Technical Report
TR-18-10
February 2019

Äspö Hard Rock Laboratory Annual Report 2017

SVENSK KÄRNBRÄNSLEHANTERING AB

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ISSN 1404-0344
SKB TR-18-10
ID 1703308
February 2019

Äspö Hard Rock Laboratory

Annual Report 2017

Svensk Kärnbränslehantering AB

Abstract

The Äspö Hard Rock Laboratory (HRL) is an important part of SKB's work with the design and construction of a deep geological repository for the final disposal of spent nuclear fuel. Äspö HRL is located in the Simpevarp area in the municipality of Oskarshamn. One of the fundamental reasons behind SKB's decision to construct an underground laboratory was to create opportunities for research, development and demonstration in a realistic and undisturbed rock environment down to repository depth. The underground part of the laboratory consists of a main access tunnel from the Simpevarp peninsula to the southern part of Äspö where the tunnel continues in a spiral down to a depth of 460 m. Äspö HRL has been in operation since 1995 and considerable international interest has been shown in its research, as well as in the development and demonstration tasks. A summary of the work performed at Äspö HRL during 2017 is given below.

Äspö Site Descriptive Model

Geoscientific research is a basic activity at Äspö HRL. The aim of the current studies is to develop geoscientific models of the Äspö HRL and increase the understanding of the rock mass properties as well as knowledge of applicable methods of measurement. Studies are performed in both laboratory and field experiments, as well as by modelling work. The activities aim to provide basic geoscientific data to the experiments and to ensure high quality of experiments and measurements related to geosciences.

The objective for producing *Äspö Site Descriptive Model* is to describe the geological, hydrogeological and groundwater chemical conditions of Äspö HRL including updated geometrical and numerical models for each geoscientific discipline. Data from the underground excavations as well as from the ground surface will be compiled systematically for these three disciplines.

The hydro monitoring programme constitutes a cornerstone for the hydrogeological research and a support to the experiments undertaken in the Äspö HRL. The monitoring system relies on about 1 500 measuring points of various hydrogeological variables.

The hydrochemistry monitoring programme is designed as monthly to biannual sampling campaigns depending on the type of aqueous environment. Surface waters are collected from permanent meteorological stations, and temporary stream, lake and sea stations. During the year 2017, sampling and analyses of surface waters have been performed at different time intervals: once a month to six times a year for stream waters and four times a year for sea water.

Research projects and development of engineered barriers

At Äspö HRL, an important goal is to demonstrate technology for and the function of important parts of the repository system. This implies translation of current scientific knowledge and state-of-the-art technology into engineering practice applicable in an operational repository. It is important that development, testing and demonstration of methods and procedures are conducted under realistic conditions and at an appropriate scale. A number of large-scale field experiments and supporting activities are therefore carried out at Äspö HRL. The experiments focus on different aspects of engineering technology and performance testing.

In addition to studying the engineered barriers, experiments are also related to the rock, its properties and in situ environmental conditions. The aim is to provide information about the long-term function of natural and repository barriers. Experiments are performed to develop and test methods and models for the description of groundwater flow, radionuclide migration, and chemical conditions at repository depth.

The project *Tunnel Production* is a technology development project with aim to establish methods and concepts for excavation of deposition tunnels in the planned Final Repository for Spent Nuclear Fuel. This includes rock excavation methods, grouting and concepts for rock reinforcement. The work at Äspö has for this project primarily focused on verifying alternative tunnel production techniques. During 2017, the project has also been studying mechanical excavation with a Tunnel Boring System (TBS).

The project *System Design of Dome Plug for Deposition Tunnels* aims to ensure that the reference design of the KBS-3V deposition tunnel end plug works as intended. By testing the design in a full-scale demonstration it is to be proven that the method for plugging of a deposition tunnel is feasible and controllable. In 2012, the experiment tunnel (TAS01) was excavated and the accurate plug location was determined. The installation of the inner parts of the plug began in late 2012 and was completed in the beginning of 2013. On March 13th 2013, the casting of the concrete dome took place. During 2017, the experiment was excavated and analysed.

Several projects are ongoing with focus on *System design of buffer and backfill*. During 2017 handling of remaning issues concerning buffer and backfill design have been planned and a new project initiated. No practical work has been performed underground.

The overall goal of the project *Developing, testing and application of improved models for bentonite expansion and erosion (POSKBAR)* is to produce a model, or expression, that can be used to quantify the mass loss of bentonite from the buffer and also the backfill due to colloid formation/gel destabilization in a situation with dilute groundwater in the repository. The model will be used in the future assessments for the long term performance of the KBS-3 repository.

For the Spent Fuel Repository in Forsmark, SKB plans to drill about 6 000 deposition holes with a capacity of up to 200 holes per year. The purpose of the *Pre study on drilling of deposition holes* is to find suitable method for producing deposition holes and to provide recommendations on how SKB should proceed in the work of testing and/or acquisition of such drilling equipment.

Detailed studies are necessary to characterize and document the Forsmark bedrock before the production of the Spent Fuel Repository so that it is constructed in accordance with conditions in the bedrock. The project *Investigation methods for ramp and shaft* will develop documentation for methods that will guide and quality assure the performance of investigations in the Spent Fuel Repository.

Work on concrete barrier. In order to verify that the suggested design solutions for a planned extension of the Final Repository for Short-Lived Radioactive Waste (SFR) can be utilized and to show that the long term safety of the repository is likely to be ensured over the entire post-closure period an R&D programme has been initiated. In order to demonstrate that SKB is able to construct the concrete caissons in accordance with requirements under current prerequisites a development program comprising a number of different development and verification steps has been initiated. This development program includes the steps from material development through casting of a representative section of a concrete caisson in the Äspö Laboratory and monitoring of its properties.

A large number of investigation boreholes have been drilled in both the area for the planned Spent Fuel Repository in Forsmark and for the Final Repository for Short-Lived Radioactive Waste (SFR). A new technology development project on *Sealing of boreholes* was therefore initiated in 2015 with the goal to optimize the sealing of SKB's investigation boreholes in Forsmark.

Bentonite material studies. SKB has developed methods and techniques for acquisition and quality control of bentonite for a long time. The long term safety requirements on the bentonite are quantified into a number of parameters; swelling pressure, hydraulic conductivity, shear strength, thermal conductivity and limitations in sulphide, total sulphur and carbon (harmful substances).

The Prototype Repository is a demonstration of the integrated function of the repository and provides a full-scale reference for tests of predictive models concerning individual components as well as the complete repository system. The layout involves altogether six deposition holes, four in an inner section and two in an outer. The relative humidity, pore pressure, total pressure and temperature in different parts of the test area are monitored. The outer test section was retrieved during 2011 after approximately eight years of water uptake of the buffer and backfill. The monitoring of the inner section will be continued at least until 2020.

In the project *Concrete and Clay* the aim of the project is to increase our understanding of the processes related to degradation of low and intermediate level waste in a concrete matrix, the degradation of the concrete itself through reactions with the groundwater and the interactions between the concrete/groundwater and adjacent materials such as bentonite and the surrounding host rock. During the time period 2010–2014 a total of 9 packages comprising concrete cylinders or bentonite blocks each containing different types of waste form materials were deposited at different locations in the Äspö HRL.

The four concrete specimens were prepared and deposited during 2010 and 2011. During 2014 the bentonite specimens comprising 150 bentonite blocks in 5 different packages were installed in TAS06. During 2017 experiment #20 was overcored and retrieved.

The *Alternative Buffer Materials (ABM)* project was started in 2006 with the purpose to evaluate different bentonites as possible buffer candidates. The ABM project consists of a combination of field experiments at the Äspö HRL and laboratory studies of the bentonites performed at a variety of laboratories, including both SKB and external partners.

SKB and Posiva are co-operating on a programme for the *KBS-3 Method with Horizontal Emplacement (KBS-3H)*. A continuation phase of the concept development is ongoing and the aim of this phase is to reach a level of understanding so that comparison of KBS-3H and KBS-3V (reference concept for both SKB and Posiva), and preparation of a PSAR, becomes possible. The most recent project phase was 2011–2017. It covers all areas of the KBS-3 method but the focus is on the KBS-3H specific issues.

The aim of the *Large Scale Gas Injection Test (Lasgit)* is to perform gas injection tests in a full-scale KBS-3 deposition hole. The installation phase, including the deposition of canister and buffer, was finalised in 2005. Water is artificially supplied and the evolution of the saturation of the buffer is continuously monitored. The preliminary hydraulic and gas injection tests were completed in 2008. During 2017 the test programme of Lasgit continued a phase of prolonged "hibernation" with moniotoring of the natural and artificial hydration of the bentonite buffer.

