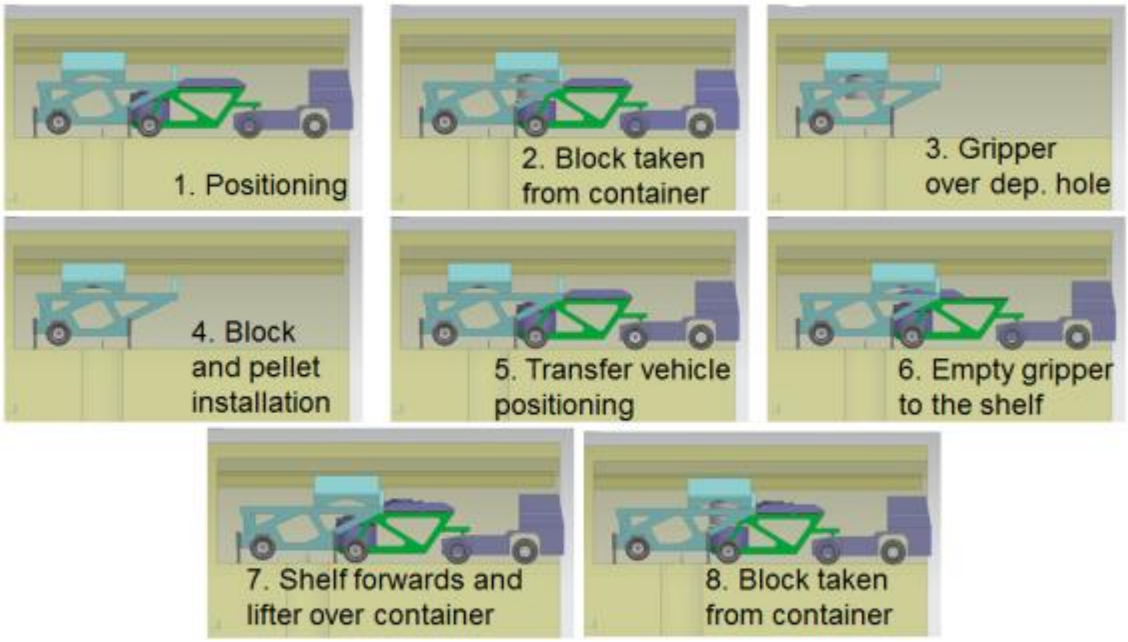
MX-80 bentonite from Wyoming was used. The delivery control showed that the material fulfilled the composition and property requirements. This bentonite was mixed with water in an intense mixer to the required water content. Successful compaction was then done using a uni-axial press. The programme included 12 rings with one water content and 31 solid cylinders with two different water contents. Evaluation afterwards showed that there was a variation in block density (where some blocks had a slightly too high average density) but this was considered acceptable for the current test since the average density of the produced blocks used within the MPT were within the acceptable variation. The reason for the variations is primarily that the facilities rented for the production of these blocks are not optimized for this type of production.

The KBS-3H deposition machine is a first prototype for demonstration of horizontal deposition in full scale. The machine was jointly designed by SKB and Posiva and manufactured in 2005–2006 within the EC project "ESDRED". It utilizes a water cushion transport principle, which works by stepwise movements inside the drift. A lifting and pushing sequence is repeated until the component being installed reaches its' destination. The full scale tests were made in the Äspö HRL in 2007. These tests had some problems due to limited control ability and an incomplete software application. During the MPT the machine was thoroughly upgraded by increased automation level and re-programming of the control system.

Preparatory work concerned installation of cables in grooves in the rock wall and installation of sensors in core holes drilled into the drift´s wall. It also concerned a pre-test with a dummy Supercontainer. After adjustments, among other things the protection of the bentonite blocks, the installation of the MPT took place. The time for installation is a key parameter and the MPT managed to install one Supercontainer in 24 hours. The reference installation time in a final repository is one Supercontainer in 6 hours. On the other hand, without sensors and cables, one Supercontainer would have been managed in 12 hours in the MPT. At this stage of KBS-3H development the present outcome is deemed acceptable as the process still contains manual tasks that would be automated in the final repository.

The compartment plug was installed in two main steps of which the first, the fastening ring installation, was done during the drift preparation stage, and the second after installation of the Supercontainer and the bentonite block. In this way the plug installation in the second step was simply a welding activity. The void between the plug and the transition block was filled with pellets. This was followed by contact grouting of the steel-concrete and concrete-rock interfaces using silica sol grout. Finally the drift voids were filled with water and the air evacuated through the plug. The air and water filling pipes were subsequently removed as planned.

Posiva has in the Onkalo underground rock characterization facility (URCF) in Finland developed and tested the final full-scale prototype machinery and methods for the transportation and installation of buffer components according to the vertical disposal concept KBS3-V in crystalline rock.



The installation of buffer blocks consists of eight basic steps.

Three different machines have been designed, manufactured as prototypes and used for demonstration of the emplacement method underground.

The developed bentonite container simplifies the handling of the buffer and protects it from the impact of the environment once the buffer components have been manufactured. Each bentonite block is put into a separate container with controlled conditions in the factory, where after the container is sealed. On top a separate compartment is filled with a large enough volume of bentonite pellets for the slot between the block and the rock wall in the deposition hole.

The bentonite block installation machine (BIM) is positioned above the deposition hole, is loaded with the bentonite container and emplaces the block in the deposition hole. It lifts the block with the aid of vacuum technology.

The bentonite block transfer device (BTD) is a trailer moved by a terminal tractor unit. It is positioned near the BIM and feeds the BIM with the bentonite container.

The first test phase (above ground testing) took place in a specially designed test and development facility at Posiva's Onkalo site. The focus of this phase was to verify the functionality, accuracy and reliability of the different machines and to fine tune the automation system controlling the machines. Most attention was given to the installation machine and the gripper part of the buffer container responsible for the vacuum lifting of the blocks and the transportation of pellet.

Tests initially showed that the installation accuracy was well within requirement. Additional laser scans, however, showed that the space within the buffer deviated from the initial measurements with up to 4 mm. The installation time also exceeded the 2 hour requirement, where the shortest installation time achieved was 3 hours 53 minutes. And this was for an installation that was still short of one ring block.

Pellet filling of the gap between the buffer and test hole wall was also tested. The procedure was that when each block had been placed in the test hole, the pellets loaded inside the container top were released into the gap between the buffer and the test hole wall. This process worked as planned.

On completion of the surface trials, work was moved underground to test the emplacement method in a repository-like environment. The test area used was in Onkalo URCF´s Demonstration Tunnel 1.

A mixture of concrete blocks and bentonite blocks was used, which was considered to be an acceptable alternative as the concrete blocks are generally more difficult to lift and handle because of their rougher surface compared to bentonite blocks.

Measurements during the installation demonstrations once again showed that the installation accuracy was within specified requirements, while subsequent laser scans once again revealed deviations. Timing of the experiment also showed that the installation was slower than anticipated (3 hours 10 minutes versus requested 2 hours). The demonstration emplacements proved the ability to install the buffer component in a safe and controlled manor.

The quality of installation is a key aspect in making sure that the multi-barrier system functions as designed after sealing and closing of the repository. To verify the quality Posiva developed a sensor system integrated into the vehicles, which transferred the information to QA-related software. Based on the studies and designs presented, it was confirmed that all QA targets can be meet using a sensor system installed on the developed machinery.

If something goes wrong either prior to, or after canister installation, buffer components might have to be removed, so that the canister can be retrieved. Different techniques for buffer removal were evaluated. By use of a combined water jet and vacuum suction method the removal time for one solid block was approximately one hour, hence complete excavation of the buffer in one full deposition hole is possible to accomplish within eight hours.

LUCOEX has been engaged in extensive **networking, dissemination, workshops and public information**. The networking and integration of technical activities between the LUCOEX partners have been developed through regular Project Progress Meetings Steering Committee Meetings and bilateral discussions and integration work. Other specialists, authorities, students and the general public have been offered information of the progress and achieved results by posted information, like Newsletters, on a public website, several open workshops, visits on-site, scholarship programme, training on-site, publication in technical magazines and journals and presentations at specific open seminars/conferences.

Each one of the LUCOEX partners experienced various **lessons learned** in both different and similar technological details as respective demonstration project addressed different aspects of technical details and different types of host rock, while many technical aspects were similar despite the differences in presumptions between the four LUCOEX experiments.

Four key technical areas were addressed in LUCOEX and the results achieved in each of them are summarised in the table below.

Key technical results achieved in the LUCOEX project.

Key technical area	Key technical results			
	Nagra	Andra	SKB	Posiva
Gallery construction	Excavation and reinforcement of disposal tunnels can be done by using standard machinery.	Excavation is possible with readily available technology.	Excavation can be done by using a push reamer guided by a straight pre-drilled pilot hole.	Excavation of disposal galleries can be done by using conventional drill and blast technology.
Manufacturing of components	Optimized granulated bentonite mixture and highly compacted bentonite blocks can be manufactured.	Component necessary for the creation of a steel lined HLW-cell supporting retrievability can be manufactured.	Necessary machines and clay components can be manufactured.	Necessary vehicles, mechanical components and clay components can be manufactured.
Installation	Pedestal design and use of highly compac-ted blocks have been shown viable. How-ever, the emplace-ment procedure was not done according to the Swiss concept.	Installation of steel liners and the operation of a HLW cell has been demonstrated for "H0" waste (packages installed without spacing buffers).	The necessary machinery for the installation has been developed. It has also been demonstrated that an installation can be carried out according to plan.	Necessary machinery for transporting and installation of the buffer components can be manufactured. Installation can be carried out as planned.
Backfilling and sealing of galleries	A backfilling machine was designed and could provide the re-quired density. Further develop-ments are needed to control density and homogeneity.	The sealing and closure is investigated in the DOPAS project.	The project has demonstrated that the drift can be sealed using a steel compartment plug.	The Posiva plug is developed in the DOPAS project.
Additional deliveries		The project has deve-loped a better under-standing of the THM behaviour of the cell and Andra is now able to compare simula-tions with the actual THM-processes in the host rock.	In addition to the planned deliverables SKB has also delivered a first data report from the monitoring for the early stages of the drift evolution.	In addition to the disposal process Posiva has also developed processes and machinery for quality assurance and fault handling necessary in case of a mishap.

Demonstration refers, by definition, to activities carried out in a predetermined manner that leads to a predetermined result. In view of this all four LUCOEX full scale experiments have been very successful. Each one of the four LUCOEX partners have shown that construction of galleries, manufacturing of buffer components, installation and sealing of galleries can be made to meet the initial state, i.e. the situation when no more adjusting measures are assumed to be made and further evolution of the repository components are driven by the repository´s THMC environment and geoscientific events.

In addition lots of experience were gained during the excavation, installation and sealing of the four proof-of-concept demonstrations, as several practical problems were experienced, which had to be solved when they appeared. They were all handled to satisfaction and contributed well to the final result with improved understanding of the engineering input. Such problems are well known to occur in industrial projects but not their nature or severity. They were expected also in LUCOEX, but no problem was so severe that it led to the deviation from the planned implementation or different functions of the resulting components from a long-term safety perspective. In the final end we concluded that the solutions to the problems provided additional knowledge and significant return of experience in the planning of new large underground experiments.

The **dissemination** activities have been recognised positively not only by the scientific community, but also by the public. The LUCOEX project has made it possible for everyone to share the main results. All "deliverables" to the EU as well as regularly published Newsletters have been posted to LUCOEX public website. In addition the LUCOEX partners have regularly reported and posted local information on their respective public websites. The scientific community was also involved and informed via several conferences as well as through the established networking channels between WMOs and within the frame of EU projects, e.g. ESDRED, DOPAS the IGD-TP.

Special efforts were made to engage young scientists and technicians, and a **scholarship and training programme** was launched. It provided in total 29 awards to workshops, conferences and training activities.

LUCOEX also wanted to contribute to a **European added value** and offered each WMO in the Member States a tailor made information exchange. This, however, was considered to be too excessive by the WMOs as useful information would be available on the website, workshops and conferences, and through visits to the respective underground research laboratory, if not the contacts within the scientific community would be enough. Due to these aspects LUCOEX on its own analysed the usefulness of the outcome for other national programmes through a study of the situation in the Member States and their possibility to benefit from LUCOEX information. The findings were that in particular Spain, Slovakia, Hungary, United Kingdom, Germany, Czech Republic and Belgium are countries which are in a position where results from the LUCOEX project can be utilized in a perspicuous future. This study has been presented at a number of conferences.

Other **lessons learned** concerned the organisation and the allocation of personal resources. A risk, recognised already from start, was that key personnel could be partly needed in other tasks than the LUCOEX project. This happened and caused eventually some delays compared to the original time schedule. Another outcome was that secondment of staff could not be made to the full extent that otherwise would have been the case. A management outcome was also that an Expert Group had too many appointed experts and could preferably have consisted of four "external" experts only. In future EU projects such a group should focus primarily on the final reporting and e.g. apply the "expert elicitation" process now going on in the EU project DOPAS.

1 Introduction

The European Council has outlined the following objective for the research area “Management of radioactive waste”:

> *“Through implementation-oriented RTD, the activities aim to establish a sound scientific and technical basis for demonstrating the technologies and safety of disposal of spent fuel and long-lived radioactive wastes in geological formations ...”*

In the FP7 work programme 2010 (European Commission C(2009)5946 from 30 July 2009) it was further stated that the expected impact of projects should be that they contribute to:

> *“The progress towards the implementing of geological disposal in line with the Vision Report and initial roadmaps of IGD-TP and the 2020 objectives of the SET-Plan, together with significant advances in the treatment and/or understanding of key remaining issues. In particular, this should lead to demonstrable improvements in robustness of associated performance and safety analyses, and ultimately to increased confidence in the safety case.*”

Waste implementers (WMOs) being deeply involved in experiments in underground laboratories (Andra, Nagra, SKB and Posiva) have addressed these objectives by implementing a joint collaboration regarding large underground concept experiments “LUCOEX”, which met the FP7 work programme theme of Fission-2010 1.1.1. The LUCOEX project has focused on four parallel experiments at the WMOs` underground research laboratories; all designed for the specific purpose of developing these kinds of underground facilities. Each experiment has addressed different concepts and different geological and technical/legal pre-conditions and all experiments were executed based on openness and willingness to share the knowledge gained to support the development of safe and reliable repositories throughout Europe. Each LUCOEX partner has focused on the following:

- Andra has in the Bure underground research laboratory in France demonstrated the construction feasibility of a complete HLW cell in Callovo-Oxfordian clay with a concept optimized for a possible future retrieval of the waste.
- Nagra has in the Mont Terri underground research laboratory in Switzerland performed the FE-experiment, which is a full-scale, multiple heater test in Opalinus Clay.
- SKB has in the Äspö Hard Rock Laboratory in Sweden demonstrated the construction and installation feasibility of the horizontal disposal concept KBS-3H in crystalline rock.
- Posiva has in the Onkalo underground rock characterization facility in Finland developed and tested the final full-scale prototype machinery and methods for the transportation and installation of buffer components according to the vertical disposal concept KBS-3V in crystalline rock.

Four key technical areas have been addressed:

- Gallery construction.
- Manufacturing and emplacement of buffer around waste canisters.
- Emplacement of waste packages.
- Backfilling and sealing of galleries.

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2 Objectives and goals

The LUCOEX project was separated into six work packages of which four addressed demonstration activities and one integration, dissemination and European values. The sixth work package addressed project management via coordination activities. The following detailed objectives and goals were for set for each work package.

2.1 Coordination and integration (Work Package 1)

The objectives for Work Package 1 were to continuously integrate the results of the different demonstration activities and to disseminate the obtained knowledge in the following way:

- Provide a broad base for integrated planning, evaluation and reporting of the outcome.
- Communicate technical findings and conclusions drawn during progress.
- Support networking among scientists and engineers with focus on creating forums for presenting and discussing the LUCOEX project.
- Invite representatives working with concepts not studied, to discuss the findings.
- Provide training opportunities by hosting activities e.g. at respective Underground Rock Laboratory carrying through demonstration activities.
- Provide program for exchange staff between participating organizations for information transfer on performed demonstration activities.
- Invite and support travel and lodging of students to participate at hosted events.
- Publish results in technical magazines and at specific seminars/conferences.

2.2 Horizontal disposal of waste packages in Opalinus Clay formation – FE Mont Terri demonstration (Work Package 2)

The objectives for Work Package 2 and the FE-experiment at Mont Terri were the following:

- Provide a confirmation of the suitability of the repository design basis or give clear insights regarding how it should be modified.
- Construct emplacement tunnel using modified standard equipment and adequate support measures.
- Manufacture the bentonite in a suitable form and density.
- Design, manufacture and test equipment necessary for waste and buffer emplacement in situ.
- Demonstrate the suitability of the concept.

2.3 Horizontal disposal of waste packages in Callovo-Oxfordian clay formation – ALC experiment at Bure (Work Package 3)

The objectives for Work Package 3 and the ALC experiment at Bure were the following:

- Construct a HWL-cell consistent with the 2009 benchmark concept including both cell head and the usable part.
- Verify the function of the cell head insert and its ability to absorb the thermal dilation of the cell stainless steel casing.
- Provide data on the casing behaviour under actual thermal load.
- Verify the design of the cell head and its ability to limit the thermal gradients on the drift wall.

2.4 Horizontal disposal of waste packages in crystalline rock – KBS-3H demonstration at Äspö (Work Package 4)

The objectives for Work Package 4 and the Multipurpose Test (MPT) at Äspö were the following:

- Test the system components in full scale and in combination with each other to obtain an initial verification of design implementation and component function.
- Test the ability to manufacture full scale components, carry out installation (according to DAWE) and monitor the initial system state of the MPT and its subsequent evolution.

In addition to the original objectives related to the MPT a drilling activity was added to LUCOEX with the objectives to:

- Demonstrate the ability to drill long, straight horizontal pilot holes in crystalline rock using guided core drilling technology.

2.5 Vertical disposal of waste packages in crystalline hard rock – KBS-3V emplacement test in Onkalo (Work Package 5)

The objectives for Work Package 5, developing and demonstrating the final prototype machinery at Onkalo URCF and participating in the MPT at Äspö were the following:

- Design, develop and manufacture emplacement machines.
- Design, develop and manufacture pellet installation equipment.
- Demonstrate the full-scale emplacement of both buffer and pellet in-situ.
- Develop quality assurance processes.
- Develop problem handling methods during installation.

2.6 Management and dissemination (Work Package 6)

The objectives for Work Package 6 managed by SKB were the following:

- Set up the both physically and virtually infrastructure to coordinate the project activities.
- Help organize and balance the LUCOEX work and activities.
- Facilitate and support the organization and management of the different work packages.
- Supervise the production of necessary documentation for the LUCOEX, to provide means of quality controlling them and to publish them, including open access.
- Disseminate results to the scientific and engineering communities and to the public.
- Act as an information and communication center about the activities of the LUCOEX.

3 Scope of work addressing objectives and goals

3.1 Coordination and integration (Work Package 1)

This WP1 was purely focused on the coordination of the project, the integration between the other work packages and dissemination of the knowledge. The work was separated into several different tasks as follows:

Task 1.1 Coordination of management meetings
The Steering Committee (SC) was formed during the grant agreement negotiations and Erik Thurner from SKB was elected to chair it. The SC had during the course of the project 9 official meetings. The final meeting was held at the end of the project. Five of these meetings are listed in the milestone plan (M1.8, M1.14, M1.17, M1.22 and M1.28). Minutes from the meetings have been posted to the project´s internal website.

A technical Expert Group (EG) consisting of four “internal” and four “external” experts, appointed by the SC, was given the mission to serve the project with reviews, cross-WP examinations and advices related to technical plans, achievements and dissemination activities. The group met on numerous occasions; both onsite at the experiments and in the offices of Nagra and Andra. Two reports (D1.7 and D1.11) were published at the time of writing and the third was planned to be published in August 2015 (D1.14).

Task 1.2 Integrated planning
The LUCOEX underground research laboratory activities were openly shared with both the project partners and externally during all phases of the project. The goal for the project was to ensure that planning, execution and outcome analysis were consistent and compatible between the addressed repository concepts. A project plan was initially developed as planned. It was sent in as a deliverable (D1.1), and was updated as an internal document during the course of the project.

Five Project Progress Meetings (PPMs) were performed in accordance with the milestone plan (M1.7, M1.13, M1.18, M1.21 and M1.27) during the course of the project where the progress of each of the Work Packages was discussed. We also discussed key risks at these meetings that were then forwarded to the SC. Minutes from these meetings were published both internally and on the external homepage as project deliverables (D1.6, D1.8, D1.10, D1.12 and D1.20).

Task 1.3 Risk assessment
The project´s risk exposure was repeatedly assessed by identification and characterisation of risks followed by evaluation of probability, judgement of possible consequence and calculation of the risk for costs, time-delay and performance respectively. Based on the identified risks we continuously during the course of the project discussed main risks and challenges at the SGM to ensure that appropriate actions were always taken.

Task 1.4 Communication Action Plan
The project continuously communicated information about the project, its progress and results to the scientific community as well as to the general public. A master plan on how this was to be performed, when and by whom, was developed in this WP1 and implemented by WP6.

The communication efforts within LUCOEX were divided into internal and external communications.

LUCOEX internal communication activities included:

- Five Project Progress Meetings (PPMs) held on different sites giving all members the opportunity to get impressions of the different sites and experiments. Each PPM was combined with a workshop focusing on certain topics relevant to the project:

    - PPM1 (SKB's main office, Sweden)
      Theme: Project planning, Risk management and Cross reviewing of plans.
    - PPM2 (on site at Olkiluoto, Finland)
      Theme workshop: Horizon2020, Tunnel and disposal cell excavation.
    - PPM3 (on site at Bure, France)
      Theme workshop: Instrumentation.
    - PPM4 (on site at Mont Terri, Switzerland)
      Theme workshop: Bentonite block/pellet manufacturing and installation.
    - PPM5 (on site at Äspö, Sweden)
      Theme workshop: Installation and sealing of drifts.
- The Projectplace.com website was setup for the storage and sharing of documents. This fulfilled its purpose. Additional functions for project planning etc were not used. Based on feedback from the Expert Group (EG) it became apparent that some support in the usage earlier in the project would have been good.
- All individual Work Packages (WPs) invited both the other partners and the EG Group to visit and participate in their individual experiments.
- Information was also shared between the members by the means of email, face-to-face meetings and through the external communication channels like the newsletters and workshops.

Project External communication was primarily handled through:
- The workshops arranged by LUCOEX in conjunction with the Project Progress Meetings (PPMs).
- The Mid-term Workshop held in conjunction with the Clay conference in France in 2012.
- The Large workshop at Äspö in 2015.
- LUCOEX external website was set up (www.lucoex.eu) and did include general information and all project deliverables.
- Scholarship programme open for students and professionals from all the members states and Switzerland.
- Training programme where young professionals were offered the opportunity to during a minimum of two weeks participate in the full scale tests on-site.
- Publication in technical magazines and journals.
- Presentations at specific seminars/conferences.

Newsletter
Four newsletters were published in accordance with the plan and both published on the homepage and distributed through E-mail to concerned parties.

General public
The general public was primarily informed through the LUCOEX website, during visits on-site at the different underground research laboratories and through the partners´ presentation of our findings at open conferences.

Task 1.5 Networking and dissemination of results
The project hosted:
- Four Workshops held in conjunction with the Project Progress Meetings (PPMs) where we had representatives from numerous European countries participating.
- Mid-term Workshop held in conjunction with the Clay conference in France in 2012 where we had participants from 13 European countries plus Japan.
- Large Workshop was held at Äspö in 2015 with roughly 80 participants from 15 European countries plus representatives from Japan and China.

The project, in addition to the hosted events, also presented the work being performed in the project at over 15 external conferences and published over 30 articles on the experiments performed.

Task 1.6 Training programmes and training activities
The LUCOEX organization, primarily during the second half of the project, prepared a selection of topics and forums for carrying through training. Each event was planned together with interested organisation after announcing the event and efforts made to encourage post-docs or students from Universities in the European Union and Switzerland to take part. The training programme was integrated with the LUCOEX Scholarship program which included a total of 20 scholarships for participation at the LUCOEX conferences and workshops and 9 on-site training scholarships.

Task 1.7 Scholarships
The LUCOEX project originally had a total budget for 20 scholarships which were made available for students, post-doc and engineers in European Union Member States and Switzerland. By the end of the project we were forced to cancel 4 scholarships because of limited interest during the start of the project but were still able to perform a total of 28 scholarships supporting 2- and 4-week training events on-site, participation in mid-term and large workshops and participation in the WP-specific workshops. Further information is available in chapter 4.2.

Task 1.8 Planning of programme on secondment of staff
Opportunities for staff secondment were planned and invitations were sent out from the hosting organizations. Because of the limited resources available within the project we were however not able to identify personnel able to participate in the other experiments during an extended period of time. We therefore focused on having information exchange activities like on-site visits at crucial parts of the individual experiments like during the Site Acceptance Test (SAT) and underground tests of the machines in Finland, during the installation sequence in Sweden/France and during mockup-tests/SAT-tests/installation in Switzerland.

Task 1.9 European added value
Our plan was to assess the existing research programmes on management of high-level waste in different member states together with respective responsible waste management organisation (WMO) and to select which activities in LUCOEX that would be of interest for them to follow in detail. An invitation was sent out to all WMOs, but only a few responded. The answers clearly showed the interest to share information and results, but only by LUCOEX public channels: newsletters, reports, participation in workshops and visits to the respective underground research laboratory.
Instead we initiated an analysis performed by a master thesis student, who studied the status within the existing European programmes for management of spent fuel and mapped what was studied in the LUCOEX project with the needs of the different programmes. These findings were reviewed by the participants and presented at a number of conferences.

Task 1.10 Final reporting of WP1
The result and experience gained from the WP1 activities were compiled in a final WP1 report.

Task 1.11 Summarising and reporting of LUCOEX results
Each work package produced results which were of interest to share with world-wide experts in order to foster an international dialogue. To support this sharing we summarized the findings in a summary report in accordance with the table of content included in the Grant Agreement.

3.2 Horizontal disposal of waste packages in Opalinus Clay formation – FE Mont Terri demonstration (Work Package 2)

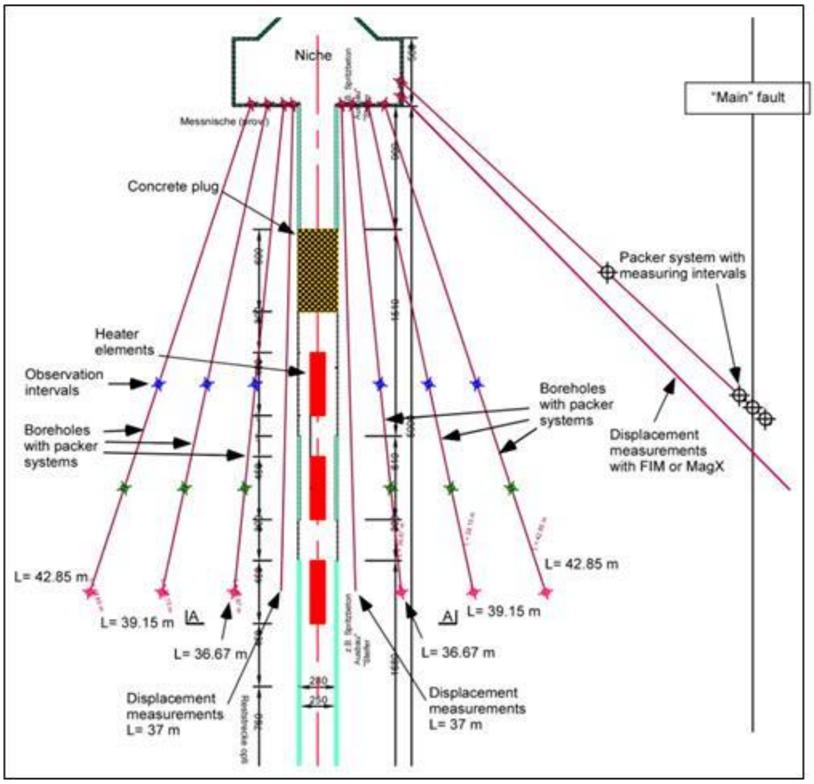

Figure 3-1. *Schematic view of FE Mont Terri demonstration project.*

Task 2.1 Detailed experiment planning

The experiment was planned in detail and documented in a work plan, which covers all preparations, equipment developments and field activities.

Task 2.2 Tunnel construction and support

Evaluation of construction and support method

The construction of emplacement tunnels in Opalinus Clay required a technology which permits mechanically excavating the tunnel and placing the support measures at a very early time just a few meters behind the face. We relied on existing tunnelling equipment which had to be modified to comply with our needs. As the actual disposal site is not yet known, it may be necessary to modify the originally planned tunnel support (bolts and mesh) so it is possible to use it at a repository depth as deep as 900 m or in tunnels that are placed in areas which are tectonically more disturbed than the Zürcher Weinland.

Modification of tunnelling machine

Following the outcome of the design studies an evaluation of existing tunnelling machines was carried out to find the most appropriate existing machine that could be modified in accordance with our needs.

Tunnel construction and ventilation period

The tunnel was constructed at Mont Terri with a diameter of 2.5 – 2.8 m and an appropriate tunnel support (e.g. low pH shotcrete liner) to host 3 dummy canisters placed on bentonite blocks. Tunnel liner of cement material may cause axial transport paths after degradation of the cement. To avoid flow along the emplacement tunnel it was foreseen that certain sections in the tunnel were constructed in a way that any axial flow path was effectively interrupted (compartmentalisation). The applicability and the performance of such an “intermediate seal section” in the emplacement tunnel, probably consisting of a section with steel rips in conjunction with bentonite, were tested in the experiment. After construction, the tunnel was ventilated for about one year to simulate the expected duration prior to waste emplacement.

Task 2.3 Preparation of the emplacement

Manufacturing of buffer blocks and the granular buffer

Building on the experience gained in previous experiments funded by the European Commission (e.g. EB experiment at Mont Terri and ESDRED), bentonite blocks and granular bentonite were manufactured from MX80 bentonite. The buffer material did not need further development, but had to be delivered just before the actual emplacement in order to avoid long storage times and possible alteration.

Development of emplacement equipment

Equipment necessary to emplace the buffer blocks, the canister and the granular buffer are designed and constructed. The emplacement equipment allowing placement of the canister together with the blocks in one working step was rail-based. The preliminary design of the existing emplacement equipment for the granular buffer was further developed. The system consists of five screw feeders systems which can be steered separately to improve the performance of the emplacement system in comparison to the original equipment used in the ESDRED project to produce an optimal homogeneity of the granular buffer.
The main emplacement equipment (multiple screw feeder device, necessary electronic control unit and testing of these parts) were designed and constructed as part of the LUCOEX project. Additional supporting equipment (e.g. rails, crane, transport wagon) and additional equipment tests were funded entirely by Nagra.

Task 2.4 Emplacement activity

The equipment, designed and manufactured in Task 2.3 was used in the underground rock laboratory Mont Terri to emplace the canister, the bentonite blocks and the granular bentonite in the tunnel and sealing section. QC procedures were developed and implemented to ensure adequate buffer density and homogeneity. Monitoring instruments, entirely funded by Nagra, were placed in the buffer.
The emplacement section was finally closed by a cement plug.

Task 2.5 Final reporting of WP2

This task addressed the compilation of all WP2 results in a final WP2 report and was summarized in a peer reviewed scientific paper.

Task 2.6 Integration

This task was linked to WP1 and addressed the following activities:

- Expert advice of other participants on the WP test plan.
- Invitations to the other participants 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 to give input to the WP.
- Review of the WP final report by the other participants to verify relevant information was complete.
- Networking for new scientists.

Networking for new scientists was management within the scholarship programme and secondment of staff.

3.3 Horizontal disposal of waste packages in Callovo-Oxfordian clay formation – ACL experiment at Bure (Work Package 3)

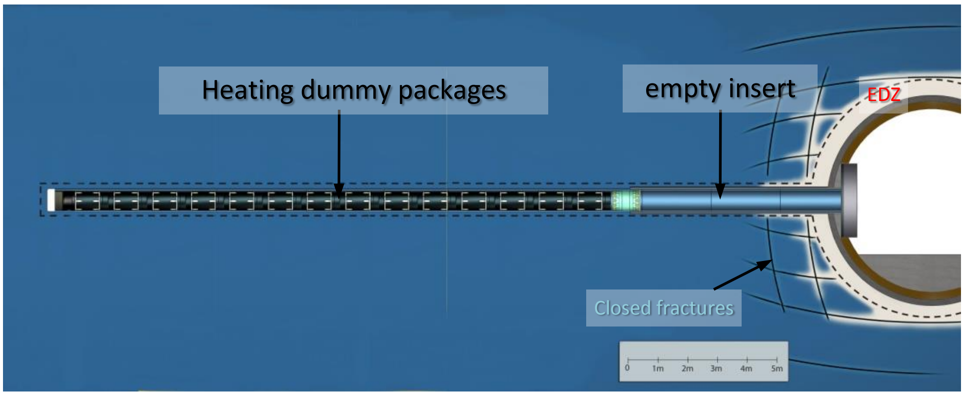

Figure 3-2. *Schematic view of ALC Experiment.*

Task 3.1 Detailed design of the experiment including an in situ test of forced casing excavation to prepare the construction of the cell

One of the key issues of demonstration of the cell in the French concept was the construction feasibility of the cell's head, which was a casing emplaced with a minimum void between the casing and the rock walls. The casing was 10 m long and was forced into the micro-tunnel to minimize the void around the casing. This had never before been done in the Callovo-Oxfordian claystone at the Meuse Haute Marne Underground Research Laboratory. A first in situ test to emplace a forced casing (consisting in five 2 m long metal tubes, diameter 775 mm) with a void of 16 mm over the diameter was made at the beginning of the project to check the feasibility with the actual excavation machine and to improve it, if necessary. The axial load on the casing was recorded during the test.

Based on the result of this pre-test the experimental test plan for the full-scale test was written. This plan describes the objective of the demonstration experiment, the geometry of the experiment, the procedure of emplacement and the prescribed heating phase.

Task 3.2 Emplacement of the cell

The purpose was to validate the emplacement procedure.

- Forcing the head insert (10 m long) into the drift wall.
- Excavating the 25 m long micro-tunnel with simultaneous emplacement of a steel casing.
- Installation of the end steel plug.
- Introducing the heaters and the shield steel plug.

The excavation of the cell is made by a guided auger drilling machine with a drilling head that could be adapted to excavate diameter of 70 to 74 cm. The machine was laser guided and allowed the control of the micro-tunnel´s direction with a precision of +/- 2 cm. The excavation was achieved with casing. The casing was a 2 m long, 70 cm in diameter and 2 cm thick metal tube. The casing was instrumented in order to provide data on the behaviour under the thermal loading.

Heaters were installed in the cell's casing between a depth of 10 m to 25 m. A shield plug was installed into the casing just at the end of the heater installation section.

In addition, boreholes were drilled to set up instrumentation around the cell in order to analyse the working of the head concept under a thermal loading: temperature (2 boreholes) to measure the thermal gradient to the drift. The relative displacement of cell casing to the insert was measured to check the running of the head with the dilatancy. Deformations of the drift at the cell head was also followed to verify the design of the cell head in order to check stress and deformation induced by the thermal gradient.

Task 3.3 Final reporting of WP3
This task addressed the compilation of all WP3 results in a final WP3 report.

Task 3.4 Integration
This task was linked to WP1 in order to increase integration and good practices between the project partners.

Subtask 3.4.1 Small workshop in conjunction with Project Progress Meetings of WP3
This subtask was linked to the Project Progress Meetings (PPMs) (WP1) and was focused on the workshop at the Bure site.

Subtask 3.4.2 Active exchange of experiences
The task was linked to WP1 and addressed the following activities:

- Invitations to the other participants to participate in Project Progress Meeting (1 every 9 months), to attend installations and demonstrations during insert test (month 2) and during emplacement of the cell (≈month 12-16) with the aim to give input to the WP.
- Networking for new scientists.
- Expert advice of other participants on the WP test plan.
- Review of the WP final report by the other participants to verify relevant information for the project. For this review a group of experts was formed with internal and external experts (like experts from the panel of technical expert (WP1) or others). The mean of this review was to serve as means for critical cross examination, assessment, integrated analysis of the results and achievements in terms of feasibility of the emplacement concept and working during the heating phase), in order to prepare conclusions for the task 1.11.

3.4 Horizontal disposal of waste packages in crystalline rock – KBS-3H demonstration at Äspö HRL (Work Package 4)

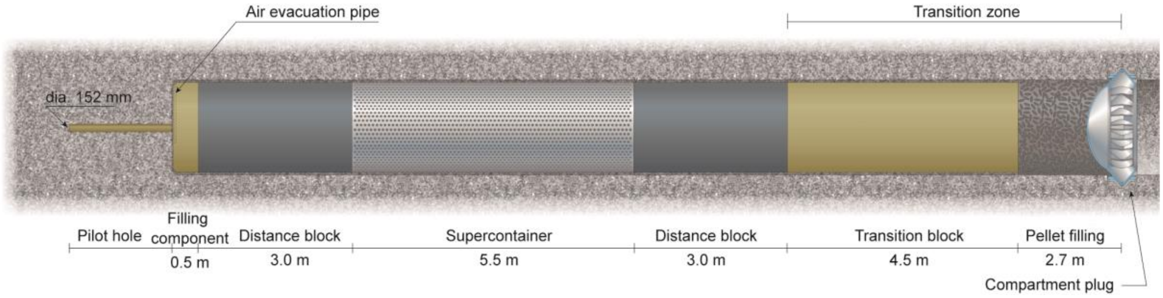

Figure 3-3. *Layout of the Multi Purpose Test (MPT).*

Task 4.1 Detailed WP planning
Detailed planning of WP4 was made together with the other WPs to increase collaboration and fellowship.

Task 4.2 Manufacturing of distance blocks and buffer blocks for the Supercontainer
Manufacturing of full scale KBS-3H buffer- and distance blocks had not been done earlier. A successful outcome of the task was a necessity, since the system design is dependent on the quality of the buffer blocks. A new mould for uniaxial block pressing was used. Isostatic compressing of buffer blocks was planned to be tested and evaluated jointly with WP5. Experience of uniaxial and isostatic compressing as well as the quality of the pressed blocks was compared and evaluated by WP5. The result was expected to guide the decision of which compression method to use in the future.

Task 4.3 Upgrading of deposit machine
Earlier test had shown that the design of the KBS-3H deposition machine was successful. However, long-term testing had shown weaknesses in both the water cushion system and the control system. These weaknesses were addressed and the deposition machine was updated prior to the installation of the Multi Purpose Test.

Task 4.4 Multi Purpose Test
The Multi Purpose Test was designed to address several issues within the KBS-3H design and bring the knowledge of the system behaviour to a more mature level. Performance of the test demonstrated the ability to properly install the system to fulfil the quality demands.

In previous KBS-3H phases two Supercontainers (SC) were assembled. In these two Supercontainers concrete dummy buffer blocks were used. The assembly process with real bentonite buffer blocks was similar as with concrete blocks, but the tools needed, precision of the task as well as the need for controlled environment was a major difference. Since there were no tools for handling bentonite buffer blocks during assembly development, testing of such was also made.

Previous deposition tests were successful in the way that the method was proven to function. The new emplacement test was expected to verify the ability to properly deposit Supercontainers and distance blocks made of real bentonite. In addition it performed a vital part of the Multi Purpose Test installation.

Full scale buffer saturation cannot be studied in a laboratory. Modelling of the process close to initial state can be done, but verification of the models is needed. Therefore the Multi Purpose Test was designed to do this. But modelling of the KBS-3H saturation process was not included in the LUCOEX project.

Thermal spalling of the rock wall can lead to leakage paths and piping. The prevention of thermal spalling was identified as a key issue both in the KBS-3V and KBS-3H designs. In the KBS-3H case thermal spalling might occur at the top of the drift. Tests showed that thermal spalling can be mitigated, if a counter pressure is applied to the rock. In the Multi Purpose Test the buffer swelling pressure in the drift was monitored closely. The test showed that the buffer will apply enough counter pressure to the rock in due time to prevent spalling.

The compartment plug in the KBS-3H design was successfully tested in full scale as a freestanding component. In the Multi Purpose Test the compartment plug was tested in combination with the other system components.

Buffer homogenisation was planned to be verified through sampling the buffer, however due to slower than expected evolution of the buffer, the MPT was prolonged and dismantling was thus removed from the LUCOEX.

Instead a 100 m length scale steered core, 76 mm, drilling operation at the Äspö HRL was included in the LUCOEX. The construction of the disposal drifts had previously been proven through the construction of the two deposition drifts (Ø 1.85 m) excavated at the -220 m level of the Äspö Hard Rock Laboratory (Äspö HRL) in Sweden; one 15 m long and one 95 m long. The challenge with producing these drifts was that the tolerances were very strict as a result of the very limited space between the Supercontainer/bentonite-components and the rock wall. This put very high requirements on the straightness of the pilot hole.

Using steered core drilling was assessed as the best alternative by the KBS-3H project and as a first step a 100 m length scale steered core drilling was carried out. It was subsequently followed by a 300 m steered core drilling operation in Onkalo, however only the 100 m drilling at Äspö HRL was included in the LUCOEX.

Task 4.5 Final reporting of WP4

This task addressed the compilation of all WP4 results in a final WP4 report.

Task 4.6 Integration

This task was linked with the WP1 in order to increase integration. The task addressed the following activities:

- Expert advice of other participants on the WP test plan.
- Invitations to the other participants to participate in meetings and to attend at component assembly, installation and operation of the tests.
- Review of the WP final report by the other participants.
- Networking for new scientists.

3.5 Vertical disposal of waste packages in crystalline hard rock – KBS-3V Emplacement test in Onkalo (Work Package 5)

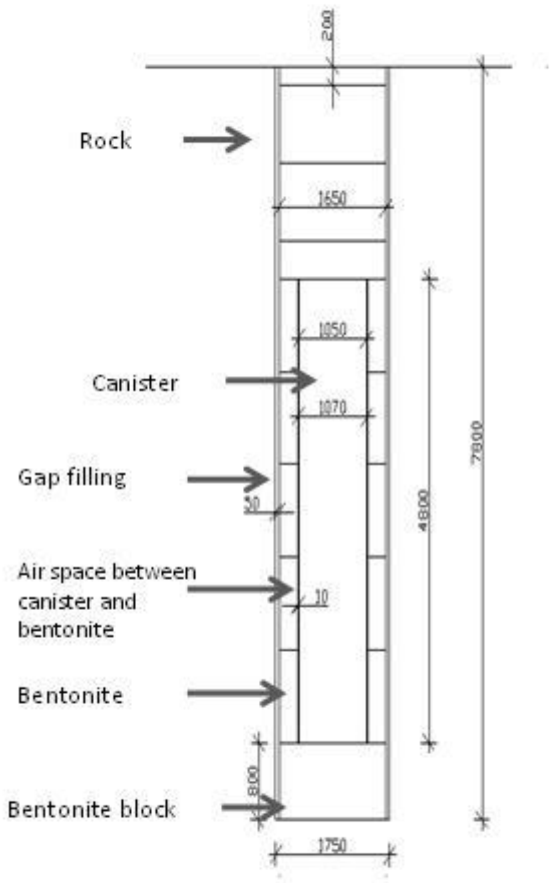

Figure 3-4. *Cross-section of the deposition hole in the Onkalo demonstration project.*

Task 5.1 Detailed WP planning

This task addressed detailed planning of the WP5 contents. All activities were discussed in detail and described in the planning document. Posiva invited the other project partners to provide expertise to this planning phase.

Task 5.2 Demonstration of buffer components emplacement

The emplacement was demonstrated in 2 full scale deposition holes in Onkalo with about 10 m distance. The aim was to test the feasibility of the emplacement method. In the first tests concrete blocks were used, while full scale bentonite blocks were used in the final tests. A dummy “canister” represented the real canister with heat emitting spent fuel. Emplacement tolerances and accuracies were studied for finding suitable methods and equipment for installation control.

The emplacement methods for bentonite blocks were developed so that it was possible to carry out the emplacement with needed speed and accuracy. For the emplacement demonstration, a vehicle frame equivalent to the deposition vehicle was constructed and the installation machinery was fixed to it.
For ensuring the correct understanding of the deposition circumstances, a “dummy” canister was emplaced with the deposition vehicle (canister installation development was though made in another project).

Development of the buffer block emplacement automatics

The buffer block installation automatics and remote controlling of the machinery was developed, so that the required tolerances and uncertainty factors and installation safety aspects could be managed.

The first installations testing automatics was done in indoor premises by using a tower-like “deposition hole”. At this stage, the deposition vehicle was replaced by a bridge crane. When the automatics were functioning and the emplacement was working fluently, testing in Onkalo started, where also an interim deposition vehicle was used. At the event of emplacing the buffer blocks also the “dummy” canister was installed by using the interim vehicle.

Development of the suction lifter
The suction lifter (already existing) was developed further and equipped with installation and positioning automatics.

Development of the emplacement machinery positioning methods
The positioning methods of the emplacement machinery were developed so that the buffer blocks could be emplaced accurately, while taking deposition tunnel forms and other restricting factors into account.

Subtask 5.2.1 Development of the tool for filling the gap between the buffer and host rock
The gap between the buffer blocks and the deposition hole wall was filled with bentonite pellets after the buffer block emplacement. The tool for filling the gap was developed and tested.

Sub-task 5.2.2 Buffer emplacement testing
The emplacement of buffer blocks and filling of gap between the buffer blocks and the wall of the deposition hole was tested in Onkalo.

Task 5.3 Quality assurance and problem handling
The installation process of the buffer was carefully planned, tested and reported to develop quality assurance procedures, which ensured the overall quality of the buffer during the disposal process.

Subtask 5.3.1 Development of the quality requirements and quality assurance methods
The emplacement work and gap filling quality requirements were defined. For this part, a description on the quality assurance was elaborated and the needed quality assurance methods defined.

Subtask 5.3.2 Development of the quality assurance equipment
The quality assurance equipment/control equipment needed for the control procedures, were designed and tested for emplacement work and gap filling.

Subtask 5.3.3 Development of problem handling methods
The problem handling methods for the management and restoration of broken buffer blocks, gap filling and other exceptional situations were developed.

A process description was made for the handling of different problems and fault situations, which might happen during emplacement. In an extreme case all the emplaced buffer blocks and the canister have to be removed from the deposition hole and the installation made once again. For this and other less severe situations there had to be readiness to act correctly.

Task 5.4 Final reporting of WP5
This task addressed the compilation of all WP5 results in a final WP5 report.

Task 5.5 Integration and dissemination

Subtask 5.5.1 Integration
Active exchange of experiences and good practices between the project partners was carried out during the WP5 duration. Experts presented advice on the WP test plan.

Researcher exchange/staff secondment activities were organised between Posiva and other participants especially in connection with the demonstrations. Important project meetings were held public with other participants in order to share information and brainstorm the solution jointly. The project partners were offered the possibility to send their researchers to participate in the WP5 activities. Internal and external experts were invited to perform reviews on the WP5 project plan, interim results, demonstrations and final report.