The objective of the project *In situ Corrosion Testing of Miniature Canisters* is to obtain a better understanding of the corrosion processes inside a failed canister. In Äspö HRL in situ experiments are performed with defect miniature canisters (defect copper shell with cast iron insert). The canisters are exposed to both natural groundwater and groundwater which has been conditioned by bentonite. Five canisters were installed in boreholes in the end of 2006/beginning of 2007. The first canister was retrieved and analysed in 2011. Two additional canisters were retrieved and analysed during 2015.

The Long Term Test of Buffer Material (LOT) project aims at studying possible alteration of the bentonite as a result of the hydro-thermal evolution, both with respect to mineralogy and to sealing properties. The LOT test series includes seven test parcels, which all contain a heater, central tube, clay buffer, instruments and parameter controlling equipment.

Mechanical and system engineering

At Äspö HRL and the Canister Laboratory in Oskarshamn, methods and technologies for the final disposal of spent nuclear fuel are being developed. Established as well as new technology will be used in the Spent Fuel Repository in Forsmark. The approximately 200 technical systems, machines and vehicles that are needed in the final repository have been identified and listed in a database called FUMIS. Extensive work has been put into assessing the degree of development and prototyping needed, costs, schedule, deadlines etc. Several activities have been ongoing through 2017, including development of equipment for milling of buffer blocks and development of equipment for backfill pellet installation.

Äspö facility

The Äspö facility comprises both the Äspö Hard Rock Laboratory and the Research Village with laboratories. The main goal for the operation of the Äspö facility is to provide a facility which is safe for everybody working in, or visiting it, and for the environment. This includes preventative and remedial maintenance in order to ensure that all systems such as drainage, electrical power, ventilation, alarm and communications are available in the underground laboratory at all times.

In *the Multi-purpose test facilities* different methods and techniques for installation of pellets and blocks in deposition tunnels are tested, and work on buffer and backfill is performed. Activities during 2017 include materials testing.

As a part of the needed infrastructure, a *Material science laboratory* has been constructed at Äspö, with focus on material chemistry of bentonite issues and competence development. The key focus areas are long term safety related research and development of methods for quality control of the bentonite buffer and backfill materials. During 2017, much focus has been on the *Material Science project*.

The operation of the facility during 2017 has been functioning very well, with a very high degree of availability.

The main goal for the unit *Communication Oskarshamn* is to create public acceptance for SKB, which is done in co-operation with other departments at SKB. During 2017, 4 522 people visited the Äspö HRL. The unit also arranged a number of events and lectures.

Future use of Äspö HRL

SKB is conducting work with the intent to seek alternative possibilities for adaptation of the Äspö Hard Rock Laboratory into a high level national research- and innovation infrastructure. The work is being spurred both by an active external interest in the future use of Äspö HRL and by a strategic vested interest. During 2017 work has been carried out within several development activities.

SKB International

SKB International offers technology, methodology and expert resources to international clients. SKB International has access to all expertise, experience and technologies that SKB has acquired and developed in its programme, and provides services to organisations and companies in spent nuclear fuel and nuclear waste management and disposal and hence provides the opportunity to save time and cost and minimise risk. For the Äspö International partners SKB International arranged different events during 2017, among them two *topical workshops* were organised.

Sammanfattning

Äspölaboratoriet i Simpevarp i Oskarshamns kommun är en viktig del i SKB:s arbete med utformning, byggande (och drift) av ett Kärnbränsleförvar. Ett av de grundläggande skälen till SKB:s beslut att anlägga ett underjordslaboratorium var att skapa förutsättningar för forskning, utveckling och demonstration i en realistisk och ostörd bergmiljö på förvarsdjup. Underjordslaboratoriet utgörs av en tunnel från Simpevarpshalvön till södra delen av Äspö där tunneln fortsätter i en spiral ner till 460 meters djup. Äspölaboratoriet har varit i drift sedan 1995 och verksamheten har väckt stort internationellt intresse. Här följer en sammanfattning av det arbete som bedrivits vid Äspölaboratoriet under 2017.

Äspö Site Descriptive Model

Forskning inom geovetenskap är en grundläggande del av arbetet vid Äspölaboratoriet. Det huvudsakliga målet med de pågående studierna är att utveckla geovetenskapliga modeller samt att öka förståelsen för bergmassans egenskaper och kunskapen om användbara mätmetoder. Studier genomförs i både laboratorier och fältexperiment, samt modelleringsarbete. Aktiviteterna levererar geovetenskaplig data till experiment och säkerställer hög kvalitet på experiment och mätningar inom geovetenskap.

Syftet med att producera *Äspö Site Descriptive Model* är att beskriva Äspö HRL:s geologiska, hydrogeologiska och grundvattenkemiska förhållanden, inklusive uppdaterade genometriska och numeriska modeller för de olika geovetenskapliga diciplinerna.

Programmet för hydromonitering utgör en grundsten i Äspö HRL:s hydrogeologiska undersökningar, och stödjer olika experiment som genomförs. Moniteringssystemet baseras på cirka 1 500 mätpunkter för olika hydrogeologiska variabler.

Programmet för hydrokemisk monitering utför provtagningar i intervall från månadsvis till två gånger per år, beroende på typ av vattenmiljö. Ytvatten samlas in från permanenta mätstationer, samt temporära provpunkter i strömmar, sjöar och hav.

Forskningsprojekt och barriärutveckling

Verksamheten vid Äspölaboratoriet har som mål att demonstrera KBS-3-systemets funktion. Detta innebär att vetenskapliga och teknologiska kunskaper används praktiskt i arbetet med att utveckla, testa och demonstrera de metoder och tillvägagångssätt som kan komma att användas vid uppförandet av ett Kärnbränsleförvar. Det är viktigt att möjlighet ges att testa och demonstrera hur KBS-3-systemet kommer att utvecklas under realistiska förhållanden. Ett flertal projekt i full skala, liksom stödjande aktiviteter, pågår vid Äspölaboratoriet. Experimenten fokuserar på olika aspekter av ingenjörsteknik och funktionstester.

Experimenten kopplar även till berget, dess egenskaper och in situ förhållanden. Målet med de pågående experimenten är att ge information om hur de naturliga och tekniska barriärerna fungerar i ett långtidsperspektiv. Experiment genomförs för att utveckla och testa metoder och modeller för grundvattenflöde, radionuklid-transport och kemiska förhållanden på förvarsdjup.

Projektet *Tunnelproduktion* är ett teknikutvecklingsprojekt med syfte att etablera metoder och koncept för tunnelproduktion för deponeringstunlar i det planerade Kärnbränsleförvaret i Forsmark. Detta inkluderar metoder för berguttag, injektering och koncept för bergförstärkning. Arbetet på Äspö har främst fokuserat på verifiering av alternativa metoder för tunnelproduktion. Under 2017 har projektet även studerat mekanisk brytning med Tunnel Boring System (TBS).

Projektet *Systemkonstruktion av Valvplugg för Deponeringstunnlar* syftar till att säkerställa att referensutformningen av KBS-3V deponeringstunnel och plugg fungerar som tänkt. Genom att testa designen i fullskala ska det visas att metoden för pluggning av en deponeringstunnel är genomförbar och kontrollerbar. Under 2012 producerades tunnelplats för test och lämpligt plugg-läge fastställdes. Installationen av pluggens inre delar påbörjades i slutet av 2012 och stod färdig i början av 2013. Gjutningen av betongkupolen genomfördes den 13 mars 2013. Under 2017 har experimentet nedmonterats och analyser har genomförts.

Flera projekt pågår med fokus på *Systemkonstruktion av buffert och återfyllnad*. Under 2017 har arbetet genomförts kring kvarvarande frågor för design av buffert och återfyllnad, och ett nytt projekt har initierat. Inget praktiskt arbete har utförts i undermarksanläggningen.

Det övergripande målet med projektet *Utveckling, test och applicering av förbättrade modeller för bentonitexpansion och -erosion (POSKBAR)* är att producera en modell som kan användas för att kvantifiera förlusten i massa av bentonit från buffert och återfyllnad på grund av kolloidformation/gel-destabilisation på grund av vatteninflöde i Kärnbränsleförvaret. Modellen kommer användas i framtida bedömningar av långtidsfunktioner i Kärnbränsleförvaret.