Subtask 5.5.2 Dissemination
Information about the developments related to this WP5 was disseminated to different stakeholder and interest groups by the following activities:

- A 30-minute documentary film about the buffer components emplacement was created. The documentary was presented on Posiva´s and the project´s websites. Public viewings were organised at different events like fairs and conferences participated.
- Demonstrations to which authorities were invited were organised three times during the WP5 duration. Planned demonstration events: the buffer block emplacement tests at indoor premises; emplacement demonstration with quality control demonstration in Onkalo; problem handling demonstration in Onkalo.
- A one-page newsletter with information on the work package activities' progress was composed in Finnish and in English and delivered to relevant national and local stakeholders/interest groups two times a year.
- WP5 produced information that was published on the project's (i.e. the website developed under WP6) and Posiva's websites.

3.6 Management and dissemination (Work Package 6)

Task 6.1 Setting up and operating the organisation for coordination of LUCOEX

A Project management office was setup within SKB for the management of the project. Work included the support and follow-up of the individual work packages including activities like:

- Writing a project handbook
- Developing and distributing templates for deliveries and reporting
- Support reporting and the distribution of information through the homepage.

Task 6.2 Project Presentation

A general project presentation was originally created in accordance with Commission´s guidelines. This presentation was extended numerous times with specific slides matching the needs of a specific conference or audience.

Task 6.3 Newsletter

Four newsletters were published during the course of the project. They were distributed both over E-mail and published online at http://www.lucoex.eu.

Task 6.4 Website portal

A project internal web-site was setup during the start of the project using www.projectplace.com. The project chose to only use the information sharing functions for documents. Applications for project planning and control were not utilized.

A public website was setup early in the project (www.lucoex.eu). It got a large overhaul during 2012 to ensure compliance with web-standards and proper operation with mobile devices. The homepage, which among other things contains all the public deliverables from the project, will remain operational until 2020.

Task 6.5 Support for production of necessary documentation regarding LUCOEX work and activities

This work included the periodic reporting and the final documentation for the project. The first periodic reporting was cumbersome and took a long time for all involved parties. The project partners and the PMO learned from those experiences and published a project handbook complemented with templates and instructions for the following reporting which proved beneficial.

Also included here was the publication of project deliverables both through the SESAM-web-portal and the LUCOEX homepage.

4 Programme implementation

4.1 Networking, dissemination, workshops and public information

A key component of the LUCOEX project was the dissemination of our findings. This was done through:

a) making it possible to visit the experiments at underground research laboratories,

b) presenting our results and findings through scientific articles and presentations at conferences,

c) producing movies from the different experiments,

d) hosting conferences and workshops,

e) having a scholarship programme to give external parties the possibility to participate both in hosted events and on site during the experiments.

All these activities were executed to our satisfaction. A disappointment, however, was that our ambition to organize tailor-made dissemination activities for individual member state with research on similar topics as LUCOEX did not meet any interest.

4.1.1 Internal Communication

LUCOEX internal communication activities included:

- Five Project Progress Meetings (PPMs) were held on different sites giving all members the opportunity to get impressions of the different sites and experiments. Each PPM was combined with a workshop focusing on certain topics related to the work performed within the project:
  - PPM1 (SKB's main office, Sweden)
    Theme: Project planning, Risk management and Cross reviewing of plans.
  - PPM2 (on site at Olkiluoto, Finland)
    Theme workshop: Horizon2020, Tunnel and disposal cell excavation.
  - PPM3 (on site at Bure, France)
    Theme workshop: Instrumentation.
  - PPM4 (on site at Mont Terri, Switzerland)
    Theme workshop: Bentonite block/pellet manufacturing and installation.
  - PPM5 (on site at Äspö HRL, Sweden)
    Theme workshop: Installation and sealing of drifts.
- The Projectplace.com website was setup for the project internal storage and sharing of documents. This was fulfilling its purpose. Additional functions for project planning were not used. Based on feedback from the Expert Group (EG) it became apparent that some support in the usage earlier in the project would have been good.
- All individual WPs invited both the other partners and the EG to visit and participate in their individual experiments.
- Information was also shared between the members by the means of email, face-to-face meetings and through the external communication channels like the newsletters and workshops.

4.1.2 External Communication

Project External communication towards other WMO's and the general public was primarily handled through:

- Open on-site visits presenting both the general work performed and the LUCOEX experiments.
- Four Workshops were held in conjunction with the Project Progress Meetings (PPMs) where we had representatives from numerous European countries participating (the first theme workshop was performed for the benefit of the project).

- Mid-term Workshop was held in conjunction with the Clay conference in France in 2012 where we had participants from 13 European countries plus Japan.
- Large Workshop was held at Äspö in 2015 with roughly 80 participants from 15 European countries plus representatives from Japan and China.
- The LUCOEX external website (http://www.lucoex.eu) which included both general information about the project and all project deliverables.
- Scholarship programme were open for students and professionals from all the members states and Switzerland.
- Training programme where young professionals were offered the opportunity to during a minimum of two weeks participate in the full scale tests on-site.
- Publication in technical magazines and journals.
- The project did in addition to the hosted events also present the work performed in the project at over 15 external conferences and published over 30 articles on the experiments performed.

4.1.3 Newsletter

Four newsletters were published in accordance with the plan and both published on the website and distributed through E-mail to concerned parties.

4.1.4 Secondment of staff

We were not able to execute secondment of staff where personnel participated in the other experiments during an extended period of time but the information exchange and visits, especially between partners with the same geological pre-requisites (clay vs hard rock) , were extensive.

4.2 Training and scholarships

4.2.1 Training programmes and training activities

The project performed nine training event by offering external post-doc/students/experts the opportunity to participate in the on-site work which were all co-financed through the LUCOEX scholarship programme.

4.2.2 Scholarships

The LUCOEX project originally had a total budget for 20 scholarships which were made available for students, post-doc and engineers in European Union Member States and Switzerland. By the end of the project we were forced to cancel 4 scholarships because of limited interest during the start of the project but were still able to perform a total of 28 scholarships supporting 2- and 4-week training events on-site, participation in mid-term and large workshops and participation in the WP-specific workshops. All scholarship events are presented below:

Event	Time of Event	Designated WP Leaders	Comment	Next Action
Mid-term 2/4-week scholarship	2012-11-01	Jacques Morel /Andra	Awarded	Awarded to Victor Serri
Mid-term 2/4-week scholarship	2014-11-01	Hanspeter Weber/Nagra	Awarded	Awarded to Lucie Hausmannova
Mid-term 2/4-week scholarship	2014-10-01	Hanspeter Weber/Nagra	Awarded	Awarded to Jan Smutec
End-term 2/4-week scholarship	2014-09-01	Magnus Kronberg/SKB	Awarded	Awarded to Alba Mon Lopez
End-term 2/4-week scholarship	2014-09-01	Keijo Haapala/Posiva	Awarded	Awarded to Pasi Båtsman
On-site 2/4-week training Bure	2014-06-16	Jacques Morel/Andra	Awarded	Awarded to Ionut Florea
On-site 2/4-week training Mt Terri	2014-06-01	Hanspeter Weber/Nagra	Awarded	Awarded to Acacia Naves
On-site 2/4-week training Äspö	2013-06-01	Magnus Kronberg/SKB	Awarded	Awarded to Jere Knuuttila
On-site 2/4-week training Onkalo	2013-06-01	Keijo Haapala/Posiva	Awarded	Awarded to Pasi Båtsman
Mid-term workshop	2012-10-25	Project Coordinator	Awarded	Awarded to Heini Laine/Reijonen
Mid-term workshop	2012-10-25	Project Coordinator	Awarded	Awarded to Ville Koskinen
End-term workshop	2015-06-02	Project Coordinator	Awarded	Awarded to Dalia Grigaliuniene
End-term workshop	2015-06-02	Project Coordinator	Awarded	Awarded to Acacia Navez
Theme-specific workshop	2012-03-01	Keijo Haapala/Posiva	Cancelled	No interest was shown
Theme-specific workshop	2012-03-01	Keijo Haapala/Posiva	Cancelled	No interest was shown

Theme-specific workshop	2012-09-01	Jacques Morel/Andra	Cancelled	No interest was shown
Theme- specific workshop	2012-09-01	Jacques Morel/Andra	Cancelled	No interest was shown
Theme-specific workshop	2013-06-01	Hanspeter Weber/Nagra	Awarded	Awarded to Jan Smutec
Theme-specific workshop	2013-06-01	Hanspeter Weber/Nagra	Awarded	Awarded to Christian Hoffman
Theme-specific workshop	2014-04-01	Magnus Kronberg/SKB	Awarded	Awarded to Paulina Nieścior
Theme-specific workshop	2014-04-01	Magnus Kronberg/SKB	Awarded	Awarded to Wioleta Olszewska
Theme-specific workshop	2013-06-01	Hanspeter Weber/Nagra	Awarded	Awarded to Heini Laine
Theme-specific workshop	2014-04-01	Magnus Kronberg/SKB	Awarded	Awarded to Darius Justinavicius
Theme-specific workshop	2014-04-01	Magnus Kronberg/SKB	Awarded	Awarded to Orlando Silva
Theme-specific workshop	2014-04-01	Magnus Kronberg/SKB	Awarded	Awarded to Dean Gentles (NDA)
End-term workshop	2015-06-02	Project Coordinator	Awarded	Awarded to Jan Smutek
End-term workshop	2015-06-02	Project Coordinator	Awarded	Awarded to Jutta Peura
End-term workshop	2015-06-02	Project Coordinator	Awarded	Awarded to Ville Sjöblom
End-term workshop	2015-06-02	Project Coordinator	Awarded	Awarded to Kevin O´Donoghue
End-term workshop	2015-06-02	Project Coordinator	Awarded	Awarded to Rob McLaverty
End-term workshop	2015-06-02	Project Coordinator	Awarded	Awarded to Marius Iordache
End-term workshop	2015-06-02	Project Coordinator	Awarded	Awarded to Kalman Benedek
End-term workshop	2015-06-02	Project Coordinator	Awarded	Awarded to Thorsten Hörbrand

4.3 Demonstration of concepts for clay rock

4.3.1 FE-experiment

The Full-Scale Emplacement (FE) experiment at the Mont Terri underground rock laboratory (URL) was 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.

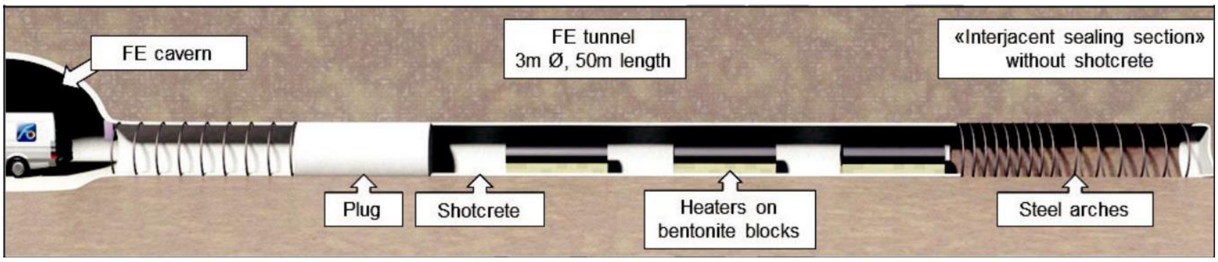

Figure 4-1. *Visualization of the general experimental layout of the Full-Scale Emplacement (FE) experiment at the Mont Terri URL; sensors and bentonite backfill are not displayed.*

Construction and Excavation

The FE-experiment is based on the Swiss disposal concept for SF / HLW.

The rock mass in the ‘far-field’ was instrumented with 45 meter long boreholes drilled from the FE cavern during 2012 before the FE tunnel was built and therefore allowed a ‘mine-by’ observation of the later tunnel excavation.

The construction of the 50 m long experimental tunnel with a diameter of approximately 3 m was completed in September 2012 using conventional equipment. During construction the ‘excavation damage zone’ (EDZ) was instrumented with radial boreholes drilled from within the tunnel. Additionally the tunnel construction was surveyed with a total of ten convergence measurement sections which were installed during the excavation within the FE tunnel with an average spacing of approx. 6 meters. At the far end of the tunnel the so-called ‘interjacent sealing section‘ (ISS) was built using only steel arches for rock support whereas the rest of the tunnel was supported by shotcrete.

Component Manufacturing

After re-assessing the range of possibilities for backfilling materials only natural (non -activated) sodium bentonite from Wyoming was used for the FE experiment. The backfill in the Swiss concept is based around both highly compacted buffer blocks and a bentonite pellet mixture.

The first step of the manufacturing process was the test production with varying production parameters to optimize density and water content in order to provide mechanical stability and long-term integrity of the blocks. Only thereafter, approx. 3'000 highly compacted bentonite blocks, each block with an average weight of approx. 24.5 kg, an average dry density of approx. 1.78 t/m^3 and an average water content of approx. 18 %, were produced. After several additional parameter optimization tests approx. 350 tons of a highly compacted and granulated bentonite mixture (GBM) were produced. The average dry "pellet" density of approx. 2.18 t/m^3 and with a very broad "pellet" size distribution, a so-called Fuller-type distribution, an overall bulk dry emplacement density of at least 1.45 t/m^3 could be achieved.

Installation

The first step in the installation process was the filling of a full 2 m long section with bentonite blocks in the ISS followed by the stepwise construction of the bentonite block pedestals, emplacement of the heaters on top of the pedestals and backfilling of the remaining open volume with granulated bentonite mixture. In the FE tunnel three heaters were emplaced with dimensions similar to those of waste canisters.

The three heaters were installed following the construction of the pedestals as seen in Figure 4-2. Finally a large amount of additional sensors were installed for observation of the bentonite buffer. They are not part of the repository concept but are installed for the THM-experiment following the proof-of-concept installation. A high degree of redundancy was pursued by using a variety of sensor technologies. The technologies used may also hint towards a monitoring arrangement in a future pilot repository as foreseen in the Swiss concept.

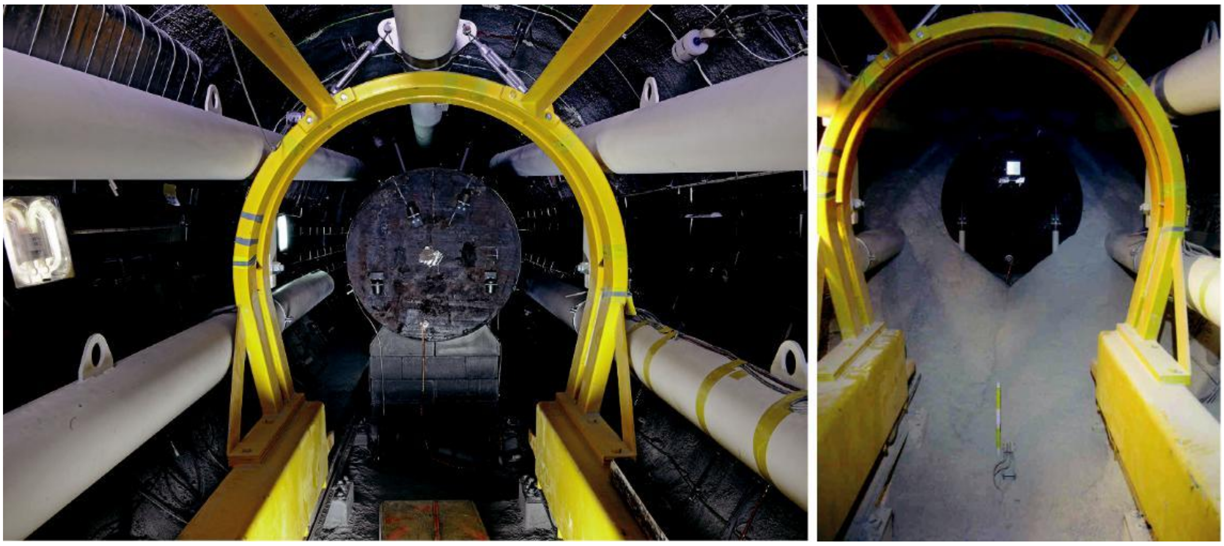

Figure 4-2. *Backfilling machine with screw conveyors driving over the heater and its pedestal (left, photo by COMET) and during backfilling operation (right).*

Backfilling and closure

The backfilling part of this project consisted of two parts: the creation of a backfilling machine (Figure 4-3) and the actual backfilling of the tunnel.

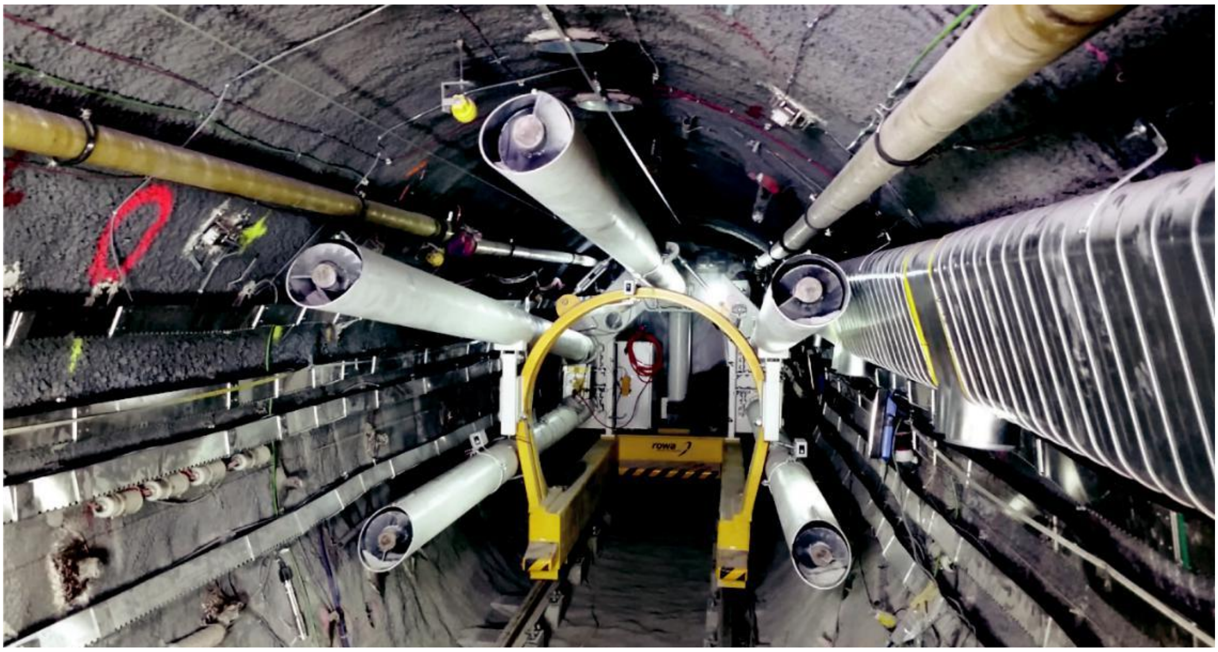

Figure 4-3. *Five screw conveyors on the backfilling machine in the FE tunnel (photo by COMET).*

The focus for the development of a prototype backfilling machine for backfilling horizontal tunnels was to achieve as dense and homogenous backfill installation as possible. The machine which was manufactured here was optimized to fit into the small diameter FE tunnel. It transports, emplaces and compresses the GBM using five auger conveyors working simultaneously. All relevant parameters such as the backfilling speed and the backfilling pressure can be controlled individually.

After an extensive design and manufacturing process; the prototype machine was successfully tested in two full-scale pre-tests in May and August 2014. Finally it was successfully used to backfill the FE tunnel with approximately 255 tons of GBM between September 2014 and January 2015. In some segments a bulk dry density of up to 156 t/m^3 was achieved. At the pre-tests, where the density measurement were performed with different methods and with a better spatial resolution, a ‘local’ bulk dry density of up to approximately 1.70 t/m^3 was measured close to some auger outlets.

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.

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.

4.3.2 ALC experiment

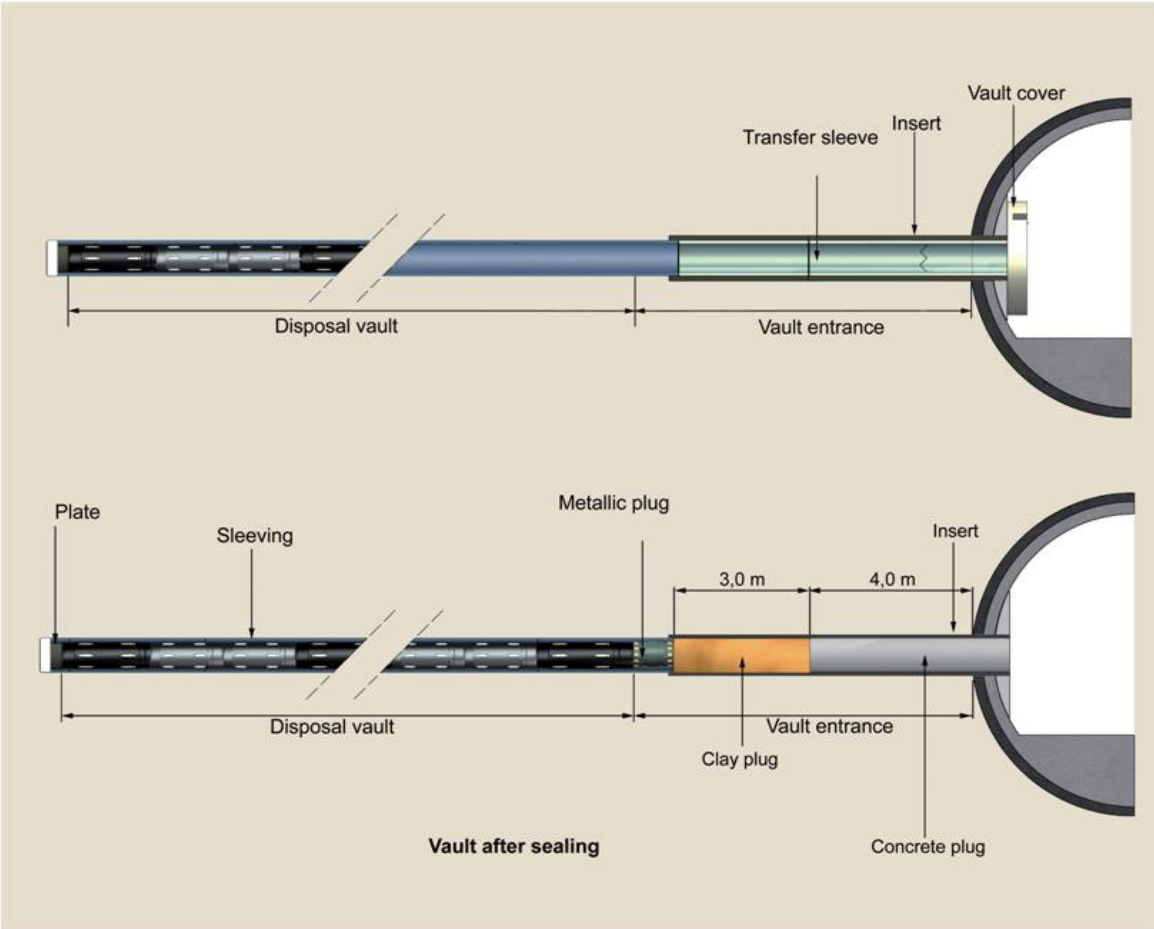

Figure 4-4. *Schematic diagram of a HLW cell according to the 2009 French benchmark concept.*

Construction and Excavation

According to Andra's 2009 benchmark concept, the HLW cell is a micro-tunnel which is approximately 40 m long and 0.7 m in diameter. It comprises a "useful part" (approx. 30 m) for package disposal and a 10-metre-long cell head. They are to be favourably aligned with respect to the natural mechanical stress field.

The useful part of the disposal cell, where the packages are placed, has a steel sleeve. The cell base is closed off by a "base plate".. A metal radiation-protection plug separates the cell head from the useful part. The cell head has a metal sleeve (called the "insert"). The insert is partly backfilled with a swelling-clay plug and then sealed with a concrete plug to provide additional safety. This final configuration corresponds to the period after cell operation and sealing.