Till det kommande Kärnbränsleförvaret i Forsmark planerar SKB att borra cirka 6 000 deponeringshål, med en kapacitet av upp till 200 hål per dag. Syftet med Förstudie borrning av deponeringshål är att hitta lämpliga metoder för att producera deponeringshål och att leverera rekommendationer för hur SKB bör fortsätta arbetet med test och inköp av borrutrustning.

Detaljerade undersökningar krävs för att karakterisera och dokumentera berggrunden i Forsmark inför den planerade konstruktionen av Kärnbränsleförvaret så att det konstrueras i enlighet med förutsättningarna i berggrunden. Projektet *Undersökningsmetoder för ramp och schakt* tar fram dokumentation av metoder som kommer guida och kvalitetssäkra genomförandet av undersökningar i Kärnbränsleförvaret.

Betongbarriärer. För att verifiera designen inför den planerade utbyggnaden av Slutförvaret för kortlivat radioaktivt avfall, SFR, har ett forskningsprogram initierats. Detta inkluderar steg från materialutveckling till gjutning av en testsektion av en betongkassun i Äspölaboratoriet.

Ett stort antal undersökningsborrhål har borrats både i områdena för det planerade Kärnbränsleförvaret och Slutförvaret för kortlivat radioaktivt avfall (SFR). Ett nytt teknikutvecklingsprojekt kring *Förslutning av borrhål* initierades 2015 med målet att optimera förslutningen av SKB:s undersökningsborrhål i Forsmark.

Materialstudier av bentonit. SKB har utvecklat metoder och tekniker för inköp och kvalitetskontroll av bentonit under en lång tid. Kraven på långsiktig säkerhet för bentoniten har kvantifierats till ett antal uppmätta parametrar.

I *Prototypförvaret* pågår en demonstration av den integrerade funktionen hos förvarets barriärer. Prototypförvaret utgör dessutom en fullskalig referens för prediktiv modellering av Kärnbränsleförvaret och barriärernas utveckling. Prototypförvaret omfattar totalt sex deponeringshål, fyra i en inre tunnelsektion och två i en yttre. Mätningar av relativ fuktighet, portryck, totalt tryck och temperatur i olika delar av testområdet genomförs kontinuerligt. Den yttre sektionen bröts och kapslarna återtogs under 2011. Moniteringen av den inre sektionen kommer fortsätta till minst år 2020.

I *"Betong- och lerprojektet"* är syftet att öka förståelsen för processer i samband med nedbrytning av låg- och medelaktivt avfall i en betongmatris, nedbrytning av betongen självt genom reaktioner med grundvattnet och växelverkan mellan betong, mark och angränsande material som bentonit och den omgivande berggrunden. Fyra betong prover installerades under 2010 och 2011. Under 2014 installerades fem bentonitprover bestående av 150 bentonitblock fördelade i 5 paket. Under 2017 togs experiment #20 upp efter att ha överborrats.

Försöket *Alternativa buffertmaterial (ABM)* startades 2006 med syftet att utvärdera olika bentonitmaterial som möjliga kandidater till bufferten. ABM-projektet består av en kombination av fältexperiment och laboratorieförsök på ett flertal laboratorier både hos SKB och externa parter.

Ett forskningsprogram för ett *KBS-3-förvar med horisontell deponering (KBS-3H)* genomförs som ett samarbetsprojekt mellan SKB och Posiva. Nu pågår en fortsättningsfas av projektet med målsättningen att utveckla KBS-3H till en sådan nivå att en jämförelse mellan 3V/3H och förberedelser inför en PSAR är möjlig. Den senaste projektfasen pågick under 2011–2017. Fasen täcker samtliga delar av KBS-3-metoden men fokuserar på KBS-3H specifika frågor.

Syftet med ett *Gasinjekteringsförsök i stor skala (Lasgit)* är att studera gastransport i ett fullstort deponeringshål (KBS-3). Installationsfasen med deponering av kapsel och buffert avslutades under 2005. Vatten tillförs bufferten på artificiell väg och utvecklingen av vattenmättnadsgraden i bufferten mäts kontinuerligt. Under 2008 avslutades de preliminära hydrauliska testerna och gasinjekteringstesterna. Under 2017 fortsatte en förlängd fas av vila, med monitering av den naturliga och artificiella bevätningen av bentonitbufferten.

Målet med projektet *In situ testning av korrosion av miniatyrkapslar* är att få en bättre förståelse av korrosionsprocesserna inuti en trasig kapsel. Vid Äspölaboratoriet genomförs in situ experiment med defekta miniatyrkapslar (genomborrat kopparhölje med gjutjärnsinsats) som utsätts för både naturligt grundvatten och grundvatten som filtrerats av bentonit. Fem kapslar installerades i borrhål runt årsskiftet 2006/2007 och sedan dess har flera rapporter publicerats som beskriver själva installationen och kemiska, elektrokemiska och mikrobiologiska mätresultat som erhållits. Under 2011 återtogs en av experimentkapslarna, kapsel tre. Ytterligare två kapslar återtogs 2015.

Projektet *Långtidstest av buffertmaterial (LOT)* syftar till att studera möjliga förändringar i bentoniten som ett resultat av hydro-termisk evolution, både sett till mineralogi och tätningsegenskaper. LOT-försöket inkluderar sju uppvärmda testpaket.

Maskin- och systemteknik

Vid Äspölaboratoriet och Kapsellaboratoriet i Oskarshamn utvecklas teknik och metoder för Kärnbränsleförvaret. Befintlig liksom nyutvecklad teknik kommer att användas. De omkring 200 tekniska system, maskiner och fordon som behövs har identifierats och har dokumenterats i en databas, FUMIS. Ett omfattande arbete har gjorts för att bedöma grad av nyutveckling, behov av prototypframtagning, kostnad, tidplaner etc. Flera aktiviteter har pågått under 2017, däribland framtagande av teknik för att fräsa buffertblock och teknik för att installera bentonitpellets.

Äspölaboratoriet

I *Äspöanläggningen* ingår både det underjordiska berglaboratoriet och Äspö forskarby. En viktig del av verksamheten vid Äspöanläggningen är administration, drift och underhåll av instrument samt utveckling av undersökningsmetoder. Huvudmålet för driften av Äspöanläggningen är att garantera säkerheten för alla som arbetar i eller besöker anläggningen samt att driva anläggningen på ett miljömässigt korrekt sätt.

I *Testhallen* provas olika metoder och tekniker för installation av pelletar och block i deponeringstunnlar och studier av erosion av buffert och återfyllningsmaterial utförs. Aktiviteter i Testhallen under 2017 inkluderar materialtester.

Ett *Laboratorium för Materialstudier* finns på Äspö, med fokus på materialkemi för bentonitfrågor och kompetensutveckling. De största fokusområdena är metodutveckling för kvalitetskontroll av bentonit som ska användas som buffert- och återfyllnadsmaterial. Under 2017 har fokus legat på studier inom *Materialstudieprojektet*.

Driften av anläggningen under 2017 har fungerat mycket bra med en mycket hög tillgänglighet.

Det huvudsakliga målet för enheten *Kommunikation Oskarshamn* är att skapa en allmän acceptans för SKB, vilket görs i samarbete med andra avdelningar inom SKB. Under 2017 besöktes Äspölaboratoriet av 4 522 personer. Enheten arrangerade ett flertal evenemang och föreläsningar under året.

Framtida bruk av Äspö HRL

SKB bedriver ett utredningsarbete med avsikt att söka alternativa möjligheter till omställning av Äspölaboratoriet till en nationell forsknings- och innovationsinfrastruktur i världsklass. Utredningsarbetet sporras dels av ett aktivt omvärldsintresse för Äspölaboratoriets framtida användning dels av ett strategiskt egenintresse. Under 2017 har arbete utförts inom flera utvecklingsaktiviteter.

SKB International

SKB International erbjuder teknologi, metodologi och expertresurser till internationella klienter. SKB International har tillgång till all den expertis, erfarenhet och teknik som SKB har införskaffat och utvecklat i sitt forskningprogram, och tillhandahåller service till företag och organisationer inom slutförvar av använt kärnbränsle. De kan därmed bidra både till besparingar i tid och pengar, samt en möjlighet att minimera risker. SKB International arrangerade olika evenemang under 2017, däribland två stycken *topical workshops*.

Contents

1 General

The Äspö Hard Rock Laboratory (HRL) is a unique research facility that extends down to a depth of 460 metres in the Swedish bedrock. For more than 30 years, this site has been central for the development of safe methods for final disposal of spent nuclear fuel.

At Äspö HRL, the Swedish Nuclear Fuel and Waste management Co. (SKB) has built up a large part of the knowledge that is now being used in the detailed design and preparations for the construction of a Spent Fuel Repository in Forsmark, as well as experience that will be used during the construction phase and future operation of the repository.

It is fair to say that Äspö HRL has contributed to world-wide knowledge about final disposal of radioactive waste in crystalline rock and today the facility serves as a model to other countries which are planning for design and construction of deep geological repositories for radioactive waste.

The Äspö HRL is not only an underground facility. On the surface lies Äspö Research Village with laboratory areas for accredited hydrochemical analyses, research activities and advanced bentonite clay investigations. Furthermore, there is a large testing hall, including an overhead crane, which is used as a multi-purpose workshop for various technical developments.

Well worth noting, SKB is today offering Äspö as an open resource for both national and international customers within wide-ranging sciences.

This report summarises the main accomplishments and initiatives carried out during 2017.

1.1 Background

Äspö HRL is located in the south east coast of Sweden, on the island Äspö, 25 kilometers north of Oskarshamn.

It was in SKB's Research, Development and Demonstration (RD&D) Programme 1986 that SKB first presented the idea of a new underground research facility. One of the fundamental reasons behind SKB's decision to construct an underground laboratory was to create an opportunity for research, development and demonstration in a realistic and undisturbed rock environment at representative repository depth.

The underground part of the laboratory consists of a main access tunnel from the Simpevarp peninsula to the southern part of the Äspö island where the tunnel continues in a spiral down to a depth of 460 m, see Figure 1-1. The total length of the tunnel is 3 600 m where the main part of the tunnel has been excavated by conventional drill and blast technique and the last 400 m have been excavated by a tunnel boring machine (TBM) with a diameter of 5 m. The underground tunnel is connected to the ground surface through a hoist shaft and two ventilation shafts.

The work with Äspö HRL has been divided into three phases: Pre-Investigation phase, Construction phase and Operational phase.

During the Pre-Investigation phase, 1986–1990, extensive field studies were made to provide a basis for the decision to locate the laboratory to a suitable site. The natural conditions of the bedrock were described and predictions made of geological, hydrogeological, geotechnical and rock-mechanical conditions to be observed during excavation of the laboratory. This phase also included planning for the construction and operational phases.

During the Construction phase, 1990–1995, comprehensive investigations and experiments were performed in parallel with construction of the laboratory. The excavation of the main access tunnel and the construction of the Äspö Research Village were completed. The construction gave important technological experience and invaluable knowledge about the design and construction of underground facilities. For example both blasting and full-face drilling were used to excavate the tunnels which made it possible to study how the rock around a tunnel is affected by the different excavation methods and what impact there could be on the flow patterns of groundwater.

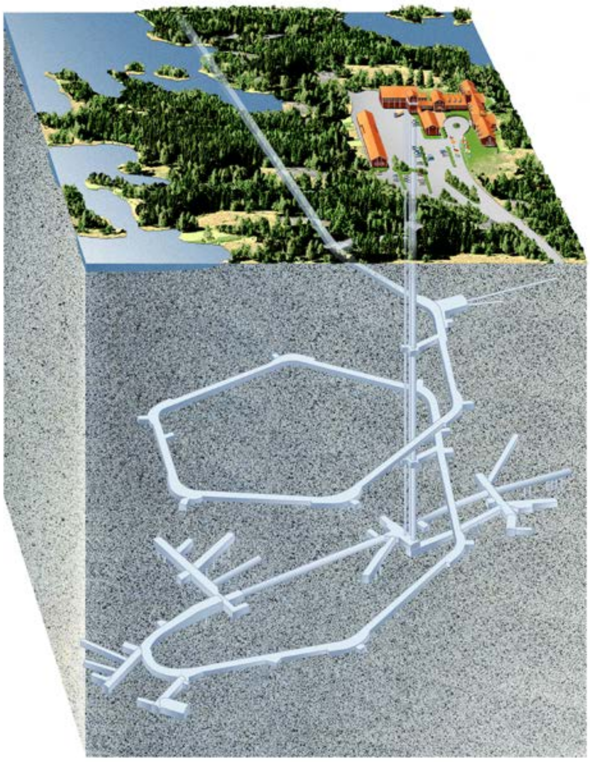

Figure 1-1. *Overview of the Äspö HRL facilities.*

The Operational phase began in 1995. A preliminary outline of the programme for this phase was given in SKB's RD&D Programme 1992. Since then the programme has been revised every third year and the detailed basis for the period 2017–2022 is described in SKB's RD&D-Programme 2016 (SKB 2016).

After the start of operation in 1995, experiments began gradually to investigate how the barriers and the other components of the Spent Fuel Repository (canister, buffer, backfill and closure) could be designed and managed in order to provide optimal functionality. A great number of experiments have been conducted to probe the features of the rock and not least what significance such features could have for the long-term safety of a geological repository for spent nuclear fuel. This can, for instance, concern how the rock retards the movement of radioactive substances or how microbes affect conditions at repository depth. The results and knowledge from these efforts have served as a basis for defining the rock's safety-related function in relation to the engineered barriers.

Äspö HRL has also been important for development and demonstration of methods for operating the future Spent Fuel Repository. Tests have been carried out on almost all of the KBS-3 method's subsystems in a realistic setting, a number of them in full scale. The results from several of these experiments comprised important material to support SKB's application for the KBS-3 system that was submitted to the Swedish authorities in 2011.

SKB's technical development is now focused on improved rock excavation technologies and design, manuacturing and installation of the engineered barriers, including several steps of quality controls. Tests are also performed to investigate, in detail, the initial performances of the engineered barriers subsequent to installation. All practical means of constructing a repository and emplacing the canisters with spent fuel are dealt with at the laboratory. This work also includes the development and testing of methods for use in the characterisation of a suitable repository site as well as the operative investigation methods to be used during construction of the underground openings.

Furthermore, Äspö HRL will be used by SKB to prepare the extension of the Final Repository for Short-Lived Radioactive Waste, the SFR at Forsmark. Specifically, the construction and control methods of casting concrete barrier caissions will be demonstrated in large scale under realistic conditions.

1.2 Goals

To meet the overall time schedule for SKB's RD&D work, the following stage goals were initially defined for the work at the Äspö HRL:

1. *Verify pre-investigation methods* – Demonstrate that investigations on the ground surface and in boreholes provide sufficient data on essential safety-related properties of the rock at repository level.
2. *Finalise detailed investigation methodology* – Refine and verify the methods and the technology needed for characterisation of the rock in the detailed site investigations.
3. *Test models for description of the barrier functions at natural conditions* – Further develop and at repository depth test methods and models for description of groundwater flow, radionuclide migration and chemical conditions during operation of a repository as well as after closure.
4. *Demonstrate technology for and function of important parts of the repository system* – In full scale tests, investigate and demonstrate the different components of importance for the long-term safety of a Spent Fuel Repository and show that high quality can be achieved in design, construction and operation of repository components.

Goal number 1 was reached at an early stage and was preparatory to the site investigations which have been implemented successfully in Oskarshamn and Forsmark.

Goal number 2 is not yet fully reached. The lessons learned from the detailed investigations during the construction phase, and the expansion of new galleries, are now used as a basis when planning for the coming detailed investigations in the Spent Fuel Repository in Forsmark. Technology development is still ongoing for certain issues.

Goal number 3 has been reached completely.

SKB's tasks related to goal number 4 will continue at Äspö HRL until 2024.

SKB has recently made a clear statement to open the facilities for a broader range of activities in the future and thus invite new stakeholders to Äspö HRL. Accordingly, a new goal has been set for Äspö, namely that the underground laboratory can continue in a new constellation after SKB has completed most of its operations in 2024.

1.3 Organization

The research, technical development and safety assessment work is organised into the Technology department, in order to facilitate co-ordination between the different activities. The Technology department comprises six units; the Technology Staff Support, Project Office, Repository Technology, Encapsulation/Canister Laboratory, Technical design, Research and Safety Assessment, and Requirements management and safety.

The unit *Repository Technology* is the residence of Äspö HRL and includes employees in Äspö, Stockholm and Forsmark. The main responsibilities of the unit are to:

- Develop, demonstrate and streamline repository technology for nuclear waste, including installation methods, transport- and handling techniques.
- Develop, manage and operate Äspö HRL as an attractive resource for experiments, demonstration tests and visitor activities.
- Actively work for a broadened use of Äspö HRL, with the aim to hand the facility over to future research- and development parties in 2024.