The HLW-cell for this demonstration was excavated in two phases where a 6 m long head section was first excavated with a speed of 0.35 meters per hour. This cell head is equipped with an insert 767 mm in external diameter (i.e. an annular space 12 mm wide at the radius) and 21 mm in thickness. The useful section of the cell was then excavated at a speed of 0.46 meters per hour and equipped with a sleeve 700 mm in external diameter (i.e. an annular space 12 mm wide at the radius) and 20 mm in thickness. The rig and processes for this drilling was previously developed within the national programme in France.

Even though the thrust remained low throughout the drilling we had a minor failure during the last 700 mm requiring intervention by personnel inside the cell.

Figure 4-5. *(left) Drilling station in gallery. (right) Drill head in position.*

Installation

After excavation, the following components were installed:

- A base plate, a sleeve head plate and an insert head plate.
- More than 150 sensors which were installed on the casing including:
    - strain gauges sectors at the sleeve intrados,
    - rock/sleeve clearance measurements,
    - relative humidity/temperature sensors in the annular space in the useful part and in the insert,
    - convergence sensors for measuring the horizontal and vertical convergence of the sleeve and insert, and
    - two temperature profiles were measured.
- Five heater elements, each of which is three meters in length and 508 mm in diameter.

Figure 4-6. *View of a heater element when it is installed (left). View of a heater/sleeve distance variation sensor section (right).*

The instruments peripheral to the cell including nine boreholes drilled from the GAN access drift and the NRD perpendicular drift to monitor the temperature, the pore pressure and the deformation of the surrounding rock, were installed prior to the cell excavation.

Sealing and closure

The sealing and closure of the proof-of-concept installation were simplified, as the components for this are investigated in the DOPAS project. In LUCOEX we installed a plug at the head of the useful section (representing the radiological protection plug) and a closing plate at the head of the insert. This allowed us to more efficiently handle the cabling necessary for the THM-experiment following the installation.

Additional studies

After performing the proof-of-concept installation we directly continued with the THM experiment. The heating phase began with a constant 220 W/m power supply for the 15 m occupied by the heater elements, at a depth of between 10 and 25 m into the cell. This power was calculated so that a temperature of 90°C would be reached at the sleeve wall in 2015.

After 2.5 years of measurements, the loss of sensors was less than 10%, mainly due to the thermal loading. The heating system had an acceptable reliability with only 4 minor failures in 2 years caused by the control cabinet fans failing.

The hydro-mechanical impact of the cell excavation, monitored on the peripheral boreholes, was consistent with the measurements taken during the excavation of the previous cells parallel to the major horizontal stress. Indeed, the excavation leads to pore pressure increase in the horizontal plane of the cell and to pore pressure drops in the vertical plane.

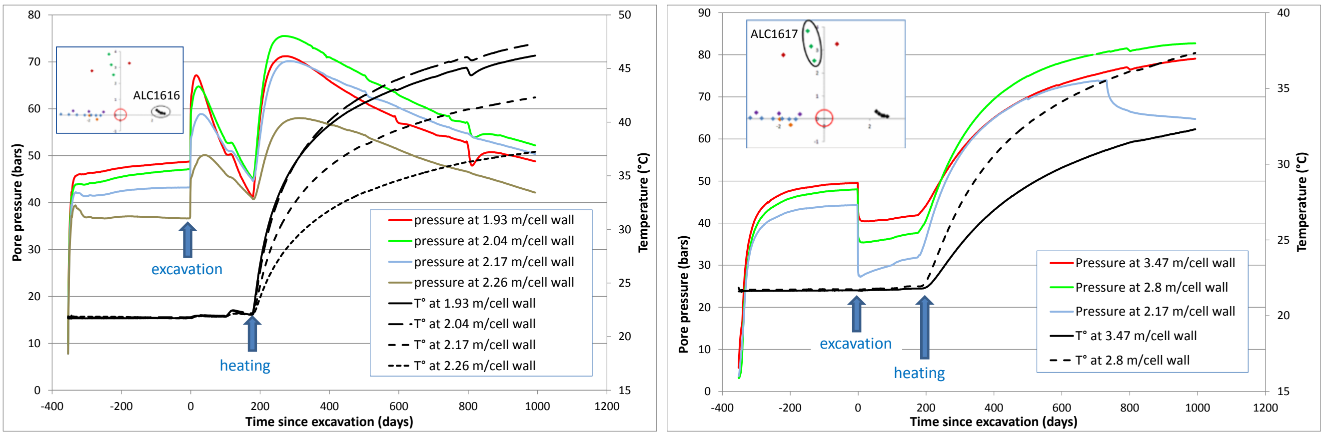

Figure 4-7. *Pore pressure and temperature evolution in the ALC1616 borehole in the horizontal plane of the cell (left) and in the ALC1617 borehole in the vertical plane of the cell (right).*

This difference in behaviour between the two directions was directly related to the anisotropy of mechanical properties of the Callovo-Oxfordian claystone.

Despite an initial annular space of 25 mm, the sleeve was subjected to a mechanical loading no later than 2 months after the drilling. This phenomenon can be explained by the partial filling of the annular space by rubble. The mechanical loading applied by the rock was localized in the horizontal direction (corresponding to the maximum extension of the fracture network around the cell) resulting in a radial bending of the sleeve. A similar loading process was already observed on the sleeve of full scale cells as well as on reduced scale tubings having the same orientation.

The THM impact of the thermal loading on the surrounding rock mass was consistent with the results obtained in previous reduced scale heating experiments. The heating leads to overpressures related to the difference in thermal expansion coefficient between pore water and rock, both in the horizontal plane and in the vertical plane of the cell. The thermal pressurization coefficient was between 3 and 5 bar/°C. Differences in time needed to reach the pore pressure peak were observed between the 2 directions due to THM anisotropy of the rock. The first numerical simulations of the experiment exhibited a quite good qualitative reproduction of the THM behaviour of the near field rock.

In agreement with results obtained in previous reduced scale heating experiments, the temperature increase leads to an acceleration of the mechanical loading applied on the sleeve (increase of the convergence rate). Once the annular gap was completely consumed in the vertical direction, the ovalization of the sleeve was blocked before decreasing gradually, indicating a decrease in load anisotropy. The experiment also permitted validation of the correct operation of the sliding connection between insert and sleeve to absorb its thermal expansion. Measurements showed that thermal expansion of the sleeve occurs both towards the end and towards the head of the cell.

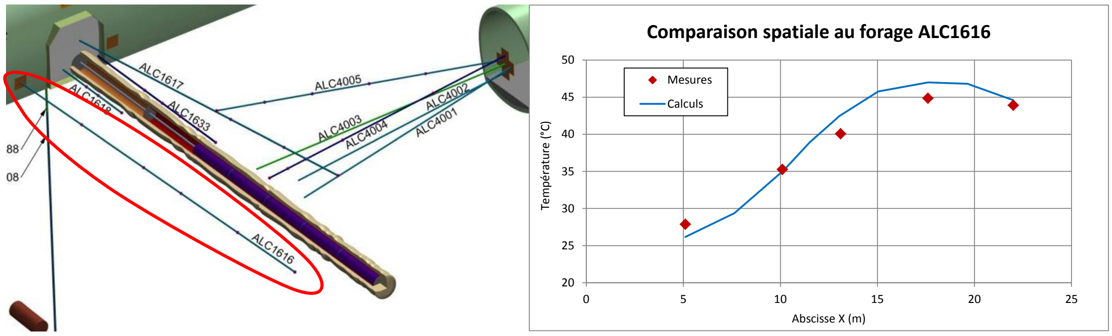

Figure 4-8. *Comparison of the calculated (in blue) vs measured (in red) axial evolution of the near-field rock temperature in the horizontal plane after 500 days of heating (ALC1616 borehole) – simulations performed by ISL.*

Numerical simulations were currently developed with the aim of helping the identification of the main mechanisms involved in the evolution of the THM behaviour of the heated cell. The calculations were performed by ISL and UPC. In both cases the THM formulation was based on a multiple-phase approach. Hydro mechanical coupling (Biot model) was used, as the thermal issue was handled separately. The initial results of the modelling of the experiment reproduce the main trends of the rock's THM behaviour.

Concerning the simulation of the thermal field, both UPC and ISL were, however, overestimating the near-field rock temperature in the heated zone and underestimate it in the cell head despite their relatively different design. However, the observed differences were not likely to hinder the overall interpretation of the experimental results. The investigations are currently continuing, with some of the main aims being to provide a better representation of the boundary conditions in drifts and to improve the description of the numerical model.

4.4 Demonstration of concepts for crystalline rock

4.4.1 KBS-3H Multi Purpose Test

Background

SKB and Posiva are developing a common method for disposal of spent nuclear fuel in crystalline rock. The method selected for the final repository is the KBS-3 method which employs copper canisters surrounded by bentonite buffer and placed at depth in crystalline bedrock. The reference design is KBS-3V employing vertical disposal of the canisters, where horizontal disposal of canisters, KBS-3H, is a possible alternative. The latter is being explored and elaborated by the two organisations with the goal to assess a potentially more cost efficient and industrialized version of the KBS-3 method. KBS-3H has been developed since 2001 and the development work is based on the KBS-3V method but with focus on KBS-3H specific issues.

Work Package 4 of the LUCOEX project was the most recent part of a stepwise development of the KBS-3H concept and integrates the key disposal components, including the Supercontainer, distance blocks, compartment plug, transition block and pellets filling in a full scale proof-of-concept installation.

In addition a drilling activity were added which demonstrates the drilling of a pilot hole, which is necessary for constructing drifts.

Construction of drifts

The construction of the disposal drifts was previously proven through the construction of the two deposition drifts (Ø 1.85 m) excavated at the -220 m level of the Äspö HRL in Sweden: one 15 m long and one 95 m long. The challenge with producing these drifts was that the tolerances are very strict as a result of the very limited space between the Supercontainer/bentonite-components and the rock wall. This puts very high requirements on the straightness of the pilot hole.

Using a combination of a Devishot (Pee-Wee) and a Reflex Gyro for deviation measurements and a DeviDrill™ steering system the ability to make corrective actions down to 0.1° compared to a more normal application of 1° steering corrections was demonstrated. Using this technology it was demonstrated that a 100 m pilot hole fulfilling the requirements for a KBS-3H drift can be achieved. Figure 4-9**Figure** illustrates the drilling results in azimuth (horizontal) and inclination (vertical). When assessing the data in relation to the KBS-3H requirements, it was concluded that the inclination deviation was maximum -2.2 mm/6 m with ±10 mm/6 m allowed and the azimuth deviation was maximum -3.5 mm/6 m with ±20 mm/6 m allowed.

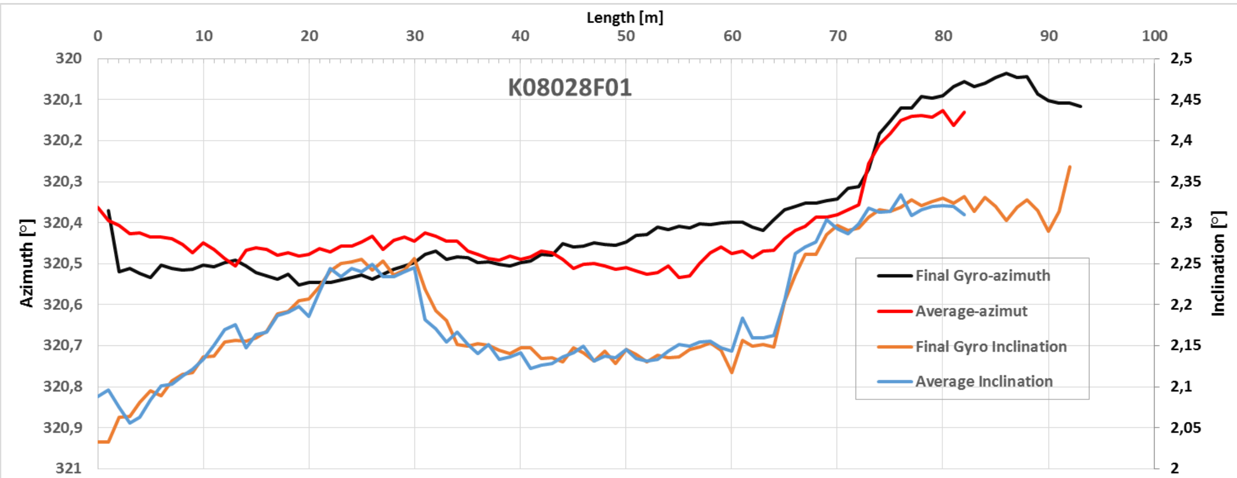

Figure 4-9. *Final deviation measurements (azimuth and inclination) with Reflex Gyro and average calculated files in the LUCOEX borehole, K08028F01.*

The results clearly demonstrates that the KBS-3H geometrical requirements can be fulfilled over a 100 m length scale. It also provides experience and a strategy going forward and testing the full 300 m, which was done at the Onkalo URCF during mid 2015.

MPT design and instrumentation

The MPT did integrate the key KBS-3H components including the Supercontainer, distance blocks, compartment plug, transition block and pellets filling.

The test was basically a shortened non-heated installation of the KBS-3H reference design - DAWE.

The components and the drift itself were extensively instrumented to be able to analyze the early evolution of the concept.

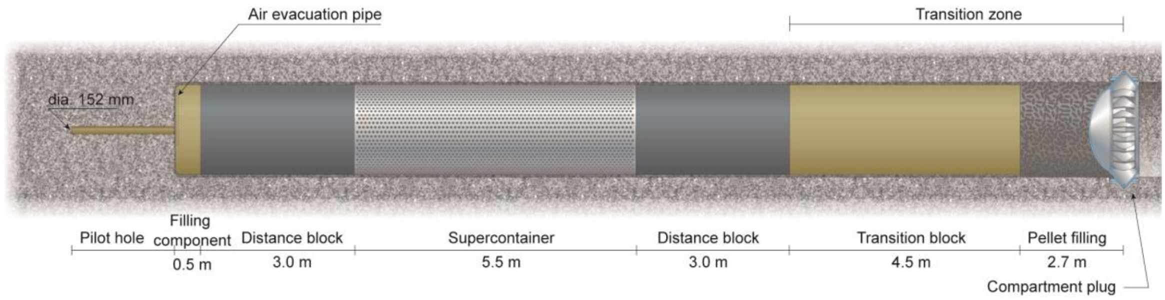

Figure 4-10. *Schematic illustration of the MPT layout.*

This proof-of-concept experiment was divided into the following main activities:

- Component manufacturing
- Machinery upgrade
- Drift preparations
- Assembly
- Installation
- Sealing and Closure

Component manufacturing

The KBS-3H bentonite blocks are larger than the KBS-3V blocks; hence a new uni-axial mould was manufactured. Its design is basically the same as that employed for KBS-3V earlier and both solid blocks and rings can be pressed with different adapters.

The buffer block manufacturing activities are listed in Table 4-1 below. The activities are listed in the order they were executed.

Table 4-1. A list of activities included in the manufacturing of the bentonite blocks

Activity	Description
Control of delivered bentonite	Samples from some of the delivered big-bags of bentonite are taken and investigated with laboratory tests.
Mixing of bentonite	Water is added to the bentonite to yield the right water content
Compaction of bentonite	Bentonite powder is compacted to blocks with a maximum compaction pressure of about 65 MPa.
Investigation of the compacted blocks	A visual inspection of the compacted blocks is made. The weight and the dimensions of the blocks are measured.
Machining of the blocks	The compacted blocks are machined to the stipulated shape
Investigation of the machined blocks	A visual inspection of the machined blocks is made. The weight and the dimensions of the blocks are measured.

A delivery of bentonite, approximately 150 tons, was purchased by SKB for different large scale experiments at Äspö HRL during winter 2012. The bentonite was originally from Wyoming and of type MX-80 and produced by AMCOL International Corporation, USA. A delivery control of the bentonite was made, which showed that the material requirements were fulfilled.

After delivery control an Eirich mixer was used to mix the material to the required water content. Successful compaction was then done using a uni-axial press. The programme included 12 rings of one water content and 31 solid cylinders with two different water contents. Evaluation afterwards showed that there was a variation in block density (where some blocks had a slightly too high average density) but this was considered acceptable for the current test since the average density of the produced blocks used within the installed experiment were within the acceptable variation. The reason for the variations is primarily that the facilities rented for the production of these blocks are not optimized for this type of production and the productions series limited in size.

Machine upgrade

The KBS-3H deposition machine is a first prototype for demonstration of horizontal deposition in full scale. The machine was jointly designed by SKB and Posiva and manufactured by ECA in 2005–2006 within the 6th Framework programme “ESDRED” of the European Commission. The machine was first demonstrated in full scale tests at the Äspö HRL in 2007.

It utilizes a water cushion transport principle, which works by stepwise movements inside the drift. A lifting and pushing sequence is repeated until the components being installed reaches its destination. The water cushions and the heavy loads from the Supercontainer make the control of the machine challenging. Machine testing before the MPT installation was troublesome due to limited control ability and an incomplete software application. During the MPT the machine was thoroughly instrumented in order to identify the reasons behind earlier control issues. A stepwise test- and upgrade programme using dummy components was carried out resulting in extensive re-programming of the control system as well as mechanical alterations. Additionally, the automation level of the machine was increased in order to avoid manual operation. These actions ensured that the MPT experiment could be reliably carried out and that the horizontal deposition concept could be evaluated as a whole.

Drift preparations

Since no tunnel was located nearby the MPT drift all cables were installed in cable notches in the rock wall. These were cut out using a standard concrete saw on rails adapted for the drifts curvature.

Core holes were drilled for rock sensors which were subsequently cast into place. A main pipe system was installed in the cable notches to limit the risk for leakages in cable bundles. Figure 4-11 illustrates the drift prepared for installation with pipes and sensors.

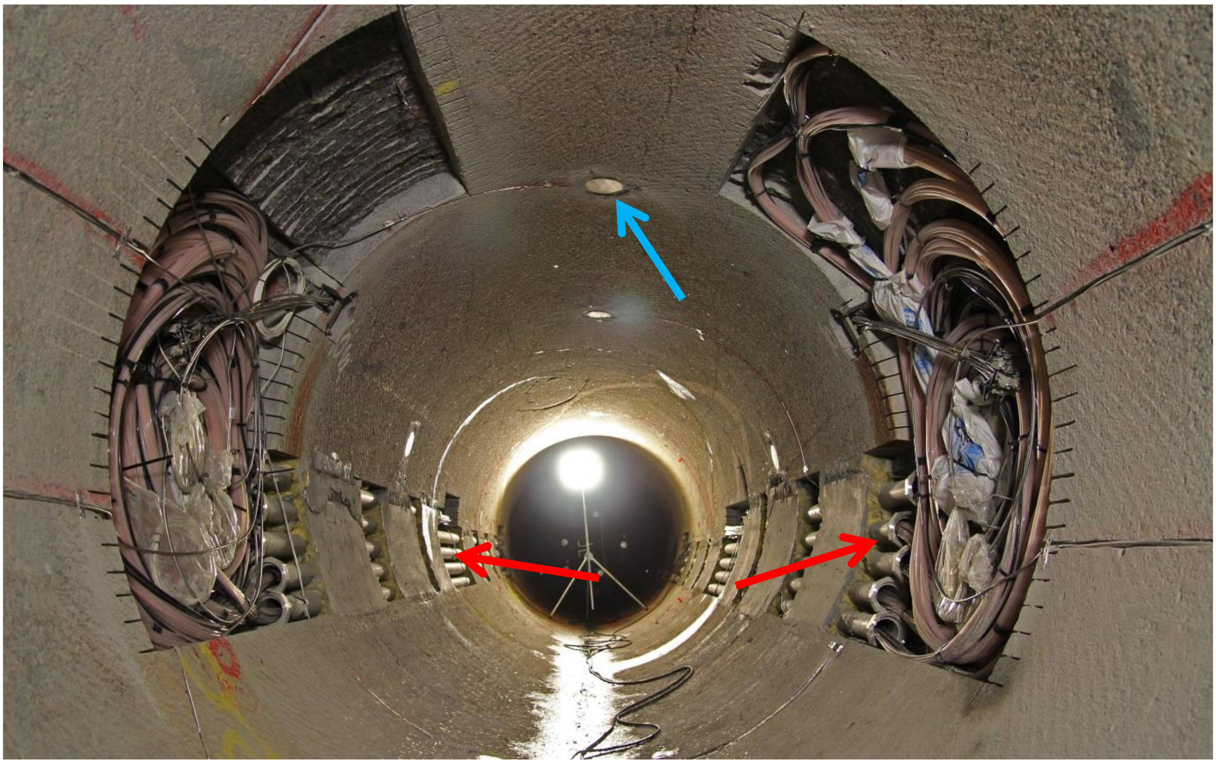

Figure 4-11. *The MPT drift prepared for installation, red arrows points at the main pipe systems and the blue arrow points at one of the many rock sensors.*

Assembly

Since the KBS-3H project had only tested the assembly of the Supercontainer with concrete dummies previously, a pre-test with a distance blocks was carried out. The pre-test integrated all steps from assembly to deposition of the Supercontainer. It was initiated in February 2013, and it quickly proved that the original intention to protect the buffer blocks with plastic foil while drilling and preparing them for assembly would be inadequate. Due to the winter season, the relative humidity (RH) was between 15-25 % at the time and the distance blocks started to develop surface cracks within an hour in conjunction with drilling. Although the surface cracks were quite small initially they were still too large and prevented the use of the vacuum hoist tools and therefore halted the work. Several actions were taken in order to address the cracking problems; all transport containers for the buffer blocks were fitted with new rubber seals, plastic bags with aluminum foil and more rigid wooden pallets were purchased. However, the installation of an industrial humidifier in the assembly facility was the main solution to the problem. It allowed for a controlled environment during assembly and the pre-test including the assembly, component transport and deposition could later be successfully carried out.

Figure 4-12. *Test distance block being moved out from the assembly facility complemented by a specially designed sensor arrangement, or cable block, in which sensor cabling could be placed during transport and installation, marked with a red arrow.*

Experiences from the pre-test were later implemented in the main MPT assembly and full scale distance- and transition blocks, as well as a Supercontainer, below, could be assembled as planned.

Figure 4-13. *Canister being lowered into the Supercontainer during assembly. Stiffening plates for straightening the shell can be seen on its outer periphery.*

Installation

For KBS-3H, an efficient installation is a key part of the design. A preliminary assessment is that the components and the plug that make up a compartment have to be installed within 10 days to ensure that the buffer remains intact when the artificial watering is initiated. With the MPT being strongly focused on the handling and installation of the full scale components, it was decided to carry out the installation as fast as possible. At the same time, the test involved in the order of 200 sensors that needed to be taken into account. The MPT installation worked out as planned with all components placed at their intended locations and with tight connection between them. Figure 4-13 illustrates the assembly of the Supercontainer.

Compared to planned operation of a KBS-3H repository where about 4 components are expected to be placed each 24 hours the corresponding MPT work was carried out at about a quarter of that speed. On the other hand, without the cabling, two components would have been managed in 24 hours during the MPT which would equal half the speed expected in a repository situation. At this stage of KBS-3H development this outcome is deemed acceptable as the process still contains manual tasks that would be automated in the final repository.