The *Repository Technology (TD)* unit is organised in the following groups:

- *Technology Development (TDT)*, providing competence for the technology development required for production and installation of concrete- and bentonite barriers; plugs, backfill, buffer and closure including the equipment, machines and vehicles needed in the repository facility. Project managing competence is also included in the group.

- *Facility operation (TDD)*, responsible for the operation and maintenance of the Äspö HRL offices, workshops and underground facilities and for development, operation and maintenance of supervision systems. Also responsible for the practical coordination of projects undertaken at the Äspö HRL, providing services (design, installations, measurements, field equipment, monitoring systems etc) and workers safety to the experiments.
- *Business support (TDV)*, responsible for planning, reporting, QA and all project administration. General administration and the staffing of the Äspö reception and the SKB switchboard are also included in the function.
- *Chemistry Laboratory and Geoscience (TDL)*, responsible for water sampling and accredited chemical water analysis and bentonite material analysis. Furthermore, geoscience support is provided and the Äspö Site Descriptive Model is managed with the purpose of having a good geoscience basis and tool for planning and deployment of underground experiments.

Each major research and development task, ordered by SKB and carried out in Äspö HRL, is organised as a project led by a Project Manager reporting to the client organisation. Each Project Manager is assisted by an on-site coordinator with responsibility for coordination and execution of project tasks at the Äspö HRL. The professional staff at the site office provides technical and administrative service to the projects.

Much of the research in Äspö HRL is undertaken in collaboration with other experts, universities and organizations. There is extensive collaboration when it comes to sharing technological expertise and experiences with SKB's peer organizations in other countries. SKB International is responsible for the Äspö International Joint Committee (IJC), which during last year consisted of five external member organisatons; BMWi, RWM, NUMO, CRIEPI and JAEA. The commitee is responsible for the coordination of the experimental work arising from the international participation.

1.4 Allocation of experiment sites

The rock volume and the available underground excavations are allocated for the different experiments so that optimal conditions are obtained, see Figure 1-2.

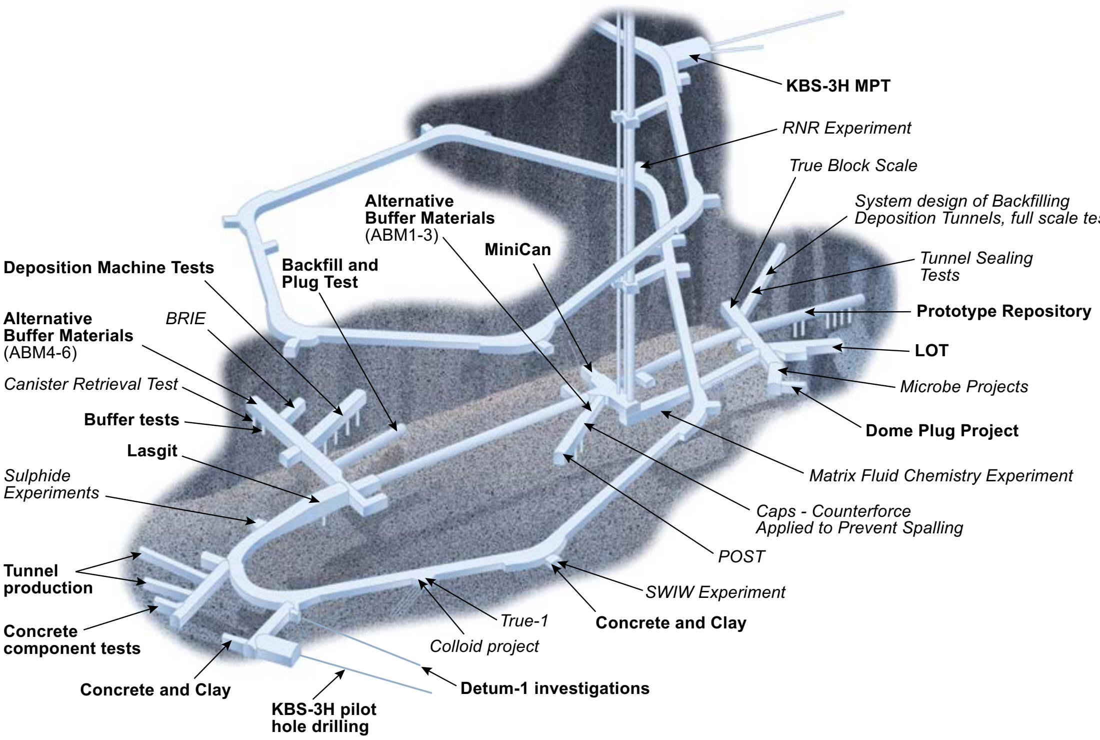

Figure 1-2. Allocation of experiment sites from –220 m to –460 m level. Ongoing experiments in bold text.

1.5 Reporting

The plans for research and technology development during 2017–2022 are described in SKB's RD&D-Programme 2016 (SKB 2016).

Detailed account of achievements to date for the Äspö HRL can be found in the Äspö HRL Annual Reports that are published in SKB's Technical Report series. This report describes the general achievements during 2017.

Detailed project information is continuously published in SKB's report series' (TR-, R- and P-reports). SKB also endorses publications of results in international scientific journals. Data collected from experiments and measurements at Äspö HRL are mainly stored in SKB's site characterisation database, Sicada.

1.6 Structure of this report

The achievements obtained at Äspö HRL during 2017 are in this report described in five chapters:

- Äspö site descriptive modelling (SDM) – Geoscience experiments, analyses and modelling to increase the knowledge of the surrounding rock.
- Research projects and development of engineered barriers – experiments, analyses and modelling to increase the knowledge of the repository barriers under natural conditions, demonstration of technology for and function of important engineered parts of the repository barrier system.
- Mechanical and system engineering – developing of technologies for the final disposal of spent nuclear fuel.
- Äspö facility – operation, maintenance, data management, monitoring, communication etc.
- SKB International.

2 Äspö site descriptive modelling (SDM)

2.1 General

The objective for producing Äspö site descriptive model is to describe the geological, hydrogeological and groundwater chemical conditions of Äspö HRL including updated geometrical and numerical models for each geoscientific discipline. Data from the underground excavations as well as from the ground surface will be compiled systematically for these three disciplines. The description and the resolution of the models have to have a detailed scale and density of data so that the increasing interest for experimental sites at Äspö HRL can be met.

The work will result:

- In a modern and updated site descriptive model and comprehensive quality checked data, updated with all available data until the end of 2016 and summarized in public report.
- In further understanding of the geological, hydrogeological and groundwater chemical conditions and processes in the rock mass at Äspö HRL.
- In testing of the developed methodology for iterative and integrated modelling.
- In further development of the modelling methodologies.

Added value of the work is to:

- Develop the geoscientific model by using the same means, methods and resolution as is intended for the facility part scale models intended to be developed during construction and operation of the planed Spent Fuel Repository in Forsmark.
- Train the staff at Äspö and Forsmark to learn and further understand modelling tools, software packages and methodology concerning conceptual and deterministic modelling methodology.

2.2 Geology

The efforts to obtain an updated version of the Äspö site descriptive model, as a multidisciplinary modelling project involving geology, hydrogeology and hydrogeochemistry, was intensified during 2017. This forthcoming model is intended as a dynamic working tool to supply the basis for the various geoscientific experiments in the laboratory. In addition, it will serve as a framework for more highly resolved modelling in parts of the facility, as well as providing input to the ongoing development of modelling methodology to be used during the construction of the Spent Fuel Repository in Forsmark.

The conceptual basis for the geological modelling was originally established by Carl-Henric Wahlgren, Geological Survey of Sweden, through an apparent analogy with the Dent fault system of north-western England (Woodcock and Rickards 2003). In this context, the Äspö-Ävrö-Simpevarp area is considered as a transfer zone, manifested as a contractional strike-slip duplex, wedging between the Äspö shear zone and a parallel zone that runs further east (ZSMNE0024A), Figure 2-1.

After extensive systematisation and evaluation of existing data from the laboratory, along with additional single-hole interpretations, draft versions of deterministic models for rock domains and deformation zones has been developed, each with property tables describing the modelling procedure and the details of individual intercepts. The model volumes cover the laboratory with its immediate surroundings and have a minimum size constraint of approximately 300 m for individual domains and zones (Figure 2-2). Currently the models contain six rock domains and 40 deformation zones. While details concerning deformation zones that originally were defined in the Laxemar SDM (SKB 2009) has been changed within the Äspö model volume, the overall position and connectivity are maintained. The draft versions of the geometrical geological models and supporting documentation will furnish for a process of interdisciplinary integration, with an aim to provide the necessary feedback for completion of the models.