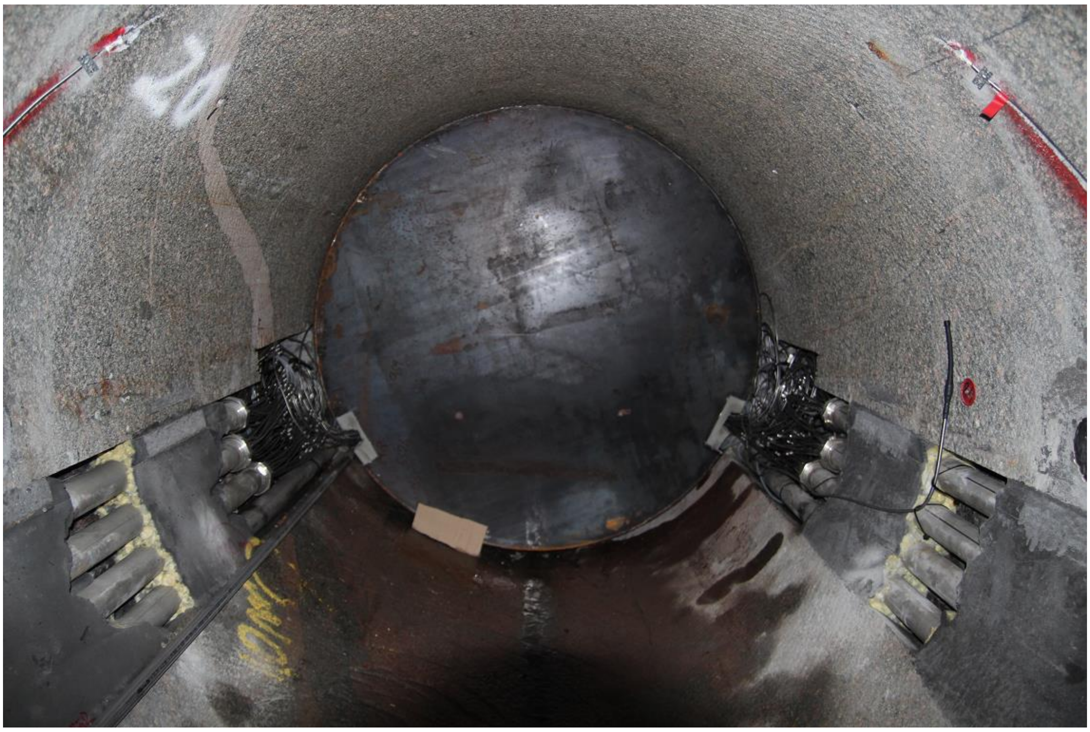

Figure 4-14. *Supercontainer positioned in the drift with all its cables pulled. The tight fit between the Supercontainer and drift wall is clearly visible.*

Sealing and Closure

The compartment plug was installed in two main steps of which the first, the fastening ring installation, was done during the drift preparation stage where a circular saw was used to cut out a slot for the plug. Once the rock was removed; the fastening ring was positioned and contact grouting tubes placed in the interfaces after which it was casted in place, Figure 4-14.

Once the casting of the fastening ring was done, its lower parts were filled with concrete to form a temporary bridge for the deposition machine to pass over.

After component installation, the plug installation was simply a welding activity given that the fastening ring was already cast in place. Installation was carried out as planned but it was identified that inspection was quite difficult due to limited space between the rock and the metal components as a small hole was missed in inspection of the welds and later caused leakages that had to be re-welded.

All cables were taken through the plug after which the void between it and the transition block was filled with pellets. This was followed by contact grouting of the steel-concrete and concrete-rock interfaces using silica sol. Finally the drift voids were filled with water and the air evacuated through the plug. The air and water filling pipes were subsequently removed as planned.

Figure 4-15. *Left, schematic illustration of the compartment plug. Right, installation of the fastening ring.*

Work package 4 conclusions

It was concluded that the MPT did demonstrate the potential of the KBS-3H design, the inherent strength of a slimmed system working with pre-assembled components. The key KBS-3H components were tested in mutual combination and the DAWE procedure were carried out basically as intended. The actual function of the components will be assessed as more sensor data is generated and results from an eventual dismantling of the test could be available in the future.

Lots of experiences were gained during the MPT and a number of areas for further optimization was identified which when addressed will make the design even more robust and cost efficient. These include:

- Harmonization of the water content of the blocks in the Supercontainer in order to simplify the handling of the clay components.
- Updates of the compartment plug design to make the welding simpler and easier to inspect.
- Addition of an extra drainage pipe at the lowermost part of the plug so naturally inflowing water can be drained prior to pellets filling.
- Integration of a grouting tube in the plug design itself in order to simplify installation and improve contact grouting.
- Suggestions for further mechanical updates on the disposition machine in order to limit water splashing from its cushions and for it to function properly with the DAWE design.

In addition to the implementation issues presented above the KBS-3H project gained a lot of experiences for future installations. Methodologies are now available for both assembly and installation of components including advanced sensor systems.

The projects concludes that construction, component manufacturing, installation and sealing of a repository for nuclear waste based on the KBS-3H concept should be feasible and the MPT has demonstrated the key steps towards this objective.

With respect to the steered core drilling operation, the fulfilment of the strict KBS-3H requirements over a 100 m length scale provides confidence that technology is available that should be able to achieve the 300 m deposition drifts which will be required. Methodologies and strategies towards fulfilling the requirements were also improved.

4.4.2 KBS-3V

SKB and Posiva are developing a common method for disposal of spent nuclear fuel in crystalline rock. The method selected for the final repository is the KBS-3 method which employs copper canisters surrounded by bentonite buffer and placed at depth in crystalline bedrock.

Work Package 5 of the LUCOEX project is a part of a stepwise development of this KBS-3 concept and included the development, manufacturing and demonstration of key disposal components and processes including the buffer and pellet installation process equipment and the processes and equipment used for the quality assurance and fault handling.

The buffer and pellets installation sequence is shown in Figure 4-16.

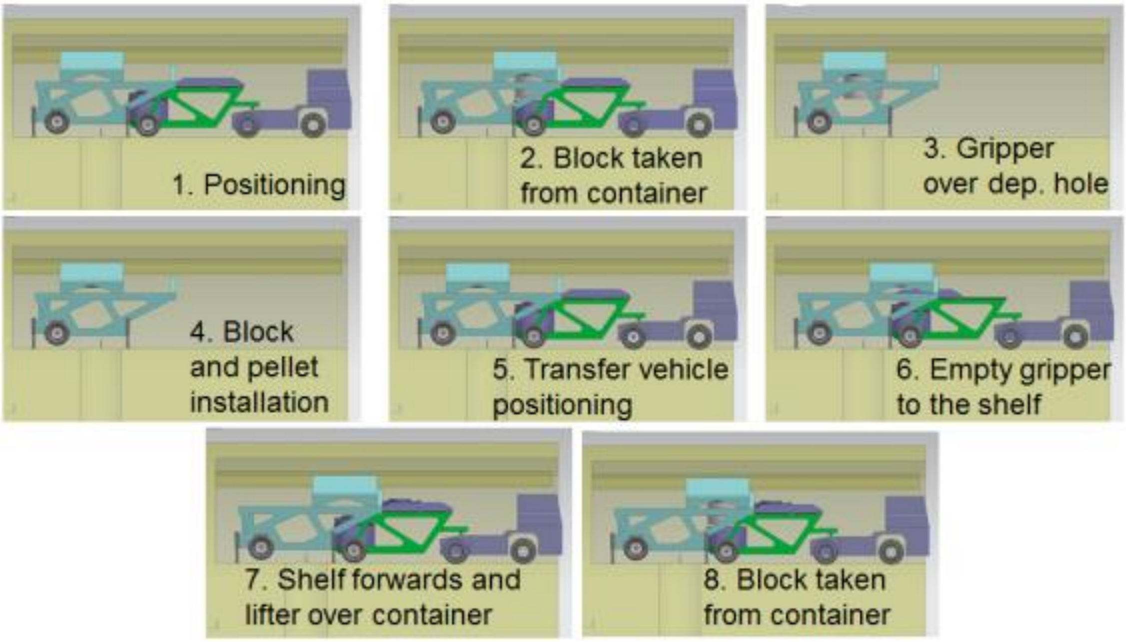

Figure 4-16. *The installation of buffer blocks consists of eight basic steps which are shown.*

Bentonite container developed

The first component designed was the bentonite container, which is used for the transportation and handling of blocks and pellets. Directly after the buffer components are manufactured they are placed in individual containers after which pellets are placed in the pellets storage compartments. Then the container is ready for further transportation to storage or directly down to the disposal tunnels.

The function of the developed container, shown in Figure 4-17, is to simplify the handling of the buffer and for protecting the buffer from effects of the environment before moving them from the manufacturing facilities. Each bentonite block is put into a separate container under controlled conditions in the factory. The container is then sealed, thereby ensuring good protection against the outside environment.

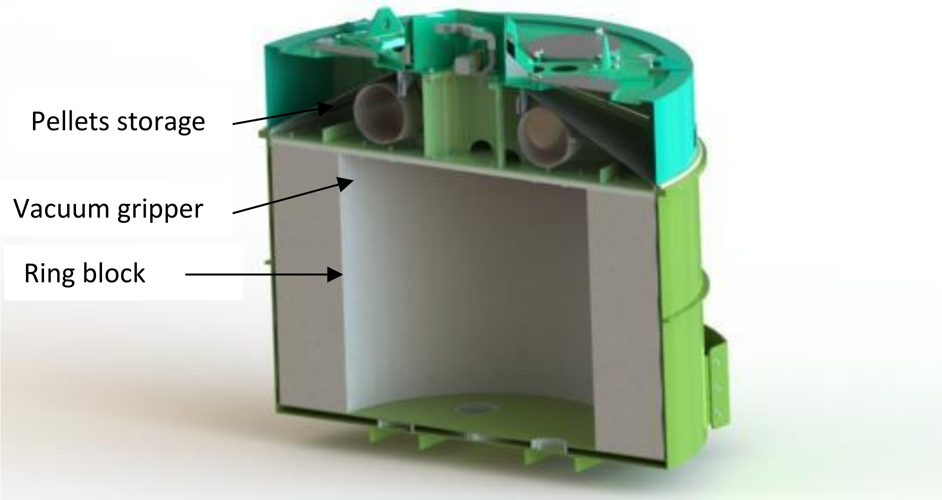

Figure 4-17. *Split view of the bentonite container with a ring block, vacuum gripper and pellets storage.*

There are six pellets compartments inside the container top. Each compartment contains a pre-measured amount of bentonite pellets, so that after each bentonite block is in place, the pellets can be filled into the remaining volume. The amount of pellets loaded into each compartment is determined by calculating the gap between block and deposition hole wall.

Bentonite block installation machine developed

The bentonite installation machine (BIM) (Figure 4-18) was a completely novel design and required very stringent construction specifications to be followed. The BIM consists of a semi-trailer format frame on top of which a lifter unit is located.

There are five primary components on this machine:

- The frame (1): It is equipped with two wheels on a single steerable axle.
- The support leg sub-frame (2): The machine is levelled using four support legs moved by electromechanical actuators. It can be moved transversely (Y-direction) allowing the positioning of the machine directly on top of the deposition hole. The sub-frame is attached to main frame via two linear guides and moved by two electromechanical actuators.
- The pulling beam (3): This contains a king pin connection that is lifted to enable the bentonite transfer device (BTD) to pick up empty container top.
- The lifter unit (4): The lifter is movable on a pair of linear guides (X-direction) and actuated by two electric motors driving gear wheels against tooth racks. A winch with three steel ropes is providing movement (Z-direction) to a mechanical gripper to raise and lower the container top with bentonite blocks and pellets.
- The gripper (5): It has three electromechanical actuators that enable accurate radial positioning of the bentonite block during the last 100 mm downwards travel. The gripper attaches to the container top via three pneumatically actuated lock pins. The container top has a vacuum lifting surface against the top surface of bentonite block.

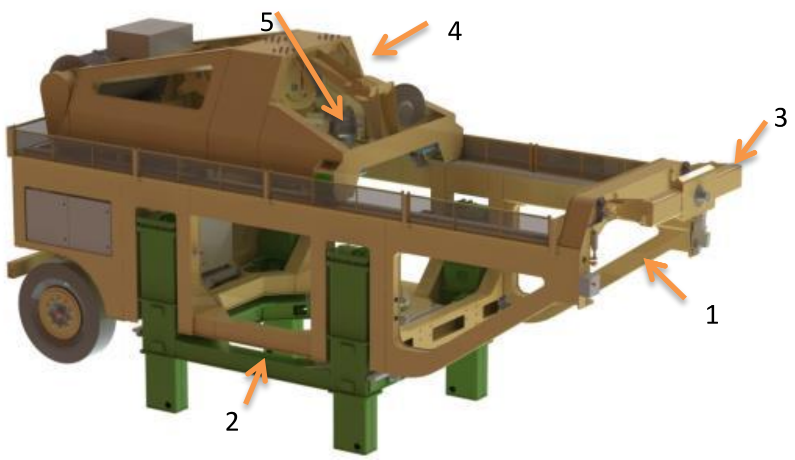

Figure 4-18. *3D-model of bentonite installation machine (BIM).*

Bentonite block transfer device developed

As with the BIM, this component was a new design and required specialised manufacturing expertise.

The bentonite transfer device (BTD), shown in Figure 4-19, is a trailer moved by a terminal tractor unit. It is equipped with a single steering axle to ease the positioning near BIM and to limit the steering effort while driving in demonstration tunnel. The BTD is steered manually by the terminal tractor operator. The operator has a direct view to BTD, assisted by live feed from video cameras on BTD. The BTD gets both its hydraulic power and electric power (for controls) from the terminal tractor. All BTD movements are actuated by hydraulic cylinders controlled by proportional valves.

The BTD can carry one block in a container. This device has a longitudinally moving platform on top to store previous container top.

Figure 4-19. *3D-model of bentonite transfer device (BTD).*

Above ground testing

The first test phase took place in a specially designed test and development facility at Posiva's Onkalo site. The focus of these tests was to verify the functionality, accuracy and reliability of the components and to fine tune the automation system controlling the machines. Most attention was given to the installation machine (Figure 4-20) and the gripper part of the buffer container (Figure 4-21) responsible for the vacuum lifting of the blocks and the transportation of pellet.

Figure 4-20. *Bentonite installation machine at the above ground test facility.*

Figure 4-21. *Gripper and concrete block have been lowered to the bottom of the test hole.*

Figure 4-22. *Filling of pellets into the gap between the buffer and the test hole wall.*

Tests initially showed that the installation accuracy was well within requirement. Additional laser scans however showed that the space within the buffer deviated from the initial measurements with up to 4 mm. The installation time also exceeded the 2 hour requirement where the shortest installation time achieved was 3 hours 53 minutes and this was for an installation that was still short of one ring block.

Pellets filling of the gap between the buffer and test hole wall was tested. As per the planned method, after each block was in place in test hole, the pellets loaded inside the container top were released into the gap between buffer and test hole wall. This process worked as planned.

Emplacement Demonstration

On completion of the surface trials, work was moved underground to test operations in an environment more representative of a deposition tunnel for Demonstration phase 2 and 3. The test area used was at Onkalo URCF Demonstration Tunnel 1.

Due to lack of a full set of bentonite blocks demonstrations were done using a mixture of both concrete blocks and bentonite blocks. This was considered an acceptable alternative as the concrete blocks are in general harder to lift and handle because of their rougher surface compared to bentonite blocks.

Measurements during the installation demonstrations once again showed that the installation accuracy was within specified requirements, while subsequent laser scans once again revealed deviations. During the debriefing three possible sources of error were identified: (1) possible measurement errors, (2) involuntary horizontal movement of the block during installation, and (3) the uneven surface of the components. Timing of the experiment also showed that the installation was slower than anticipated (3 hours 10 minutes vs allotted 2 hours). Even with these deviations we consider that we have proven our ability to install the buffer component in a safe and controlled manor.

Quality Assurance during buffer emplacement

The quality of installation is a key aspect in making sure that the multi-barrier system functions as designed. To verify the quality we developed a sensor system integrated into the vehicles and abled to transfer the information to QA-related software. The items that need to be controlled were:

- The integrity of the buffer blocks during the process.
- The position of the assembled buffer and the bentonite blocks.
- The width of the gap between assembled block and the host rock.
- The compactness in the gap between the pellets and the host rock.

Based on the studies and designs presented we are confident that all QA targets can be meet using a sensor system installed on the developed machinery.

Problem handling equipment designed

If something goes wrong either prior to or after canister installation we need to be able to remove the buffer material and any other remaining material from the deposition hole to be able to take back the canister. We have in this project evaluated different techniques for this, including:

- Lifting medium and large pieces of buffer material by attaching lifting eyelets and anchors.
- Breaking larger pieces using heavy drill-hammer and vacuum cleaner (industrial cleaning lorry).
- Combined water jet and vacuum suction rig.

Based on these tests we see that the usage of anchors to remove broken bentonite block parts is limited to specific cases, where the bentonite still retains its strength near manufacturing values. If there has been exposure to humidity or severe shocks, there is a very high risk that this method is not suitable. Breakage and vacuum cleaning is the only viable option in that case.

A combined water jet and vacuum suction rig was designed and tested. Our conclusion is that it can be used in all problem solving cases involving bentonite removal from deposition hole; manually before canister is installed, or by remote control after canister installation. Based on the test at the Onkalo URCF, the removal time for one solid block is approximately one hour, hence complete excavation of a full borehole should be able to be accomplished in an eight-hour day.

4.5 Evaluation and analysis of lessons learned

4.5.1 Technical results

The four large-scale demonstration projects in LUCOEX represent key projects for the geological repository programmes and concepts which were addressed by the four LUCOEX partners. Not only from a technical and scientific aspect but also for reassuring the scientific community, the authorities and the public that with reasonable effort excavation, disposal and backfilling in clay and crystalline rock can successfully and soundly be accomplished. The outcome and findings of the LUCOEX project are also relevant for the European as well as the world-wide radioactive waste management community.

Each of the LUCOEX partners experienced various lessons learned in both different and similar technological details as respective demonstration project addressed different aspects of technical details and different types of host rock while many technical aspects were similar despite the differences in presumptions between the four LUCOEX experiments. Such differences and similarities were often addressed in presentations at the regular workshops held in the course of the LUCOEX project.

Four key technical areas were addressed in LUCOEX and the results achieved in each of them are summarised in Table 4-2.

Table 4-2. Key technical results achieved in the LUCOEX project.

Key technical area	Key technical results			
	Nagra	Andra	SKB	Posiva
Gallery construction	Excavation and reinforcement of disposal tunnels using standard machinery have been shown.	Some limitations were identified in regard to secondary systems when drilling the disposal cell. It was however shown that excavation is possible with readily available technology.	Previous excavation has shown that excavation can be executed using a push reamer guided by a straight pre-drilled pilot hole. The project has demonstrated that it is feasible to drill the necessary pilot hole for a 100 m drift (300 m will be tested during 2015).	Excavation done in parallel with the LUCOEX-project has shown that excavation of the disposal galleries can be done using conventional drill and blast technology complemented with roadheader technology for shaping the floor necessary for efficient operation of vehicles operating in the tunnels. LUCEX has developed machinery optimized for these tunnels.
Manufacturing of components	Extensive research has shown how to produce an optimized granulated bentonite mixture and highly compacted bentonite blocks.	Component necessary for the creation of a steel lined HLW-cell supporting retrievability was manufactured. No clay components are, however, used in this concept.	The project has demonstrated that the necessary mechanical and clay components can be manufactured. A comparison between pressing techniques for the clay components, uniaxial and isostatic pressing, has also been carried out.	The project has demonstrated that the necessary vehicles, mechanical components and clay components can be manufactured. A comparison between pressing techniques for the clay components, uniaxial and isostatic pressing, has been carried out.
Installation	Pedestal design and use of highly compacted blocks have been shown viable. However, as a consequence of the THM objective of the experiment, the emplacement procedure was not done according to the Swiss concept.	Installation of steel liners and the operation of a HLW cell have been demonstrated for "H0" waste (packages installed without spacing buffers).	The project has developed the necessary machinery for performing the installation and also demonstrated that an installation can be carried out according to plan.	The project has developed the necessary machinery for transporting and performing the installation of the buffer and pellet components. Canister installation machinery has been developed in parallel with the LUCOEX project. Posiva has demonstrated that an installation can be carried out according to the planned process but at a slower pace.
Backfilling and sealing of galleries	A backfilling machine was designed and proved useable to install the backfill material with the required density. Further	The sealing and closure is investigated in the DOPAS project.	The project has demonstrated that the drift can be sealed using a metal compartment plug.	The Posiva plug is developed in the DOPAS project while the backfilling was being developed in parallel to the LUCOEX-project.

	developments are required to control the density and its homogeneity.			
Additional deliveries	The heater experiment, which is the Swiss continuation of the LUCOEX project has been initiated. The results will be published outside the scope of the LUCOEX-project.	The project has developed a better understanding of the THM behaviour of the cell and we are now able to compare simulations with the actual THM-processes in the host rock.	In addition to the planned deliverables SKB has also delivered a first data report from the monitoring for the early stages of the drift evolution.	In addition to the disposal process Posiva has also developed processes and machinery for quality assurance and fault handling necessary in case of a mishap.

Demonstration refers, by definition, to activities carried out in a predetermined manner that leads to a predetermined result. In view of this all four LUCOEX full scale experiments have been very successful. Each one of the four LUCOEX partners have shown that construction of galleries, manufacturing of buffer components, installation and sealing of galleries can be made to meet the initial state, i.e. the situation when no more adjusting measures are assumed to be made and further evolution of the repository components are driven by the repository´s chemical environment and geoscientific events.

In addition, a lot of experience was gained during the excavation, installation and sealing of the four proof-of-concept demonstrations, as several practical problems were experienced, which had to be solved when they appeared. They were all handled to our satisfaction and contributed well to the final result with improved understanding of the engineering input. Such problems are well known to occur in industrial projects and were expected also in LUCOEX, but not their nature or severity. But no problem was so severe that it led to the deviation from the planned implementation or different functions of the resulting components from a long-term safety perspective.

With the continued monitoring of the thermal evolution in the Nagra and Andra cases the understanding of the THM-processes necessary for developing the safety case for the repository concept was improved, for SKB continued monitoring will increase the understanding of the buffer evolution (non heated experiment). Other key tasks included the improvement as well as the development of additional machines to increase the automation level in the final repository.

For Andra the lessons learned of the HLW cell reference design, a new full scale heating experiment has been planned to be initiated in 2017. The main change relates to the backfilling of the initial annular space by a cement/bentonite grout, whose main function is to neutralize the acid transient disturbance induced by the oxidation of pyrites in the cell wall. This phenomenon, highlighted in in-situ experiments performed on steel samples, may lead to high short-term corrosion rates. The aim of that experiment will essentially be to determine the thermomechanical behaviour of the (sleeve / cement grout / damaged rock / undisturbed rock) system.

For SKB the experience gained during the MPT has identified a number of areas for further optimization, which when addressed will make the design even more robust and cost efficient.

Posiva compared isostatic and uniaxial compaction before the manufacturing of the blocks to the LUCOEX project. This study was part of Posiva’s and SKB’s ongoing development of buffer manufacturing techniques that is to be decided on later, after the end of the LUCOEX project. The analysis concluded there are not many differences in regards to quality between an isostatically and a uniaxially compacted block.

No big enough isostatic press was available for the LUCOEX project and the blocks were manufactured by uniaxial compaction.

4.5.2 Dissemination

One important part for the parties in the LUCOEX project is to make the public aware of the engineering status achieved by the project. The tool for this has been the dissemination process, through which it has been made possible for the public to access to the main results documented as EU project reports ("deliverables"), which can be downloaded e.g. from the LUCOEX project website www.lucoex.eu. Further visibility for the project was gained with the help of the underground research laboratories´ and the parties´ regularly reporting and posting of information on their websites www.mont-terri.ch, www.nagra.ch, www.andra.fr, www.skb.se and www.posiva.fi.

The scientific community was furthermore involved and informed via several conferences (see Appendix I) and publications (see Appendix IV).

One main advantage of European projects – besides all other aspects – is the close collaboration between the different organisations and involved people and therefore the continuous knowledge exchange which is especially important for education and training of younger scientists and technicians. In total 15 apprentices from different European countries worked at the different underground research laboratories or the parties' other laboratory facilities in the framework of the LUCOEX project and the associated WPs.