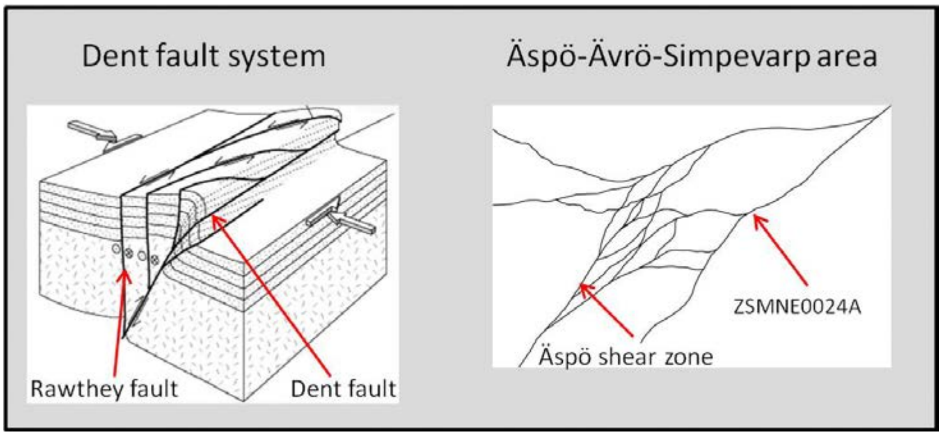

Figure 2-1. *Comparison of the Dent fault system (Woodcock and Rickards 2003) and the 2D map view of the inferred deformation zones in the Simpevarp-Ävrö-Äspö area.*

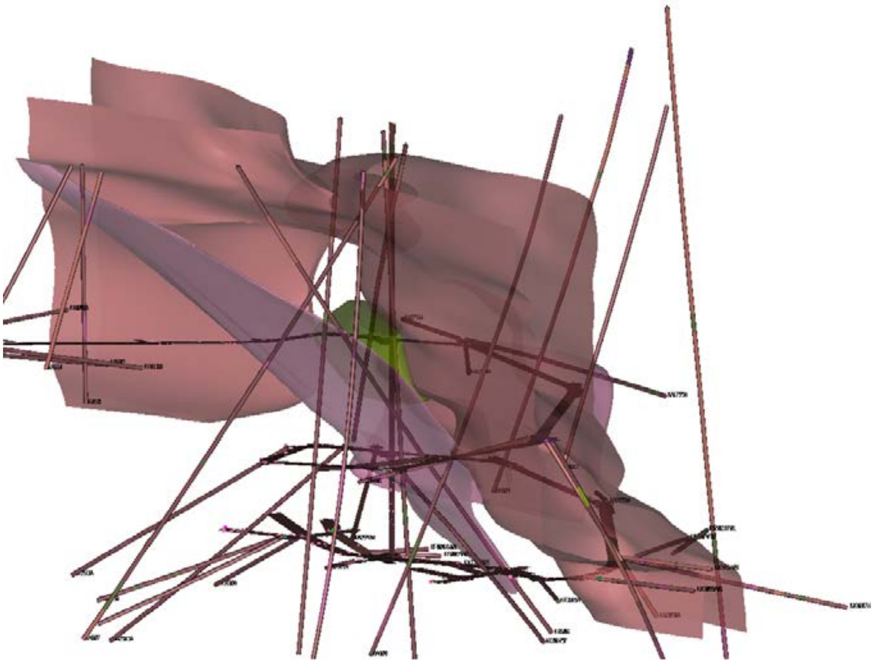

Figure 2-2. *Three-dimensional model view from south-east showing four of the inferred rock domains within the Äspö model volume relative to the borehole geology and the geometry of the laboratory.*

2.2.1 Related projects

Tunnel Production

As guidance for the forthcoming tunnelling by a so-called Mobile miner, the geological conditions and engineering characteristics have been evaluated for a distance of 300 m along the TASA tunnel. The compilation includes information on rock overburden, water inflow, as well as the design of tunnel support and sealing measures within TASA along the distance of interest.

Methods for investigations

Development of methodology for detailed geological investigations of the accesses (ramp and shafts) to the planned Spent Fuel Repository in Forsmark has been initiated and will proceed during 2018. The digital systems developed by SKB for collection of geological data from boreholes and underground openings (i.e. tunnels and shafts) are Boremap and RoCS *(Rock Characterization System)*, respectively. The Boremap-system has been continuously adapted to the needs of SKB since the introduction prior to the site investigations at Forsmark and Simpevarp and further development is judged to be rather limited. The use of the RoCS for regular tunnel mapping in the laboratory, primarily in the Äspö expansion project, has on the other hand revealed a demand for additional adaption and development before application. To provide input to this work, the RoCS is currently being tested within the framework of the laboratory, focusing on the following aspects of the system:

- Optimization of the photogrammetric process to create a digital mapping record, which includes illumination, photographic setup for underground openings with various geometry and texture, as well as change of software.
- Comparison between regular mapping performed at "arm's length" distance in a tunnel and remote mapping where only the photogrammetric compilation is used as input. The issue is the level of detailed achieved by the remote mapping.
- Harmonization to the current SKB nomenclature applied by the Boremap-system.
- Mapping methodology with special focus on fractures and the subsequent processing of these data.

So far, the testing in the laboratory has been limited to tunnel TAS04 and a few deposition holes (e.g. DO0010G01), but intent is to include additional openings, such as the TBM assembly hall.

2.3 Hydrogeology

Background

An understanding of the hydrogeological framework, i.e. geometries, processes and parameters, is often a requirement from the different experiments undertaken in the Äspö HRL tunnel. This understanding has developed over time with a first descriptive model produced 1997 and a second one in 2002.

Through the different experiments and projects undertaken in the tunnel, additional data is collected and understanding is gained for the local experimental volume. As such this local knowledge constitutes a building block for integration in the larger scale site descriptive volume. With new experiments new locals model are providing input to the gradual updating and refining of the site descriptive model.

The main features are the inclusion of data collected from various experiments and the adoption of the modelling procedures developed during the Site Investigations at Oskarshamn and Östhammar. The intention is to develop the site descriptive model (SDM) into a dynamic working tool suitable with short turn over times for predictions in support of the experiments in the laboratory as well as to test hydrogeological hypotheses in order to improve the conceptual understanding.

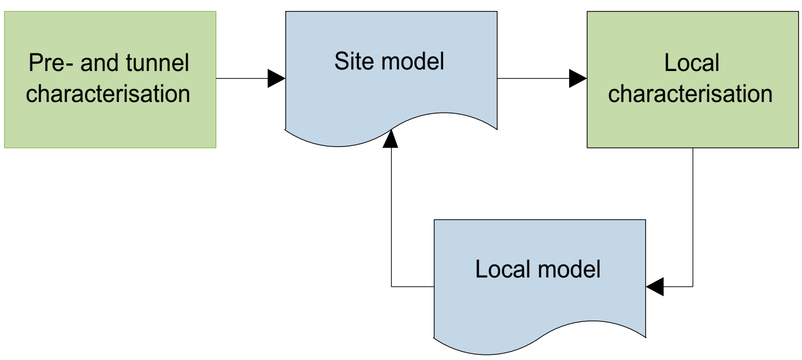

Figure 2-3. *Evolution of local- and site descriptive model.*

Objectives

The major aims of the hydrogeological activities are to:

- Maintain and develop the understanding of the hydrogeological properties of the Äspö HRL rock mass.
- Maintain and develop the knowledge of applicable measurement and analysis methods.
- Support of experiments and measurements in the hydrogeological field to ensure they are performed with required quality.
- Provide hydrogeological support to active and planned experiments at Äspö HRL.
- Provide hydrogeological expertise to SKB at large.

Experimental concept

The concept is to maintain and develop the understanding the hydrogeological properties and processes of the Äspö site as well as of the hydrogeological characterisation and analysis methodology at large. This is done by involving experts in dedicated projects and internal activities. The involvement will strengthen the competence and experience of the experts which in turn will support experiments and projects with hydrogeological expertise.