The hands-on approach from the LUCOEX parties in implementing and finishing such full scale demonstration projects successfully has been recognised positively not only by the scientific community, but also by the public. It has been perceived positively when waste management organisations (WMO) test their concepts, ideas and plans in real scale and when the outcome including potential difficulties are discussed openly. This has made the participating WMOs more credible but also provided a basis for a continuous improvement process.

In this context the parties tried to make their work more transparent and understandable by inviting the interested science community and the public to visit the underground research facilities, which also run scientific exhibition centres. Additionally Nagra and Posiva produced videos to explain the LUCOEX project and made them publicly available.

Therefore the dissemination process of the LUCOEX project can be considered as extremely successful. Nevertheless, the analysis and synthesis of the experimental data and outcome has just begun. So further disseminations measures (such as publications and presentations at workshops) initiated by the LUCOEX parties or other experimental partners can 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.

4.6 European added value

Our plan was to assess the existing research programmes on management of high-level waste in different member states together with respective responsible waste management organisation (WMO) and to select which activities in LUCOEX that would be of interest for them to follow in detail. An invitation was sent out to all WMOs, but only a few responded. The answers clearly showed the interest to share information and results, but only by LUCOEX public channels: newsletters, reports, participation in workshops and visits to the respective underground research laboratory.

Instead we initiated an analysis performed by a master thesis student, who studied the status within the existing European programmes for management of spent fuel and mapped what is studied in the LUCOEX project with the needs of the different programmes. The findings were that in particular Spain, Slovakia, Hungary, United Kingdom, Germany, Czech Republic and Belgium are countries which are in a position where results from the LUCOEX project can be utilized in a perspicuous future.

The study has been reviewed by the participants and presented at a number of conferences.

4.7 Expert group findings

The main objectives of the LUCOEX Project were to demonstrate, through four large scale experiments, the technical feasibility *in situ* of safe and reliable construction, manufacturing, disposal or sealing activities for long-lived high-level nuclear waste repository components, in various host rock formations and for various national disposal concepts (at different stages of advancement).

In this context, the EG's overall mission was to assess:

- 1- The added value generated through the technical and scientific integration in LUCOEX during progress of the project;
- 2- The soundness and relevance of the technical approach;
- 3- The scientific and engineering standard of the work carried out; 4- The progress of the technical/scientific work reached at the end of the Project and the fulfilment of the stated objectives,
- 5- The level of dissemination reached.

The EG considers that the four technical objectives were technically fulfilled by the four LUCOEX Project partners:

- 1- In spite of the short duration (four years) of the LUCOEX Project, it can be concluded that the fact of successfully launching four large experiments brings evidence of the feasibility of the concepts studied and provides confidence to the stakeholders;
- 2- Most solutions developed /experiments launched are a first and provide additional knowledge to the scientific or technical community;
- 3- The identified (and in most cases solved) problems and technical gaps have helped in better understanding the pertinent issues ; they constitute a rich and solid return of experience for future action;
- 4- The experience gained in this general project should also help in the planning of new large scale demonstrations or in improving the design basis of the repository components which were studied in LUCOEX.

However, it is evident that the duration of the LUCOEX Project has mainly allowed the preparation and launching of large experiments: for some of them (e.g. FE or ALC or MPT), where phenomenology monitoring is concerned, their in-depth evaluation will require at least one more decade, a fact which prevents the implementing organisations from forming a definitive conclusion as far as long term safety is concerned.

Similarly, the absence in the experiments of radioactive waste (and its containment) and hence the absence of a nuclear environment has led, understandably at this stage of RD&D, to various simplifications in the demonstration set-up, in machinery construction or finally in operations. The nuclear safety and engineering aspects will have to be given serious consideration (integrated) in the future developments by the Participants, in particular those with a more proximal industrial milestone (i.e. a target date around 2025-2030 for starting effective disposal activities).

The EG considers that the level of dissemination reached by the LUCOEX Project is also quite satisfactory:

- The EG acknowledges the quality and variety of the presentations of the main LUCOEX Project results, as delivered by the Project Participants, at different international events. The invitation of representatives from other large European projects (such as DOPAS) to attend the LUCOEX Conference, was considered as good practice to be further promoted and followed;

- The LUCOEX has regularly provided information on the work progress to the public, the stakeholders and the scientific and technical community, via its "Newsletter" and timely updates of its "visitor's friendly" Website;
- Some young engineers / students had the opportunity to work as "staff secondment" or with scholarships and develop in so doing a significant knowledge in waste management.

In summary, the EG views the LUCOEX Project outcomes (and the four Participants' contribution) as representing a valuable step towards implementation, which should help the technical and scientific community in its future work as well as the stakeholders in forming their opinion about the acceptability of a Deep Geological Repository as a long-term solution for the safe management of certain radioactive wastes.

5 Management strategies

5.1 Management approach

The project´s main management document has been the Project Plan, which was developed initially as planned. Its role has been to serve as the project´s quality assurance tool by providing internal technical and administrative guidance. It describes the objectives and presumptions for the technical work, responsibilities and obligations for staff and different engaged groups, how dissemination of results may take place, and how project progress and results shall be reported.

This plan has been regularly updated during the course of the project in order to provide up-to-date information, and has addressed the following.

5.2 Performance of Steering Committee

The Steering Committee (SC) was formed during the grant agreement negotiations and Erik Thurner from SKB was elected to chair it. The SC has during the course of the project had 9 official meetings. The final meeting was held in October 2015. Minutes from the meetings have been posted to the project´s internal website.

An Expert Group (EG) consisting of four “internal” and four “external” experts, appointed by the SC, has been given the mission to serve the project with reviews, cross-WP examinations and advices related to technical plans, achievements and dissemination activities.

Five Project Progress Meetings (PPM) were held during the course of the project where the progress of each of the Work Packages has been discussed. Key risks were discussed and evaluated at these meetings. The results were then forwarded to the SC. Minutes from the meetings were published both internally and on the external homepage.

5.3 Day-to-day management

5.3.1 Setting up and operating the organisation for coordination of LUCOEX

A Project Management Office (PMO) was setup within SKB for the management of the project. Work included the support and follow-up of the individual work packages like:

- Updating the Project Plan.
- Creating a project handbook
- Updating Project Presentation.
- Updating the project´s complete risk assessment.
- Compiling Newsletters.
- Updating the website portals
- Developing and distributing templates for deliveries and reporting.
- Support reporting and the distribution of information through the homepage.
- Managing the Steering Committee meetings.

Project Presentation

A general project presentation was originally created in accordance with Commission´s guidelines. This presentation was thereafter extended numerous times with specific slides matching the needs of a specific conference or audience.

Risk assessment

The project´s risk exposure was repeatedly assessed by the Project Management Office (PMO) and the chair of the SC during the course of the project. The risk assessment has been a permanent item on the SCs meetings during the course of the project

Newsletter

Four newsletters were published during the course of the project. They were both posted on the public part of the website and distributed through E-mail to concerned parties.

In addition Posiva has published specific newsletters on the progress of WP5.

Website portal

A project internal website was setup during the start of the project using projectplace.com. The project has chosen to only use the information sharing functions for documents. Applications for project planning and control have not been utilized. Based on feedback from the EG the support in the usage was improved, but rather late. The feedback also resulted in a more intense day-to-day management of structure and information downloads by the PMO.

A public website was in addition setup early in the project. It got a large overhaul during 2012 to ensure compliance with web-standards and proper operation with mobile devices. The homepage will remain operational until 2020.

Support for production of necessary documentation regarding LUCOEX

This includes work with the periodic reporting and the final documentation for the project. The first periodic reporting was cumbersome and took a long time for all involved parties. The project partners and the PMO learned from those experiences and setup a good system of templates and instructions for the following reporting which proved beneficial.

5.3.2 Communication

The communication efforts within LUCOEX were divided into internal and external communications as follows.

Internal

Five Project Progress Meetings (PPMs) were held on different sites giving all members the opportunity to get information of the different LUCOEX partners´ sites and experiments. Each PPM has been combined with a workshop focusing on certain topics relevant to the LUCOEX project. These workshops had representatives from numerous European countries participating.

- PPM1 (SKB’s main office, Sweden)
  Theme: Project planning, Risk management and Cross reviewing of plans.
- PPM2 (on site at Olkiluoto, Finland)
  Theme workshop: Horizon2020, Tunnel and disposal cell excavation.
- PPM3 (on site at Bure, France)
  Theme workshop: Instrumentation.

- PPM4 (on site at Mont Terri)
  Theme workshop: Bentonite block/pellet manufacturing and installation.
- PPM5 (on site at Äspö HRL, Sweden)
  Theme workshop: Installation and sealing of drifts.

All individual WPs invited both the other partners and the EG members to visit and participate in their individual experiments.

Information was also shared between the LUCOEX partners by the means of email, face-to-face meetings and through the external communication channels like the newsletters and workshops.

External

- Open on-site visits presenting both the general work performed and the LUCOEX experiments
- Four Workshops were held in conjunction with the Project Progress Meetings (PPMs) where we have had representatives from numerous European countries participating (the first theme workshop was performed for the benefit of the project).
- Mid-term Workshop was held in conjunction with the Clay conference in France in 2012 where we had participants from 13 European countries plus Japan.
- Large Workshop was held at Äspö in 2015 with roughly 80 participants from 15 European countries plus representatives from Japan and China.
- The LUCOEX external website (http://www.lucoex.eu) which includes both general information about the project and all project deliverables.
- Scholarship programme open for students and professionals from all the members states and Switzerland.
- Training programme where young professionals have been offered the opportunity to during a minimum of two weeks participate in the full scale tests on-site.
- Publication in technical magazines and journals.
- The project has in addition to the hosted events also presented the work performed in the project at over 15 external conferences and published over 30 articles on the experiments performed

5.3.3 Networking and dissemination of results

Besides the four workshops held in conjunction with Project Progress Meetings (PPMs), the project hosted a Mid-term Workshop that was held in conjunction with the Clay conference in France in 2012. This workshop had participants from 13 European countries plus Japan.

A Large Workshop was held at Äspö in 2015 with roughly 80 participants from 15 European countries, Japan and China.

The project has in addition to the hosted events also presented the work being performed in the project at over 15 external conferences and published over 30 articles on the experiments performed.

5.4 Major decisions/changes made

No major changes or decisions were made in regards to the project deliverables, communication action plan or project plan with the exception of the activities altered by the amendment request made in 2014.

A challenge for the project was to raise the external interest for the work we were doing. During the first half of the project we had hardly any external interest in the scholarship program and other WMOs wasn't interested in actively participating in a common analysis of how they could benefit from the work that was being done. We therefore made the decision to more actively promote the scholarship program through other channels like directly through universities, the IGD-TP and the New Lancer network which raised the interest for the scholarship program. We also made the decision to ask a Master Theses student to do an "external" analysis of the current state of the different European waste management organisations and if (and how) they could benefit from the work performed within the LUCOEX project.

A major risk was identified early in the project where lab results indicated that it would take substantially longer for SKB's MPT (KBS-3H) installation to reach a saturated stage than originally planned in 2010. The Steering Committee (SC) was informed of this and an active decision was made to initially continue as planned. During following SC-meetings it was however identified that the saturated stage would never be reached within the scope of the LUCOEX-project and that the planned dismantling of the experiment couldn't be included in the scope of the project. A decision was therefore made to send in a request for amendment excluding the dismantling of the experiment.

Another major risk identified early in the project was the challenge of our very ambitious time-plan where there were very little room for deviations. We now know that all four experiments had substantial delays and challenges during their execution including but not limited to:

- Drill rig break down in France.
- Length of design/procurement/manufacturing processes for the backfilling machine in Switzerland.
- In Finland Posiva was forced to construct a new test hall for machinery to be able to finalise the WP5 work.
- Challenges with storage conditions of buffer blocks in Sweden resulting in cracking of blocks.
- Much slower saturation process for the clay components used.

The SC was continuously informed about these potential delays and made the decision in 2013 that we had to start to negotiate with the European Commission for an extension of the project if we are to be able to execute the project without sacrificing the scientific results and quality of our deliverables. This did result in the 2014 LUCOEX Amendment request.

5.4.1 The amendment

The work with an amendment to the grant agreement was initiated in the end of 2013. The key changes requested were:

- Removal of the dismantling of KBS-3H installation from the scope of the project to ensure that the experiment will be given the opportunity to reach a more saturated stage. Without this change SKB would have risked much of the scientific findings from the installation which was not considered acceptable by the project partners. This change was accepted by the European Commission (EC).
- SKB would include a data report by the end of the project to present the early evolution of the installation to ensure that the information gathered from the instrumentation install to that point would be made available. This change was accepted by the EC.
- SKB would perform and report the findings from a new activity: Steered core drilling. The activity was identified as an area of common interest. This change was accepted by the EC.
- Organisational changes (within both project partners and key suppliers) and lessons learned during the first 3 years of the LUCOEX project made the original division of cost and planned man-time for staff exchange impossible to meet. Changes were therefore requested in regards division of cost (between personnel, indirect, sub contracting, etc) and for where the man time was dedicated within the individual work packages. Total man time was kept constant. Maximum EC contribution from the grant agreement was not exceeded. Theses change was accepted by the EC.

- With the identified delays and change of scope presented above we came to the conclusion that it would be impossible to handle this within the allotted time frame. We therefore requested a project extension of 12 months where we clearly stated how the time was to be used. This extension also included the estimate on how long time that was needed for a good reporting to be done in a controlled manor. The EC accepted the reasoning and gave the project 8 more months to finalize the project. We made the analysis that this was possible assuming that the Expert Group (EG) could finalize their reporting based on preliminary reports and presentations.

6 Other outcomes

All four demonstration experiments met their objectives set at the beginning of the LUCOEX project with one main exception: the Multi Purpose Test (MPT) installation (WP4). That experiment was considered to benefit from a longer operational period than the six months allocated at the start of the LUCOEX project and dismantling of the experiment was removed from the scope of LUCOEX.

A series of items can be mentioned as by-products:

6.1 FE (Work Package 2)

- The bentonite was ordered via a public bidding. During this process a new provider with significantly lower prices (without impact on the quality) was identified.
- The quality control of emplaced buffer material was developed more than originally anticipated: not only the overall dry density of the buffer was measured, but methods to measure the dry density locally were also developed (in off-site facilities) to estimate buffer heterogeneity. Those results might be used in the future in a new EC application (Homo-bento).
- During off-site pre-tests, several techniques were experimented to prevent de-mixing of the granulated bentonite mixture during emplacement. De-mixing is known to have a negative effect on the emplaced dry density. Besides the improvement of the intrinsic material characteristics of the GBM design of the mixture towards a self-compacting material, slope coverage by a flexible mat during emplacement was found to have a positive effect. Nevertheless this technique could not be applied in the FE tunnel, because the mat was conflicting with the THM instrumentation. In the FE on-site emplacement, GBM de-mixing (without slope coverage) was worse than anticipated. In fact, from the pouring mixture dry density of approx. 1.45 g/cm^3, the gain of dry density during emplacement by compaction by the augers (up to 1.5 g/cm^3) was less than anticipated.
- Approximately 350 tons of GBM were emplaced (incl. pre-tests) by the FE backfilling machine. During emplacement in the FE tunnel, clear signs of screw wears (not abrasion related) were detected. This wear was stronger than anticipated, but did not prevent us from finishing the FE backfilling. A rough engineering guess is that 500 to 1000 additional tons could have been emplaced without need for important repairs of the prototype machine.
- All project shareholders were invited at the off-site testing facility for a two-day workshop. During this occasion, the functioning of the developed backfilling machine was showed to a wide group of experts (including LUCOEX partners), leading to interesting technical discussions.
- 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.

6.2 ALC (Work Package 3)

- Two additional deliverables have been provided:
    - Initial data report after one year.
    - Initial data report after two years.

6.3 MPT (Work Package 4)

- Major results gained from the planning, installation and monitoring of the MPT have been of great value to the development work for both the KBS-3H and the KBS-3V concepts within SKB and Posiva.
- Experiences regarding the use of sensors, manufacturing of bentonite blocks and pellets, have been discussed between the LUCOEX partners and other organisations at workshops, seminars and meetings.
- The LUCOEX project has influenced the cooperation between Nagra, Andra, Posiva and SKB regarding machine development and bentonite procurement.
- The LUCOEX project has also promoted a new route of networking, one between the LUCOEX partners´ technical staff members.
- A drilling activity has been added to the LUCOEX project with the objective to demonstrate the ability to drill long, straight horizontal pilot holes in crystalline rock using guided core drilling technology.

6.4 KBS-3V (Work Package 5)

- The LUCOEX project has influenced a new cooperation contacts between Nagra, Andra, Posiva and SKB staff and subcontractors regarding machine development and bentonite procurement.
- Despite four separate work packages, all have the same terms of references: need to execute disposal of spent nuclear fuel, swelling clay, and underground test facility. Therefore workshops and meeting have been fruitful and influenced data transfer between partners.
- Manufacturing of clay blocks and pellets and seeking for suitable clay material have influenced conversation between LUCOEX partners. The results of that have been new options to purchase the material and engagement of new manufacturers for clay components.
- The disposal concepts are different between the partners, but exploring each concept evoked thought like: would this be better than our concept, and is it something we can apply in our work?
- Solving bentonite buffer installation problems with special tools is more challenging than expected. Results achieved so far are a starting point for the future work. Development of tools for problem handling will continue. Substantial work remains before the final tools have been developed. This could be a topic for a new EC project.
- Reporting of work by documentary film has been shown to be a good way of sharing the information in particular to persons who are not experts, but who need the information on disposal of spent nuclear fuel in their role of decision makers. The film acts as an incentive to explore the “heavy reports”.

7 Discussion and conclusions

7.1 Analysis and discussion of programme implementation and resulting outcomes.

The LUCOEX-project has provided a check on the suitability of the different emplacement concepts and given the stakeholders a possibility to understand and compare important parameters for the implementation and the long-term safety of the concepts. Important experience has been obtained regarding testing and improving of methods, equipment, technologies, processes and operability related to the gallery construction, manufacturing and emplacement of buffer around waste canisters, emplacement of waste packages, and backfilling and sealing of galleries.

Project partners

The stakeholders that have gained the most out of the project are the project participants.

They have gained a lot of information through the actual work performed within the scope of the LUCOEX-project which has been a part of the stepwise development of repository technology within the individual national waste management programs. This includes both technical know-how from excavation operations, development and operation of advanced machinery, material science investigations and backfilling and closing of the cells/drifts. All this information is an essential milestone for the construction, operation and sealing of nuclear waste repositories in a safe and reliable manner. Without the information developed – this would not be possible. In addition NAGRA, ANDRA and SKB are using the installations performed within the LUCOEX-project for developing a better understanding of the early development of the repository in regards to THM-processes and material science where crucial information has already been gained necessary for the safety case for the different repositories.

Finally the project partners have received a lot of know-how through both formal interactions (like the hosted events such as conferences, workshops and site visits) and informal contacts through direct contact, e-mail and individual site visits. This has given the project participants a better understanding of alternative technologies and a base for extended cooperation beyond the scope of the LUCOEX-project. An example is the ongoing discussions between Sweden and Finland regarding choosing a common technique for the production of buffer and possibly backfill components – which also could extend all the way to a common production facility for these components. This work is based on the experiences gained in Sweden, Finland and Switzerland regarding the production of highly compacted bentonite components using uniaxial and isostatic compression.

The cooperation has also given the project participants a chance to compare the information gathered both before and during the LUCOEX project. In combination with the feedback from the Expert Group (EG), this has allowed the project partners a second opinion and feedback on the work they are performing.

In conclusion; the LUCOEX-project has given the project partners necessary information in the stepwise development of final repositories for nuclear waste. The work has also paved the way for ongoing material science and THM-studies necessary for the evolution of the safety cases. The project has also increased the interconnections between the WMOs through networking events. All this is expected to result in more efficient and safe repositories for nuclear waste in the individual countries participating in the project.

External stakeholders

The secondary stakeholders are the European Commission, all the external project participants and the general public who have participated in the events hosted and at conferences where the project has been presented.

European Commission

The European Commission outlined in its decision 2006/976/EURATOM that the projects within the research area “management of radioactive waste” should:

“Through implementation-oriented RTD, the activities aim to establish a sound scientific and technical basis for demonstrating the technologies and safety of disposal of spent fuel and long-lived radioactive wastes in geological formations ...”

This combined with the FP7 work program 2010 (European Commission C(2009)5946 from 30 July 2009) where it is stated that the projects should contribute:

“to the progress towards the implementing of geological disposal in line with the Vision Report and initial roadmaps of IGD-TP and the 2020 objectives of the SET-Plan, together with significant advances in the treatment and/or understanding of key remaining issues. In particular, this should lead to demonstrable improvements in robustness of associated performance and safety analyses, and ultimately to increased confidence in the safety case ...”

The project has through the work performed in the LUCOEX supported these goals by:

- Demonstrating key aspects of building, manufacturing key components for, operating and closing repositories for long-lived radioactive wastes in geological formations with the current level of technology.
- Creating a foundation for future studies on material- and thermal processes linked to the operation and long term safety of a repository for long-lived radioactive wastes in geological formations.
- Taken the next step in the stepwise implementation of geological disposals for radioactive waste where we expect that the first repository in crystalline rock will be made operational within the following decade.
- Identifying key remaining issues including primarily optimization and increasing the installation speed.

External project participants

The external project participants include representative from fourteen countries in Europe, North America and Asia who participated in the events hosted by the project. Also included are the 28 scholarship recipients who took the opportunity to participate in the hosted events and also to participate and support the work at the URLs in Bure, Mont Terri, Onkalo and Äspö during the course of the project through the training scholarships.

The LUCOEX-project considers that we have been successful in sharing the knowledge and experiences from the project to these external project participants who has been given in-depth knowledge about the work that has been performed. Some have also contributed back to the project through the scholarship training program.

By sharing the knowledge with these, most often, experts within the field we expect to be able to support other counties in their work with creating national geological repositories for nuclear waste. The information shared will allow them to kick-start their national programs by using the programs and technical development within Sweden, Finland, France and Switzerland as templates for their own solution. Adaptions of the concepts to their local legislation and geological conditions will be necessary but it will be far more time and cost efficient than having to designing everything from the ground up. By using an existing program as a base we also expect that it will be easier for the less developed programs to achieve public acceptance for both the repository concept as well as the safety case if best practices from LUCOEX partner organizations are used.

General public

The long lasting impact of this project is also to a large extent the legacy which has been past to all the visitors and scholarship recipients who took the opportunity to visit and participate in the experiments on-site in Bure, Mont Terri, Onkalo and Äspö during the course of the project.

In addition we have during the LUCOEX-project published numerous articles and presented the project at different conferences and workshop (listed in appendix I and IV).

Each of the scholarship recipients have also spread the knowledge from the project through their own words by presenting the LUCOEX-project “at home” when returning back from a workshop or by writing a report on the subject studied during an training internship.

Finally we see that the LUCOEX-homepage (www.lucoex.eu) has had between 100 – 1000 unique visitors each week downloading reports and deliverables from the project homepage. By keeping the homepage live during the following years and by ensuring that it is easily indexed by search engines like Google and Bing we ensure a continued spreading of the knowledge.

The LUCOEX project considers that we have been successful in sharing the knowledge and experiences from the project to the general public through the efforts listed above.

7.2 Possible applicability of results to different repository concepts in different host rock types (clay, crystalline rock and salt).

The findings by the study on possible applicability of LUCOEX´s results to different repository concepts in European were that although all countries being member states have responsible organisations, knowledge of waste inventory and knowledge of domestic geology they represented programmes that were in a an early phase of discussing the existence of suitable domestic host rocks and consequently suitable repository technology, and Finland who has selected site and repository concept and has constructed an underground rock characterisation facility at the selected site. Some programmes prefer an international solution for geological disposal with respect to their small amounts of waste. Since LUCOEX is focusing on studies on relatively advanced level of repository technology, programmes in too less advanced phases have not yet reached progresses where LUCOEX findings are relevant, but on a very general level. This is also true for countries with small amounts of waste, if a multi-national repository would become a reality. On the other hand, the LUCOEX findings can help the less advanced programmes in their discussion and development of suitable repository concept. In a broader picture the LUCOEX work can be useful for guidelines on how to structure preparatory work in terms of design and long-term safety analysis to be applied on repository concepts in the future. To those countries, which have reached a more advanced phase (the study specifically mentions Spain, Slovakia, Hungary, United Kingdom, Germany, Czech Republic and Belgium), it is very likely that the LUCOEX results are useful. All of them have either clay or crystalline rock as possible host rock for geological disposal.

Many of the member state programmes are or have been collaborating with LUCOEX partners in different issues on geological disposal, e.g. through other EU-supported research-development-demonstration projects. The networks that have been created in this way often works as an informal forum for information exchange. Consequently the broad outcome of the LUCOEX project has already been disseminated to many staff members, which in turn has opened up for more formal contacts on details and practical experiences.

7.3 Critical analysis of parts that became a success and parts those were not so successful.

The project has been successful in sharing the knowledge gained during the course of the project addressing several different dissemination activities like:

- Mont Terri, Bure, Äspö and Onkalo have been open to all visitors e.g. project partners, experts, authorities and the general public.
- Internal project meetings and workshops.
- Networking and direct contact between experts and engineers.
- Dialogue between the Expert Group (EG) and the project partners.
- Hosted 4+1 open workshops and two conferences focusing on key aspects of the construction, operation and closure of repositories for long-lived nuclear waste.

- Performing 28 scholarships resulting in either a technical report (from the training internships) or a presentation done by the scholarship recipient when the get back “home”.
- Published 36 articles relating to the work performed within the LUCOEX-project.
- Produced 3 Movies or video clips relating to the work performed within the LUCOEX-project available at http://www.lucoex.eu/conference/ .
- The LUCOEX-project has hosted or participated at 33 different dissemination activities including everything from newsletters, Poster sessions and conference presentations to hosting conferences.

Through these efforts we have increased the understanding of where we stand today in the stepwise development of repositories for long-lived nuclear waste. We have also openly shared the information and the experiences from the LUCOEX project which in combination with the openness of the project parties regarding their national programmes and concepts, give any less advanced programme a good technical starting point for creating a programme and concept of their own. This is expected to both lower costs and increase the safety level as more resources are directed towards similar and common solutions.

In the beginning we thought that a direct contact between the LUCOEX project and parties interested in taking part of the project´s progress would be the most efficient way of conveying the project´s findings. But we learned that there already existed different networks and different ways of exchanging information between the Member Stats´ technical staff members, e.g, the IGD-TP. And that the LUCOEX agenda for dissemination was good enough to provide early hints about progress that could be of possible interest.

Some specific observations have been reported form the LUCOEX activities:

7.3.1 FE (Work Package 2)

In the framework of the FE experiment, a series of backfilling pre-tests were performed. This allowed for:

- Visualizing (and understanding) the segregation effect that leads to lower emplacement dry density. Countermeasures were proposed to prevent segregation. Those could not be carried out in the framework of the FE backfilling because they were conflicting with another aim (emplacement of sensors around the heaters)
- Developing novel methods to monitor the backfilling dry density, not only at large scale, but also to detect local heterogeneities.
- Project schedule had to be delayed by several months. This delay was caused by: 1) technical problems during the tunnel excavation, 2) initial underestimation of the time necessary to set up tenders for relatively large operations according to WTO rules (e.g. manufacturing of bentonite blocks and granulated bentonite mixture and ordering of backfilling machine). Nevertheless, the delay was relatively small (relative to the 4 years duration of the project) and did not prevent Nagra to finish in time the high quality project documentation required by LUCOEX.
- From kick-off on, the FE project was organized with clear sub-tasks. Responsibility for each subtask was attributed to a different person in Nagra that was responsible for its execution. A close follow-up on the different sub-tasks and coordination meetings with strict deadline checks led to a successful project performance.
- During the implementation phase, characterized by intense activities with a high degree of interfaces between several shareholders, daily reports were sent to all project shareholders. This was experimented as useful for all project shareholders actively involved in the project (e.a. for information about foreseen small 1- or 2-days schedule shifts) and as positive and transparent information flow for less active shareholders.

7.3.2 ALC (Work Package 3)

A failure of the drilling machine occurred 70 cm before the depth target due to the blocking of the eccentrics of the cutting wheel into the 1st sleeve element. This technical failure did not affect either the implementation of the experiment (sleeve instrumentation and installation of the heating system) or the interpretation of the measurements. The analysis of this failure has led to modifications of the micro-TBM. They consist in the improvement of the mechanical connection between the cutting head and the first sleeve element by adding four hydraulic jacks. A new 40 m long HLW cell has since been successfully drilled.

Another “not so successful result” is the failure of all the total pressure sensors which have been specially developed for this experiment from load cells using strain gauges technology. None has resisted the thermal loading. A new design will be studied by the company in charge of the instrumentation of the casing for the next heating cell test planned in 2017.

What we consider to be successful results is mainly the fact that the ALC experiment contributes to increase the reliability of Andra’s HLW cells design, especially in regards to the impact of a thermal loading (the THM behaviour of the cell is fully consistent with the THM behaviour measured on previous small scale experiments and it is qualitatively well reproduced by the first numerical simulations). It will also provide valuable feedback towards implementing new full scale heating experiments consistent with the new benchmark concept.

7.3.3 MPT (Work Package 4)

The planning and preparation of the MPT took longer time than expected. This together with the needed extension of the saturation period resulted in the dismantling of the test could not be finished within the original LUCOEX timeframe. Instead this gave an, with acceptance from EC, opportunity to add a task on demonstration of the ability to drill long, straight horizontal pilot holes in crystalline rock using guided core drilling technology. To use a more slim drilling method with steering devices is more efficient than the previous method tested at Äspö HRL 10 years ago. To be able to drill straight boreholes it is important to both the KBS-3H and KBS-3V concepts. Another advantage with the slim drilling method is that the drilling hole is easier to characterise due to the drill core you get from the drilling. This is not the case with the previous drilling method used.

New results were obtained regarding how the buffer blocks were affected by humidity and temperature during transportation, storage and handling after they were manufactured. The buffer blocks started to crack quicker than expected, the plastic protection taken on and off during handling was not enough. Instead a controlled environment was implemented and it was demonstrated that by handling them in a controlled and optimised environment, drying can, as expected, be mitigated. The importance of handling the buffer blocks in a controlled environment before installation in deposition drifts/holes will be stressed further when updating requirements and designing facilities. This is of interest for both KBS-3H and KBS-3V.

In the installation of the MPT both wireless and wired sensors were used. The outcome so far is that the wireless sensors are not as reliable as the wired. Further tests of wireless sensors are of interest as the wireless sensors have an advantage in full scale tests.

To demonstrate repository concepts by accomplishing full scale tests is important to SKB. Lessons learned from the MPT are the importance of clear objectives and thoroughly planning and preparation phase which will influence tests and demonstration in the future.

To change the coordinator during the project phase is challenging. The optimum is that the coordinator can be involved from the planning of application until the end of the project. In the Lucoex project this could be handled in a fruitful way as the first coordinator have been available for support along the whole project phase.

7.3.4 KBS-3V (Work Package 5)

We were successful in finding that it is possible to meet the accuracy requirements of buffer installation.

We were also successful with the performance of the vacuum lifting tool, which worked well. The lifting safety was noticeable right from the start of the lift. The leaking of vacuum air did not increase during the lift.

We were not so successful with the combined installation of buffer blocks and bentonite pellets in the gap between the buffer blocks and rock wall. There was some variation in the width of the gap, therefore the top surface of the pellets filling was not so even as expected. This gap variation is difficult to adjust to when pre-loading pellets in the bentonite container, and if there is not especial reason to do the filling simultaneously with the buffer blocks, the pouring of pellets into the gap after installation of all buffer blocks would be the easiest way to fill the gap evenly.

7.4 Possible improvements in future EC demonstration projects.

Workshops and LUCOEX project meetings allowed for critical review of the experiments implementation and development. Internal feedback was always welcome and perceived as very constructive. Nevertheless this feedback was basically theoretical and based only on information provided by one partner to the other partners. A possible improvement could be that the WP leaders or other WP expertise review more of the other organisations key planning and implementation documents. In addition to providing more expert input to the reviewed documents, this could allow for the identification of even more areas of interaction between WPs.

The personnel resources allocated to the project were too small and should preferably be larger in future EC projects. And the time allocated for visits to the other partners´ projects was not enough. It is understood that this kind of interaction is difficult to carry out in practice. From a private/professional life balance point of view it is difficult for involved personnel to find time for secondment of staff or integration of external partner in other partners' project teams. And such interaction was given low priority, although the activities would have brought a positive return to respective experiment. Preferably the Project Plan should include more specific plans on how to participate in the other partners´ work, e.g. when and how to participate, what to do and the mixing of work between partners. This should include a detailed plan and more accurate allocation of personnel resources for visits and secondment of staff.

Interaction with other EC projects fully outside of our field of expertise might also help us to improve the way in which EC projects are handled by 1) looking into how the neighbours are handling different general project aspects, 2) receiving a fully external and objective feedback from colleagues involved in technically different matters

7.5 Critical analysis of possible improvements in management strategy

Demonstration experiments are in essence prototype experiments. The prototype character has direct implications on the management of such an experiment. An EC project adds a lot of benefits but also demands on the Work Package leaders and key WP members. This needs to be stressed when setting up the project and doing the recourse planning.

A five year project also implies recourse risks and it could be considered that the WP leaders should have an appointed assistant WP leader already at the start of the project, perhaps they could have slightly different profiles, such as one with technical and one with administrational responsibilities. This could facilitate the possible sharing of dissemination tasks as well as provide an informed replacement in case of recourses leaving the companies, the project, parental leaves or illnesses. The same applies for the project coordinator.

Involved personnel in the LUCOEX project were partly only used to smaller scientific experiments and have to face larger scale practical problems. Their resolution had to be done without jeopardizing the scientific components of the demonstration experiments, which needed extra time.

Time management was also difficult because many unforeseen problems arose during the development of the project. This could have been somehow improved by a very clear initial definition of the experimental objectives, but it was also related to the definition of requirements of specific aspects that were only discovered along the work. Consequently additional resources as those planned in the beginning of the project had to be integrated in the project to cope with deadlines agreed in the framework of LUCOEX.

Because of its larger scale, a demonstration experiment also involves setting up tendering procedures according to the World Trade Organization standards. Those procedures took time. Tendering time was underestimated in the beginning of the project.

Involved personnel had sometimes the feeling to perform an experiment with multiple facets not necessarily foreseen from the beginning.

The information material for EC-projects is quite extensive. It is very detailed and preparatory orientation requires a lot of work. A major improvement would be a “light version” with good examples.

The reporting work is burdensome and takes resources from the experimental work. Any easing of this work would improve the project´s factual result.

We further conclude that an expert group may play a major coordination and integration role in future European projects. But we believe that the LUCOEX Expert Groups (EG) proposal for changes could promote a more efficient way of working.

- The number of appointed experts should be less than the eight in LUCOEX, where the number of experts was too high for the purpose (making almost impossible the attendance of all experts at a time to a given meeting or a site visit). A group of four experts instead of eight looks sensible and more adapted.
- The experts consider that the assessment work should be carried out by “external experts” only and not by “internal experts”, in order to provide a fully independent evaluation.
- The experts’ intermediary findings and recommendations had little if not nil influence on the technical work implementation. This fact (well understood since the budgets and calendars were tight for all the LUCOEX partners) leads to propose a different Scope of Mission for the expertise. For instance the evaluation work could be focused on the final summary reports only, at the end of the technical WPs. In such a case, a different methodology could as well be envisaged, such as the “Expert Elicitation” process, now ongoing in the DOPAS project.

8 Summary

The four most advanced waste management programs in Europe have as part of their step-vice development of repository concepts for long-lived radioactive waste come together in the LUCOEX project with the common objective to demonstrate the technical feasibility for a safe and reliable disposal of radioactive waste in geological formations.

This demonstration has been done by executing four parallel experiments at different underground research laboratories, all designed for the specific purpose of developing these kinds of underground facilities. Each experiment has focused on different concepts and different geological and technical/legal pre-conditions and all experiments have been executed with a focus on openness and willingness to share the knowledge gained to support the development of safe and reliable repositories throughout Europe.

In the Bure Underground laboratory in France Andra has demonstrated the construction feasibility of a complete HLW cell in Callovo-Oxfordian clay with a concept optimized for a possible future retrieval of the waste. As a secondary objective they have developed a better understanding for the cell and its mechanical behavior under thermal loading as well as the thermo-hydro-mechanical (THM) behavior of the surrounding rock, mainly in terms of the overpressure caused by the heating phase.

Andra's counterpart in Switzerland, Nagra, has performed the FE-experiment in the Mont Terri URL, which is a full-scale, multiple heater test in Opalinus Clay. The experiment includes a) the verification of the technical feasibility of constructing a repository tunnel using standard industrial equipment, b) the optimization of the bentonite buffer material production and c) the investigation of (horizontal) canister and buffer emplacement procedures at underground conditions including the development of key machinery. A secondary goal (not part of LUCOEX) was to investigate the coupled THM effects onto the host rock to validate existing THM models.

The excavations of horizontal disposal tunnels with vertical disposal positions in crystalline rock, KBS-3V, are constructed using conventional technology and the sealing is managed by the EU-project DOPAS. Therefore Posiva has in Finland focused on remaining issues for this concept including a) development of the final prototype machinery necessary for the transportation and installation of buffer components; b) Method and tools for filling the gap between the bentonite blocks and the host rock with bentonite pellets and c) Methods and strategies for quality assurance and problem handling. The work in Finland was finalized with a successful full-scale installation using the developed machinery and concepts.

An alternative strategy developed for the disposal in crystalline rock is to place the canisters horizontally in drifts, KBS-3H. The process is newer and it has the potential to be more cost efficient than "vertical disposal" but it isn't as mature as the KBS-3V concept and require more development work. In this project SKB has shown that it is technically feasible to a) drill straight enough pilot holes for horizontal disposal drifts; b) manufacture the necessary buffer components; c) assemble all components including the Supercontainer; d) deposit bentonite components and the Supercontainer, and finally e) seal and monitor the activities within the drift. The secondary goal for SKB was to investigate the early buffer evolution in the drift to update existing material models.

The common result for the four experiments is that all technical objectives have been fulfilled by the LUCOEX partners. Many minor technical problems were experienced but they could all be handled to our satisfaction.

The public component of the LUCOEX project has been the dissemination of the findings. This has been done through a) making it possible to visit the experiments at the URLs, b) presenting our results and findings through scientific articles and presentations at conferences, c) producing movies from the different experiments, d) hosting conferences and workshops and finally having an ambitious scholarship program to give external parties the possibility to participate both in hosted events and on site training during the experiments.

Identified successes and failures.

We are very satisfied with the outcome of the dissemination activities. From the beginning we thought that once we had explained our openness to share the LUCOEX´ results we would be contacted by parties interested to take part of the project´s progress. This, however, was not the case. Instead we had to focus on means of presenting the progress results and make them as publically available as possible. In doing so, we consider ourselves successful in changing strategy and reaching out to a wide audience with our messages. We also believed that the scholarship programme should be of great interest once its existence was properly announced. Neither this was the case, so we had to use our networks and all available contacts in order to orally express our offers.

The messages on progress became based on the successful development of the four experiments of the LUCOEX projects with valuable experiences on disposal cell construction, buffer component manufacturing, components installation and disposal cell sealing. No major failure occurred. The serious ones were connected to time delays with background in too optimistic assumptions of purchasing, available personnel resources and the value in being able to observe the installations longer time than available to the LUCOEX project. Technical minor problems occurred continuously during the project but they were all solved in a good way. These kinds of problems were expected to occur, as they do in all industrial projects, but in the LUCOEX case without any significant influence on completion of the LUCOEX project and the results obtained. In the final end we concluded that the solutions to the problems provided additional knowledge and significant return of experience in the planning of new large underground experiments.

9 Acknowledgement

The steering committee would like to acknowledge the huge work effort invested by both project partners and work package managers in making the LUCOEX project a reality. We would also like to thank the European Commission and the project officer for their continued support throughout the project.

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APPENDIX I – PROJECT DELIVERABLES

Project Deliverables							
NO.	Title	Main author	Delivery date from Annex I (proj month)	Actual date (project month)	Delay	Open access[1] provided	available on the lucoex.eu homepage
1.01	*Project Plan*	*SKB*	*3*	*5*	*2*	*yes*	*yes*
1.02	*Risk Assessment*	*SKB*	*3*	*5*	*2*	*yes*	*yes*
1.03	*Training programme*	*SKB*	*4*	*9*	*5*	*yes*	*yes*
1.04	*Programme on staff secondment*	*SKB*	*4*	*9*	*5*	*yes*	*yes*
1.05	*Communication Action Plan*	*SKB*	*6*	*9*	*3*	*yes*	*yes*
1.06	*Minutes from PPM No.1*	*SKB*	*12*	*5*	*-7*	*yes*	*yes*
1.07	*Expert Group Report No. 1*	*SKB*	*18*	*26/ updated 47*	*8/29*	*yes*	*yes*
1.08	*Minutes from PPM No.2*	*SKB*	*21*	*18*	*-3*	*yes*	*yes*
1.09	*Compilation of presentations from Mid-term Workshop*	*SKB*	*26*	*28*	*2*	*yes*	*yes*
1.10	*Minutes from PPM No. 3*	*SKB*	*30*	*39*	*9*	*yes*	*yes*
1.11	*Expert Group Report #2*	*SKB*	*36*	*50*	*14*	*yes*	*yes*
1.12	*Minutes from PPM No.4*	*SKB*	*39*	*39*	*0*	*yes*	*yes*
1.13	*Proceedings from the Large Workshop*	*SKB*	*46*	*58*	*12*	*yes*	*yes*
1.14	*Expert Group Report #3*	*SKB*	*54*	*59*	*5*	*yes*	*yes*
1.15	*Result of LUCOEX with possible use in other EU Member States' concepts*	*SKB*	*48*	*47*	*-1*	*yes*	*yes*
1.16	*Publishable technical report on WP2 result*	*NAGRA*	*54*	*58*	*4*	*yes*	*yes*
1.17	*Publishable technical report on WP3 result*	*ANDRA*	*54*	*58*	*4*	*yes*	*yes*
1.18	*Publishable technical report on WP4 result*	*SKB*	*54*	*58*	*4*	*yes*	*yes*
1.19	*Publishable technical report on WP5 result*	*SKB*	*54*	*58*	*4*	*yes*	*yes*
1.20	*Minutes from PPM No.5*	*SKB*	*46*	*50*	*4*	*yes*	*yes*
1.21	*Final Report WP1*	*SKB*	*55*	*58*	*3*	*yes*	*yes*
1.22	*Final Project Technical Report*	*SKB*	*56*	*58*	*2*	*yes*	*yes*
2.01	*Workplan*	*NAGRA*	*6*	*18*	*12*	*yes*	*yes*
2.02	*Report on construction of the emplacement tunnel*	*NAGRA*	*15*	*48*	*33*	*yes*	*yes*
2.03	*Requirements, manufacturing and QC of the buffer components*	*NAGRA*	*51*	*58*	*7*	*yes*	*yes*
2.04	*Construction of emplacement equipment*	*NAGRA*	*36*	*52*	*22*	*yes*	*yes*

[1] 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.

2.05	*Emplacement report*	*NAGRA*	*51*	*58*	*7*	*yes*	*yes*
2.06	*Final report of WP2*	*NAGRA*	*54*	*58*	*4*	*yes*	*yes*
3.01	*Report on the preliminary test of forced casing digging*	*ANDRA*	*6*	*9*	*3*	*yes*	*yes*
3.02	*Test plan of the ALC experiment*	*ANDRA*	*9*	*11*	*2*	*yes*	*yes*
3.03	*Report of the digging and emplacement of the cell*	*ANDRA*	*34*	*39*	*5*	*yes*	*yes*
3.04	*Final report of WP 3*	*ANDRA*	*51*	*58*	*7*	*yes*	*yes*
4.01	*Working Report on manufacturing of distance blocks and blocks for the supercontainer*	*SKB*	*16*	*48*	*32*	*yes*	*yes*
4.02	*Working Report on the upgrades done to the deposit machine*	*SKB*	*25*	*48*	*23*	*yes*	*yes*
4.03	*Working report on the Multi Purpose test*	*SKB*	*50*	*58*	*8*	*yes*	*yes*
4.04	*Final report of WP 4*	*SKB*	*54*	*58*	*4*	*yes*	*yes*
4.05	*Steered core drilling in crystaline rock*	*SKB*	*50*	*58*	*8*	*yes*	*yes*
4.06	*Initial Data report: MPT-test*	*SKB*	*52*	*58*	*6*	*yes*	*yes*
4.07	*Comparison between uni-axial and isostatic compaction method for the production of bentonite components*	*SKB*	*56*	*58*	*2*	*yes*	*yes*
4.08	*Steered drilling at Äspö*	*SKB*	*56*	*58*	*2*	*yes*	*yes*
5.01	*Detailed project Plan*	*POSIVA*	*3*	*11*	*8*	*yes*	*yes*
5.02	*Buffer Emplacement test*	*POSIVA*	*51*	*58*	*7*	*yes*	*yes*
5.03	*Memo on designing the gap filling tool.*	*POSIVA*	*51*	*58*	*7*	*yes*	*yes*
5.04	*Memo on buffer emplacement testing*	*POSIVA*	*51*	*58*	*7*	*yes*	*yes*
5.05	*Quality Assurance and Problem Handling during buffer emplacement*	*POSIVA*	*54*	*58*	*4*	*yes*	*yes*
5.06	*Definition of the WP5 emplacement process phases and their quality requirements.*	*POSIVA*	*12*	*15*	*3*	*yes*	*yes*
5.07	*Memo on Development of quality assurance tools.*	*POSIVA*	*54*	*58*	*4*	*yes*	*yes*
5.08	*Plans for solving the emplacement problem situations.*	*POSIVA*	*50*	*58*	*4*	*yes*	*yes*
5.09	*Final report of WP 5*	*POSIVA*	*55*	*58*	*3*	*yes*	*yes*
5.10	*Plan on WP5 integration and dissemination*	*POSIVA*	*5*	*12*	*7*	*yes*	*yes*
5.11	*Project expert review report*	*POSIVA*	*55*	*58*	*3*	*yes*	*yes*
5.12	*Interim report on the project reviews*	*POSIVA*	*12*	*15*	*3*	*yes*	*yes*
5.13	*Interim report on the project reviews*	*POSIVA*	*24*	*28*	*4*	*yes*	*yes*
5.14	*Interim report on the project reviews*	*POSIVA*	*48*	*58*	*10*	*yes*	*yes*
5.15	*WP5 Newsletter Posiva*	*POSIVA*	*12*	*15*	*3*	*yes*	*yes*
5.16	*WP5 Newsletter Posiva*	*POSIVA*	*24*	*28*	*0*	*yes*	*yes*

5.17	*WP5 Newsletter Posiva*	*POSIVA*	*36*	*50*	*14*	*yes*	*yes*
5.18	*Paper for professional journal*	*POSIVA*	*24*	*28*	*4*	*yes*	*yes*
5.19	*Paper for professional journal*	*POSIVA*	*54*	*58*	*4*	*yes*	*yes*
5.20	*Documentary film of buffer installation demos*	*POSIVA*	*54*	*58*	*16*	*yes*	*yes*
6.01	*Project Presentation document*	*SKB*	*3*	*6*	*3*	*yes*	*yes*
6.02	*Web-site portal*	*SKB*	*4*	*7*	*3*	*yes*	*yes*
6.03	*Newsletter*	*SKB*	*12*	*15*	*3*	*yes*	*yes*
6.04	*Periodic report to be submitted to the Commission*	*SKB*	*18*	*28*	*2*	*NO*	*NO*
6.05	*Newsletter*	*SKB*	*24*	*28*	*2*	*yes*	*yes*
6.06	*Newsletter*	*SKB*	*36*	*40*	*0*	*yes*	*yes*
6.07	*Periodic report to be submitted to the Commission*	*SKB*	*36*	*58*	*0*	*NO*	*NO*
6.08	*Periodic report to be submitted to the Commission*	*SKB*	*56*	*59*	*0*	*NO*	*NO*
6.09	*Newsletter*	*SKB*	*48*	*58*	*0*	*yes*	*yes*
6.10	*LUCOEX Final Project Report*	*SKB*	*56*	*59*	*0*	*yes*	*yes*

APPENDIX II - INTERNAL PROGRESS EVALUATIONS, WHEN AND WHAT OUTCOME

The experiments within the LUCOEX-project were continuously evaluated within each individual work package. In addition we had planned progress evaluations for the complete LUCOEX project at the project progress meetings and steering committee meetings listed below.