Results

Hydrogeological resources were largely provided to the following major projects and activity

i) the Modern2020 project with the aim to provide the means for developing and implementing an effective and efficient nuclear waste repository operational monitoring programme (www.modern2020.eu)

ii) the Detailed investigation methodology project for developing hydrogeological methodology and instrumentation required for the construction of the Spent Fuel Repository in Forsmark.

iii) the updating of the Äspö Site Descriptive Model

Work with the Äspö Site Descriptive Model have progressed with and completed the preparation stage which comprise the extraction and compilation of existing hydrogeological data and of compiling existing hydrogeological models. The compiled data consist of spatially distribution parameters such as transmissivity and storativity, of "natural" groundwater flow rates and of long-term monitoring variables of groundwater pressure in borehole and inflow rates and electrical conductivity of tunnel water. Basic analysis have been done on the monitoring data with identification and extraction of representative reference values of spatially distributed monitoring data being characteristic for the different stages of the evolution of the tunnel and hence its impact on the groundwater system as well as identification of major disturbances on the groundwater system, natural (e.g. rainfall event) and anthropogenic (e.g. tunnel construction). The characteristic values concern estimation of mean, max/min and 30-year trend.

Hydrogeological parameterisation of rock units and deformations zones was initiated with 41 strategically chosen boreholes where geological single hole interpretation (SHI) was performed. This parameterisation resulted in 14 of 41 boreholes having sufficient data for a parameterisation of most rock units and deformations zones for each borehole. This warranted the development of a new, approximative approach for obtaining hydraulic conductivities for the rock units and the deformation zones. This new approach entails extracting borehole drilling information from internal reports since it is not available (in most cases) from the site characterisation database which makes the exercise vary laborious and time consuming. The data extraction, K-value calculation and assignment is in progress, 85 % of the SHI-boreholes remaining to be done.

Existing models with regional cover were identified and mined for hydraulic conductivity data and to support considerations when establishing boundary conditions. The work was compiled in two short memos.

2.3.1 Hydro monitoring programme

Background

The hydro monitoring programme constitutes a cornerstone for the hydrogeological research and a support to the experiments undertaken in the Äspö HRL. Monitoring was also required by the water rights court, when granting the permission to execute the construction works for the tunnel. A staged approach of monitoring has been adopted according to Figure 2-4. Monitoring initiated as part of the pre-investigation for the site selection process. Upon completed characterisation boreholes were retained for long term monitoring in support of establishing a baseline. The monitoring system is also utilised for characterisation during construction and to develop site descriptive models.

During its operational phase the laboratory houses a number of different research experiments which are conducted simultaneously at different locations throughout the tunnelsystem. The monitoring system is critical for these several experiments for various reasons. In conjuction with the site descriptive model it provides:

- Means to select an appropriate experimental site.
- Initial and boundary conditions for the experiment.
- Direct data to experiments.
- Means to minimize hydraulic disturbances between experiments.

The monitoring of water level in surface boreholes started in 1987 and the construction of the tunnel started in October 1990. The tunnel excavation began to affect the groundwater level in many surface boreholes during the spring of 1991. A computerised Hydro Monitoring System (HMS) was introduced in 1992 and the first pressure measurements from tunnel drilled boreholes were included in the HMS in March 1992.

Objectives

The purpose with monitoring is to:

- Provide base data for tunneldrainage processes and impact on its surrounding.
- Establish and follow up a baseline of the groundwater head and groundwater flow situations.
- Provide information about the hydraulic boundary conditions for the experiments and modelling in the Äspö HRL.
- Provide data to various groundwater flow and transport modelling exercises, including the comparison of predicted head with actual head.

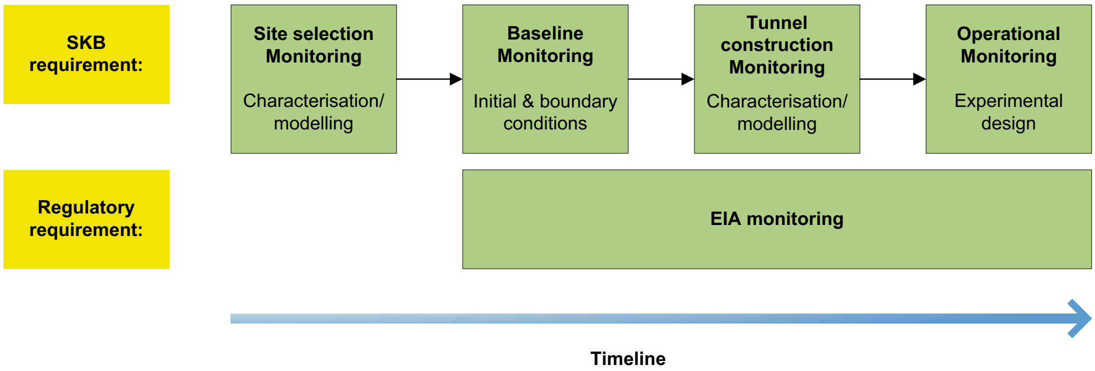

Figure 2-4. *The staged approach of monitoring at Äspö.*

Experimental concept

The monitoring system relies on a relatively large number of measuring points of various hydrogeological variables (about 1 500).

Water level and groundwater pressure constitute the bulk of the data collection where we at present record from about 400 locations mostly from the tunnel. For longterm monitoring boreholes are instrumented with up to ten pressure sections where water samples may be taken or tracers injected/circulated. The tunnel drainage is monitored through V-notch weirs at 29 locations of which water salinity is also measured at 22 stations. Hydrological monitoring of flow and salinity is performed in two streams and one meteorological station is recording wind, radiation, precipitation, pressure and humidity. Surface hydrological and soil aquifers monitoring were initiated during the site investigation in Oskarshamn. Some of these monitoring stations were later incorporated into the Äspö HRL monitoring system.

Results

The monitoring system is continuously maintained and data collected. The hydrogeological monitoring system has functioned well and the monitoring points in the tunnels have been maintained. The monitoring system has provided continuous support for the experiments and projects in their planning and execution and for the tunnel activites operations.

Quality control of data is performed at different levels and scope; weekly, semiannually and annually in internal, non-public documents.

In support of the site for the Spent Fuel Repository in Forsmark, a transfer of knowledge and know-how from Äspö Hard Rock Laboratory to Forsmark Site administration on all aspects of hydrogeological monitoring is continued. This is sustained on a structured and recurrent basis comprising technical, organisational and Q/A & Q/C issues.

2.4 Geochemistry

The Äspö area is equipped with numerous sampling spots specially selected for the characterisation of the local hydrogeological system, including three main aqueous environments denoted as:

1. The surface environment: precipitation, stream, lake and sea water (i.e. surface water).
2. The near surface environment: regolith aquifer (i.e. near surface water).
3. The deep environment: water-bearing fracture network (i.e. groundwater).

The chemical and isotopic compositions of these different waters are determined on regular basis, as part of the hydrogeochemical monitoring program. Hydrogeochemical data is also collected from deep boreholes drilled along the Äspö HRL, in the framework of specific research and development projects carried out by the Swedish nuclear fuel and waste management company and its international partners.

2.4.1 Hydrochemistry monitoring program

The monitoring program is designed as monthly to biannual sampling campaigns depending on the type of aqueous environment. Surface waters are collected from permanent meteorological stations, and temporary stream, lake and sea stations. Near surface waters are collected, through pumping, in shallow boreholes – also named soil tubes in the SKB literature – reaching the bottom of the regolith aquifer. Ground waters are collected in packed-off sections of percussion and core-drilled boreholes, either by pumping (subvertical surface boreholes) or by artificial drainage (subhorizontal tunnel boreholes). Analyses take place at Äspö chemical laboratory as well as in external laboratories.

Figure 2-5. *Ongoing sampling of ground water from packed-off sections (left figure) and analysis of anions at the Äspö chemical laboratory from collected water (right figure).*

Objectives

The hydrogeochemical monitoring program aims to provide primary data for the long-term ongoing SKB research and development program and experiments in the tunnel at Äspö. This program maintains the continuity of hydrogeochemical time series started, for some of them, since the beginning of the excavation of the Äspö Hard Rock Laboratory in 1990. These time series allow a continuous improvement of the site model, which, in turn, aims to gain knowledge and ultimately predict the influence of an underground facility and its activities on the hydrogeological system. Additionally, the monitoring program provides data for external research organisations, through Nova R&D.

Results

During the year 2017, sampling and analyses of surface waters have been performed at different time intervals: once a month to six times a year for stream waters and four times a year for sea water. In a similar way, near surface waters have been sampled and analysed six times a year. By contrast, sampling campaigns have been carried out twice for ground waters, one completed in May and the other in November, mainly from tunnel boreholes. All analytical data are quality assured and stored in SKB database to provide background information for modelling. Figure 2-6 presents various groundwater types in different borehole sections at the site.