NO.	Name	Venue	Documentation	Outcome	Is open access[2] provided to the documentation?
SCM01	SCM01	Tele conf	SKBdoc id 1426939	The permanent SC members declared the Steering Committee formally established. Erik Thurner was elected as chair of the SC. The coordinator presented steering documentation of the project.	No
SCM02	SCM02	SKB head office	SKBdoc id 1274478	Announcement of the internal expert group members. Dates for the upcoming SCM and PPM were set. Planning of the mid term workshop. The www.projectplace.com was made available for the participants.	No
SCM03	SCM03	Tele conf	SKBdoc id 1426945	Review comments on the project plan are discussed. The project plan will be submitted to EC after approval (Deliverable D1.1). The risk assessment was discussed and the document will be submitted to the SC after approval (D1.2)	No
SCM04	SCM04	Tele conf	SKBdoc id 1325882	The SC Chair was given the mandate to finalise the contract with the external expert group members. The SC Chair/Coordinator were given the	No

[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.

				mandate to negotiate the replacement with the EC within the frame of the LUCOEX Grant Agreement. The workshop in conjunction with PPM02 was address two themes: “Tunnel and disposal cell excavation” and “Buffer components design and manufacturing”.	
SCM05	SCM05	Posiva, Vuojoki mansion	SKBdoc id 1342343	Mainly follow-up work of the project.	No
SCM06	SCM06	Andra office at Bure	SKBdoc id 1378612	Mainly follow-up work of the project. Identified delay in WP4 was discussed. The SC approved the proposal of Jacques Morel taking over as WP3-Leader and Jan Gugala as the SKB deputy representative in LUCOEX Steering Committee.	No
SCM07	SCM07	Mövenpick hotel, Zürich	SKBdoc id 1426962	Due to delays in WP4 the coordinator will contact the EC and re-negotiate the scope of WP4 with the aim to remove the dismantling of the MPT from the scope of the WP and instead suggest to include the 50% modelling done by SKB into the scope of the WP4. Follow-up of the project.	No
SCM08	SCM08	Äspö HRL, SKB	SKBdoc id 1437518	Due to identified delay in WP5 the WP5 leader will distribute a updated time-table and updated risk analysis including possible actions to manage the identified risks for WP5 but the delay will not require a change of the project timetable. Possible themes of the large workshop were discussed. Follow-up of the project.	No
SCM09	SCM09	Tele conf	SKBdoc id 1461887	The SC accepted the conditions given by EC regarding the amendments.	No

				Planning of the large workshop (end conference) Follow-up of the project	
SCM10	SCM10	Forum, Oskarshamn	SKBdoc id 1488288	Detailed follow-up of the project and all deliverables. The SC agreed on the quality assurance of the reports is done within each organisation.	No
SCM11	SCM11	Tele conf	SKBdoc id 1493415	Detailed follow-up of the project and all deliverables. The SC agreed on sharing common costs.	No
PPM01	PPM01	SKB head office	Minutes available on project web		Yes
PPM02	PPM02	Olkiluoto, Finland	Minutes available on project web		Yes
PPM03	PPM03	Andras office at Bure	Minutes and presentations available on project web		Yes
PPM04	PPM04	Mövenpick hotel, Zürich	Minutes and presentations available on project web		Yes
PPM05	PPM05	Äspö HRL, SKB	Minutes and presentations available on project web		Yes

APPENDIX III – MILESTONES

PROJECT MILESTONES						
NO.	Milestone Name	Work Package	Lead beneficiary	Planned Delivery Month	Actual Delivery Month	Comments
MS01	Steering Committee Meeting No 1	WP1	SKB	2	2	
MS02	Project Plan	WP1	SKB	3	3	
MS03	Initial Risk Assessment	WP1	SKB	4	5	
MS04	Training programme	WP1	SKB	4	9	
MS05	Programme on staff secondment	WP1	SKB	4	9	
MS06	Communication Action Plan	WP1	SKB	6	9	
MS07	Project Progress Meeting No 1	WP1	SKB	10	5	
MS08	Steering Committee Meeting No 2	WP1	SKB	10	5	
MS09	Announcement of Mid-term Workshop	WP1	SKB	12	18	
MS10	Announcement of two 2-week training events	WP1	SKB	18	18	
MS11	Announcement of participation in Mid-term Workshop	WP1	SKB	18	18	
MS12	Characteristics of “other” concepts compiled and communicated with respective country	WP1	SKB	19	46	
MS13	Project Progress Meeting No 2	WP1	SKB	19	15	
MS14	Steering Committee Meeting No 3	WP1	SKB	19	4	
MS15	Mid-term workshop held	WP1	SKB	24	21	
MS16	Project Progress Meeting No 3	WP1	SKB	28	21	
MS17	Steering Committee Meeting No 4 held	WP1	SKB	28	12	
MS18	Announcement of Large Workshop	WP1	SKB	34	42	
MS19	Announcement of two 2-week training events #2	WP1	SKB	36	36	
MS20	Announcement completed for all 4 on-site training events	WP1	SKB	36	42	
MS21	Project Progress Meeting No 4 held	WP1	SKB	37	34	
MS22	Steering Committee Meeting No 5 held	WP1	SKB	37	15	
MS23	Announcement of participation in Large Workshop	WP1	SKB	40	51	
MS24	Announcement completed for all 8 participations in WP-specific Workshops	WP1	SKB	40	51	

MS25	List of valuable findings with possible impact on other European Union Member States	WP1	SKB	46	56	
MS26	Proceedings from Large Workshop	WP1	SKB	46	56	
MS27	Project Progress Meeting No 5 held	WP1	SKB	46	48	
MS28	Steering Committee Meeting No 6 held	WP1	SKB	46	21	
MS29	LUCOEX Final Project Technical Report	WP1	SKB	48	56	
MS30	Final version of workplan	WP2	NAGRA	6	18	
MS31	Decision on excavation method	WP2	NAGRA	6	20	
MS32	Start of excavation	WP2	NAGRA	10	17	
MS33	Production of blocks and granular bentonite finished	WP2	NAGRA	24	40	
MS34	Prototypes of emplacement equipment tested and ready for use	WP2	NAGRA	24	44	
MS35	Start of emplacement	WP2	NAGRA	25	45	
MS36	Construction of plug	WP2	NAGRA	27	52	
MS37	Test plan	WP3	ANDRA	9	11	
MS38	Heaters tested in workshop	WP3	ANDRA	12	24	
MS39	Completed cell installation	WP3	ANDRA	16	34	
MS40	Workshop of WP3 n°1	WP3	ANDRA	18	18	
MS41	Heating phase start	WP3	ANDRA	20	36	
MS42	Workshop of WP3 n°2	WP3	ANDRA	36	36	
MS43	Expert advice on the final report of WP3	WP3	ANDRA	46	55	
MS44	All components for Multi-Purpose Test manufactured	WP4	SKB	18	32	
MS45	Deposit machine upgrade completed	WP4	SKB	18	46	
MS46	The initial stage reached in the Multi-Purpose Test	WP4	SKB	19	50	
MS47	Final report completed	WP4	SKB	46	54	
MS48	Detailed project plan ready	WP5	POSIVA	3	11	
MS49	The emplacement problem situations mapped	WP5	POSIVA	5	46	
MS50	Plan of WP5 integration and dissemination ready	WP5	POSIVA	5	15	
MS51	The emplacement process phases	WP5	POSIVA	11	36	

	and their quality requirements defined.					
MS52	Plans for solving the emplacement problem situations finalised	WP5	POSIVA	13	48	
MS53	Design of gap filling tool ready	WP5	POSIVA	21	44	
MS54	The design and construction of the needed equipment finalized	WP5	POSIVA	30	44	
MS55	Testing realised with bentonite blocks in ONKALO completed	WP5	POSIVA	33	52	
MS56	Development of quality assurance tools ready	WP5	POSIVA	35	51	
MS57	The report of WP5 Quality Assurance and Problem Handling during buffer installation ready.	WP5	POSIVA	38	51	
MS58	WP5 final report ready	WP5	POSIVA	48	54	
MS59	Project organisation in operation	WP6	SKB	2	2	
MS60	Project Presentation document	WP6	SKB	3	6	
MS61	Web-site Portal in operation	WP6	SKB	4	7	
MS62	Newsletter	WP6	SKB	12	12	
MS63	Newsletter	WP6	SKB	24	26	
MS64	Newsletter	WP6	SKB	36	38	
MS65	Newsletter	WP6	SKB	48	48	
MS66	LUCOEX Final Project Report	WP6	SKB	48	56	

APPENDIX IV – LIST OF DISSEMINATION ACTIVITIES

LUCOEX: 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	*Web*	*SKB*	*www.lucoex.eu*	*2011-2020*	*online*	*Open to all*	*--*	*International*
2	*Workshop*	*SKB*	*Project Planning, Risk management and Cross reviewing of plans*	*Mar 14th -15th 2011*	*SKB's main office Stockholm*	*Project partner organizations*	*≈20*	*Project partner organizations*
3	*Workshop*	*Posiva*	*Excavation methods for drifts and HLW cells*	*2012 Mar 14-15*	*Olkiluoto, Finland*	*Scientific community and open for all*	*≈40*	*Europe*
4	*Workshop*	*Andra*	*Instrumentation of Full scale emplacement experiment*	*2012 Oct 25-26*	*Montpellier, France*	*Scientific community and open for all*	*≈60*	*Europe*
5	*Workshop*	*Nagra*	*Bentonite Block/Pellet manufacturing and installation*	*2013 Sep 30th-Oct 1st*	*on site in Mont Terri*	*Scientific community and open for all*	*≈60*	*Europe*
6	*Workshop*	*SKB*	*Installation and Sealing of drifts*	*2014 May 13th-14th*	*Äspö, Sweden*	*Scientific community and open for all*	*≈60*	*Europe*
7	*Midterm Conference*	*SKB*	*Achievements within the LUCOEX project*	*Oct 25th -26th 2012*	*Montpellier, France*	*Scientific community and open for all*	*≈40*	*Europe*
8	*End Conference*	*SKB*	*Multiple presentations on various subjects*	*2015 June 2-4*	*Oskarshamn, Sweden*	*Scientific community and open for all*	*≈80*	*Europe*
9	*IGDTP – Geodisposal 2014*	*Andra, Nagra, SKB, Posiva*	*4 presentations on Full scale disposal cell demonstrators in clay formation and crystalline rock*	*2014 June 24-26th*	*Manchester, UK*	*Scientific community and open for all*	*≈400*	*Europe*
10	*Euradwaste '13*	*SKB/Nagra/ Andra/Posiva*	*LUCOEX – Demonstrating the technical feasibility of disposal of spent nuclear fuel in geological formations*	*2013 Oct 14-16*	*Vilnius, Lithuania*	*Scientific community and open for all*	*≈400*	*Europe*
11	*Exhibition*	*SWT+Nagra*	*Mont Terri URL*	*ongoing*	*St.Ursanne, Switzerland*	*Civil Society & Scientific Comm.*		*Europe*
12	*Press release*	*Nagra*	*The FE Experiment/ LUCOEX*	*14.11.2014*	*St.Ursanne, Switzerland*	*Media*	*≈20*	*Switzerland*
13	*Press conf.*	*Nagra*	*The FE Experiment/ LUCOEX*	*21.11.2014*	*St.Ursanne, Switzerland*	*Media*	*≈20*	*Switzerland*
14	*Articles*	*various*	*Various articles about the FE*	*Nov. 2014*	*Various newspapers*	*Civil Society*		*Switzerland*
15	*Interview*	*Nagra*	*The FE Experiment/ LUCOEX*	*26.1.2015*	*SRF Swiss National TV*	*Civil Society*		*Switzerland*

[3] publications, conferences, workshops, web, press releases, flyers, articles published in the popular press, videos, media briefings, presentations, exhibitions, thesis, interviews, films, TV clips, posters, Other.

[4] Scientific Community (higher education, Research), Industry, Civil Society, Policy makers, Medias, Other ('multiple choices' is possible).

16	*Video*	*Nagra*	*The FE Experiment/ LUCOEX*	*May 2015*	*youtube/3iuH5NyG53k*	*Civil Society & Media*	*Youtube*	*International*
17	*Conference*	*Swisstopo*	*Mont Terri Technical Meeting 30*	*8.-9.2.2012*	*St.Ursanne, Switzerland*	*Scientific Community & Industry*	*≈100*	*Europe*
18	*Conference*	*Andra*	*Clay Conference*	*23.-25.10.2012*	*Montpellier, France*	*Scientific Community & Industry*	*≈400*	*Europe*
19	*Conference*	*Swisstopo*	*Mont Terri Technical Meeting 31*	*13.-14.2.2013*	*St.Ursanne, Switzerland*	*Scientific Community & Industry*	*≈120*	*Europe*
20	*Conference*	*BGR*	*PEBS Bentonite Workshop*	*6.-7.2.2014*	*Hannover, Germany*	*Scientific Community & Industry*	*≈200*	*Europe*
21	*Conference*	*Swisstopo*	*Mont Terri Technical Meeting 32*	*12.-13.2.2014*	*St.Ursanne, Switzerland*	*Scientific Community & Industry*	*≈120*	*Europe*
22	*Workshop*	*Nagra*	*Backfilling Machine / Bentonite*	*19.-20.5.2014*	*Grono, Switzerland*	*Scientific Community & Industry*	*≈50*	*Europe*
23	*Conference*	*Swisstopo*	*Mont Terri Technical Meeting 33*	*11.-12.2.2015*	*Porrentruy, Switzerland*	*Scientific Community & Industry*	*≈150*	*Europe*
24	*Conference*	*ONDRAF*	*Clay Conference*	*23.-26.3.2015*	*Brussels, Belgium*	*Scientific Community & Industry*	*≈400*	*International*
25	*Energy and Environment – ISRM Symposium Eurock 2013*	*Andra*	*Feasibility and behavior of a full scale disposal cell in a deep clay layer*	*2013 Sept 21-26*	*Wroclaw, Poland*	*Scientific community*	*≈400*	*Europe*
26	*10th Euroconference on Rock Physics and Rock Mechanics*	*Andra*	*THM behavior of a full scale disposal cell demonstrator in 500 m deep clay formation*	*2014 May 12-15*	*Aussois, France*	*Scientific community*	*≈200*	*Europe*
27	*Clays in Natural and Engineered Barriers for Radioactive Waste, 6th International Conference*	*Andra*	*Feasibility of excavation and THM behavior of a full scale disposal cell for nuclear waste in 500 m deep clay formation*	*2015 Mar 23-26*	*Brussels, Belgium*	*Scientific community*	*≈400*	*Worldwide*
28	*Clays in Natural and Engineered Barriers for Radioactive Waste Confinement, 6th International Conference, Brussels,*	*SKB/B+Tech/ Aitemin*	*Poster:* *KBS-3H Multi Purpose Test*	*2015 Mar 23–26*	*Brussels*	*Scientific Community and open for all*	*~400*	*Europe*
29	*AutomaatioXX seminar*	*SKB*	*Spent nuclear fuel deposition machine lifting control and pallet adjustment*	*2013 May 22nd*	*Helsinki*	*Scientific Community and open for all*	*~100*	*Europe*
30	*Newsletter 1*	*SKB*	*LUCOEX – Newsletter*	*2012 Mar 8th*	*online*	*Open to all*	*--*	*International*
31	*Newsletter 2*	*SKB*	*LUCOEX – Newsletter*	*2013 Feb 1st*	*online*	*Open to all*	*--*	*International*

32	*Newsletter 3*	*SKB*	*LUCOEX – Newsletter*	*2014 Jan 25th*	*online*	*Open to all*	--	*International*
33	*Newsletter 4*	*SKB*	*LUCOEX – Newsletter*	*2015 Aug 31st*	*online*	*Open to all*	--	*International*

APPENDIX V – ARTICLES AND PAPERS

LUCOEX: LIST OF SCIENTIFIC PUBLICATIONS

NO.	Title	Main author	Title of the periodical or the series	Number, date or frequency	Publisher	Place of publication	Year of publication	Relevant pages	Permanent identifiers[5] (if available)	Is/Will open access[6] provided to this publication?
1	Liggande kopparkapslar utreds för miljoner	Monica Kleja	Ny Teknik, Oct 16th 2014 (Publisher Talentum Media AB, Sweden)							Yes
2	State-of-art, proof-of-concept installations for repository concepts based in crystalline rock	Magnus Kronberg	Mineralogical Magazine, Planed publication 2015 in the UK.							Yes
3	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
4	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
5	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
6	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
7	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
8	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

[5] 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.
[6] 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.

9	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
10	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
11	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
12	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**
13	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**
14	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**
15	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**
16	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**
17	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**
18	The Full-Scale Emplacement Experiment – Implementation of a multiple heater experiment at the Mont Terri URL	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**

		Köhler S.; Sakaki T.; Weber HP.; Vietor T.:				
19	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**
20	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**
21	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**
22	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**
23	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**
24	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**
25	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**
26	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**
27	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**

28	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**
29	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.	**2**	*www.jsce-int.org*	**Yes**
30	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**
31	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**
32	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**	*sites.agu.org*	**yes**
33	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**	*sites.agu.org*	**yes**
34	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**	www.modern-fp7.eu	**yes**
35	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**
36	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 VI – SCHOLARSHIP PROGRAM

LUCOEX SCHOLARSHIP PROGRAM						
Event	**Time of Event**	**Detailed announcement**	**Designated WP Leaders**	**Agreement**	**Deliverables**	**Comment**
Mid-term 2-week scholarship	*2012-11-01*	*2011-12-01*	*Jacques Morel /Andra*	*1474890*	*1494891*	*Victor Serri*
Mid-term 2-week scholarship	*2014-11-01*	*2011-12-01*	*Hanspeter Weber/Nagra*	*1449689*	*1465907*	*Lucie Hausmannova*
Mid-term 2-week scholarship	*2014-10-01*	*2011-12-01*	*Hanspeter Weber/Nagra*	*1452531*	*1465908*	*Jan Smutec*
End-term 2-week scholarship	*2014-09-01*	*2013-08-01*	*Magnus Kronberg/SKB*	*1454690*	*1466410*	*Alba Mon Lopez*
End-term 2-week scholarship	*2014-09-01*	*2013-08-01*	*Keijo Haapala/Posiva*	*1488902*	*1513714*	*Pasi Båtsman*
On-site 2-week training Bure	*2014-06-16*	*2013-02-01*	*Jacques Morel/Andra*	*1452365*	*1452362*	*Ionut FLOREA*
On-site 2-week training Mt Terri	*2014-06-01*	*2013-04-01*	*Hanspeter Weber/Nagra*	*1460084*	*1460086*	*Acacia Naves*
On-site 2-week training Äspö	*2013-06-01*	*2012-04-01*	*Magnus Kronberg/SKB*	*1465932*	*1426461*	*Jere Knuuttila*
On-site 2-week training Onkalo	*2013-06-01*	*2012-04-01*	*Keijo Haapala/Posiva*	*1488904*	*1513716*	*Pasi Båtsman*
Mid-term workshop	*2012-10-25*	*2011-12-01*	*Project Coordinator*	*1356832*	*1477753*	*Heini Laine (Reijonen)*
Mid-term workshop	*2012-10-25*	*2011-12-01*	*Project Coordinator*	*1356831*	*1466419*	*Ville Koskinen*
End-term workshop	*2015-06-02*	*2014-10-01*	*Project Coordinator*	*1488083*	*1487442, 1487441*	*Dalia Grigaliuniene*
End-term workshop	*2015-06-02*	*2014-10-01*	*Project Coordinator*	*1488084*	*Poster 1487443 Presentation 1491661*	*Acacia Navez*
Theme-specific workshop	*2012-03-01*	*2011-12-01*	*Keijo Haapala/Posiva*			*Cancelled - limited interest.*
Theme-specific workshop	*2012-03-01*	*2011-12-01*	*Keijo Haapala/Posiva*			*Cancelled - limited interest.*
Theme-specific workshop	*2012-09-01*	*2012-01-01*	*Jacques Morel/Andra*			*Cancelled - limited interest.*
Theme- specific workshop	*2012-09-01*	*2012-01-01*	*Jacques Morel/Andra*			*Cancelled - limited interest.*

Theme-specific workshop	*2013-06-01*	*2012-10-01*	*Hanspeter Weber/Nagra*	*1426218*	*1465957*	*Jan Smutec*
Theme-specific workshop	*2013-06-01*	*2012-10-01*	*Hanspeter Weber/Nagra*	*1426220*	*Presentation at WS 1491718*	*Christian Hoffman*
Theme-specific workshop	*2014-04-01*	*2013-09-01*	*Magnus Kronberg/SKB*	*1436426*	*1460021*	*Paulina Nieścior-Browińska*
Theme-specific workshop	*2014-04-01*	*2013-09-01*	*Magnus Kronberg/SKB*	*1436424*	*1460021*	*Wioleta Olszewska*
Theme-specific workshop	*2013-06-01*	*2012-10-01*	*Hanspeter Weber/Nagra Keijo Haapala*	*1491922*	*1477733*	*Heini Laine.*
Theme-specific workshop	*2014-04-01*	*2013-09-01*	*Magnus Kronberg/SKB*	*1466425*	*1460026*	*Darius Justinavicius*
Theme-specific workshop	*2014-04-01*	*2013-09-01*	*Magnus Kronberg/SKB*	*1452361*	*1436423*	*Orlando Silva (Amorf21)*
Theme-specific workshop	*2014-04-01*	*2013-09-01*	*Magnus Kronberg/SKB*	*1452368*	*1465972*	*Dean Gentles (NDA)*
End-term workshop	*2015-06-02*	*2014-10-01*	*Project Coordinator*	*1488085*	*1491769*	*Jan Smutek*
End-term workshop	*2015-06-02*	*2014-10-01*	*Project Coordinator*	*1488075*	*kommer innan 23/9 2015*	*Jutta Peura*
End-term workshop	*2015-06-02*	*2014-10-01*	*Project Coordinator*	*1488074*	*kommer innan 23/9 2016*	*Ville Sjöblom*
End-term workshop	*2015-06-02*	*2014-10-01*	*Project Coordinator*	*1488078*	*Poster 1488069 Presentation 1487450*	*Kevin O´Donoghue*
End-term workshop	*2015-06-02*	*2014-10-01*	*Project Coordinator*	*1488079*	*Poster 1488069 Presentation 1487450*	*Rob McLaverty*
End-term workshop	*2015-06-02*	*2014-10-01*	*Project Coordinator*	*1488080*	*Participation in panel at conference*	*Marius Iordache*
End-term workshop	*2015-06-02*	*2014-10-01*	*Project Coordinator*	*1488082*	*Participation in panel at conference*	*Kalman Benedek*

End-term workshop	*2015-06-02*	*2014-10-01*	*Project Coordinator*	*1488086*	*Poster 1488090*	*Thorsten Hörbrand*