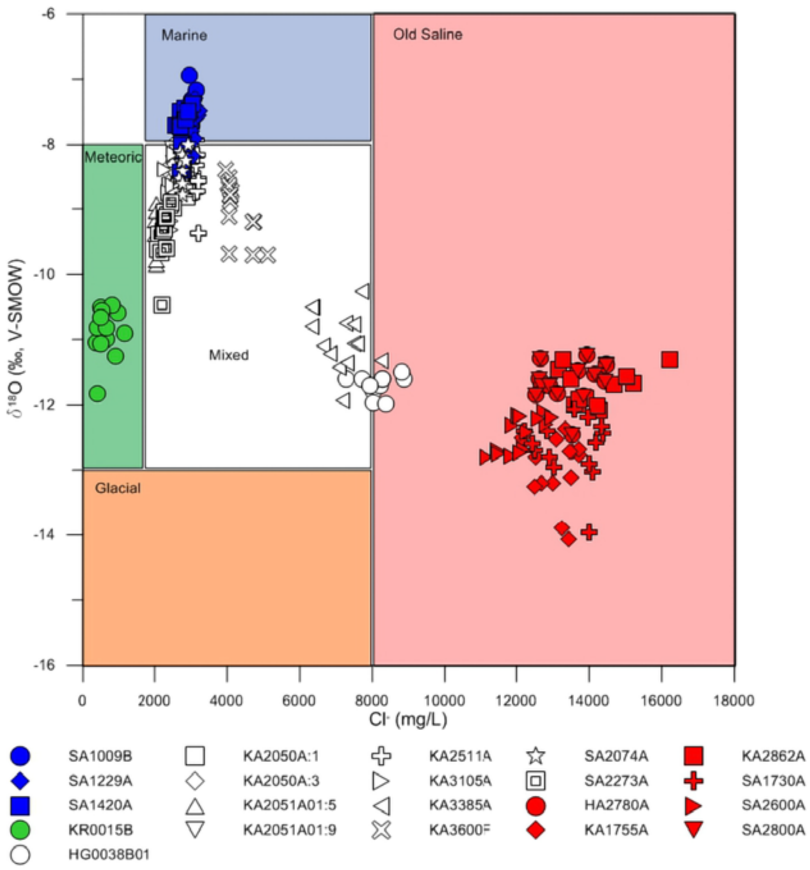

***Figure 2-6.** Scatter plot of Cl⁻ concentration versus δ18O values for groundwater collected at the Äspö HRL from different borehole sections over a several years. A classification model to identify different water types in the tunnel, except mixed water the boreholes contains marine, meteoric and old saline water type.*

3 Research projects and development of engineered barriers

3.1 General

To develop the engineered barriers of the repositories for spent fuel and radioactive waste and to demonstrate their function, work is performed at Äspö HRL. The work comprises translation of current scientific knowledge and state-of-the-art technology into engineering practices applicable in a real repository.

Furthermore, research projects are conducted in order to develop the knowledge of the repository barriers and their function in the long-term perspective.

It is important that research, development, testing and demonstration of methods and procedures, as well as testing and demonstration of repository system performance, are conducted under realistic conditions and at appropriate scale. A number of large-scale field experiments and supporting activities are therefore conducted at Äspö HRL. There are also ongoing projects at Äspö that primarily is comprised of laboratory work in the bentonite research laboratory and the chemistry laboratory.

The experiments focus on different aspects of engineering technology and performance testing and are in line with what is adressed in SKB's RD&D programme.

During 2017 the following experiments and projects concerning the engineered barriers were ongoing, either in active or in monitoring stage:

- Tunnel production.
- Dismantling of the dome plug.
- System design of buffer and backfill.
- Developing, testing and application of improved models for bentonite expansion and erosion.
- Pre-study on drilling of deposition holes.
- Investigation methods for ramp and shafts.
- Development of concrete barriers.
- Borehole sealing.
- Bentonite material studies.
- Prototype repository.
- Concrete and clay.
- Alternative buffer materials.
- KBS-3 method with horizontal emplacement.
- Large scale gas injection test.
- In situ corrosion testing of miniature canisters.
- Long term test of buffer materials.

These projects are described in the following sections.

3.2 Tunnel Production

Background

Tunnel Production is a technology development project with the aim to establish methods and concepts for excavation, grouting and rock reinforcement of deposition tunnels in the planned repository for spent nuclear fuel. The developed methods should be safe, efficient and optimized for the requirements and conditions prevailing in Forsmark.

Results

The work at Äspö has for this project primarily focused on verifying alternative tunnel production techniques as reported in the previous annual report where the verifying tests with wire sawing was presented. The results from those tests are currently being combined with other studies and tests performed into a technical report comparing different production techniques available for the production of the disposal galleries. SKB has, based on the findings presented in that report, identified a gap in regards to our knowledge and understanding of mechanical excavation. To increase our understanding of strenghts and weaknesses with the different technologies available today, SKB has started a new study focused on mechanical excavation and opened a dialogue with key suppliers with the goal to compile the information necessary to create a complete decision support document for choosing the optimal excavation technique for the production of the deposition tunnels.

The technical focus of the study is to aswer the following questions:

1. Can mechanical excavation be used cost efficiently in the very hard Forsmark rock which has a uniaxial compressive strength of 200–400 MPa and an indirect tensile strength of 10–17 MPa?
2. Are the traditional models for prediction of cutter wear and productivity applicable in our case?
3. Which existing technical solutions are available today that can complement the TBM-technology?
4. How can mechanical excavation fit into our existing processes?
5. What are the main practical advantages and disadvantages with mechanical excavation?
6. What is the resulting tunnel quality in regards to EDZ?

To answer the topics above, SKB has initiated a number of cooperations where the two most prominent activities are a study that is done in cooperation with Sandvik Mining and Construction G.m.b.H. regarding cuttability and cutter wear and secondly a project which is done in cooperation with Bergteamet, Vinnova and the universities in Luleå and Umeå regarding the productivity and main advantages and disadvantages with mechanical excavation.

Cuttability and cutter wear

SKB has to verify cuttability and cutter wear sent two large rock samples (2.15 × 1.85 × 1.25 m, L × H × W) representing the two main rock domains present at repository level in Forsmark to Sandvik Mining and Construction G.m.b.H in Austria who will carry out the analysis of practical key properties. The goal is also to give us data to efficiently be able to compare conventional disc cutting with the undercutting technology when applied to the actual geology present in Forsmark.

Figure 3-1. *Large block representative of RFM029 rock domain split into two 13 ton pieces that was later cut to size (2.15 × 1.85 × 1.25 m, L × H × W) before being sent to Sandvik.*

Figure 3-2. *Smaller block representative of the RFM045 rock domain being prepared for transport to Sandvik.*

Mechanical excavation – the TBS test

In order to increase our understanding of mechanical excavation to a point where we confidently can make a decision regarding which technology to use for the excavation of the deposition tunnels, SKB has joined a cooperation project led by Bergteamet which has as a goal to test mechanical excavation with a Tunnel Boring System (TBS).

The main purpose of the cooperation around the TBS test is to demonstrate and validate mechanical excavation. The expected main benefits with mechanical excavation are:

- Higher quality tunnel with reduced EDZ and a reduced risk of quality deviations.
- More cost efficient tunnel production.
- Higher level of occupational safety.

The project is financially supported by Vinnova and the project consortium consists of four partners with different areas of expertise:

- Bergteamet: Owner of the machine and experiences in rock excavation.
- Luleå Tekniska Högskola: Tunnel production technique and analysis of productivity.
- Umeå Universitet: Occupational safety analysis.
- SKB: facility management and design and analysis of tunnel quality.

SKB has during 2017 only prepared the test site and transported all of the components of the TBS to Äspö. Preparations have also included the preliminary design of the tunnel to be constructed which is seen in the figure below and the construction of an assembly area for the mobile miner just outside the tunnel entrance.

The work with the TBS test will continue during 2018 with the assembly, test drive and the actual tunnel production. The results of the test which are expected to answer the questions relating to how well the TBS is able to fulfil productivity claims from the existing models, what the benefits and drawbacks of using this technology are and how this technology can be applied in our production process. Studies will also be done on the quality of the resulting tunnel.

The findings from the TBS test will be combined with the laboratory tests done regarding cut-ability of the Forsmark rock and a recommendation regarding the applicability of mechanical excavation in Forsmark will be presented in a public report during 2019.

Figure 3-3. *TBS also referred to as Mobile Miner planned to be tested at Äspö during 2018.*

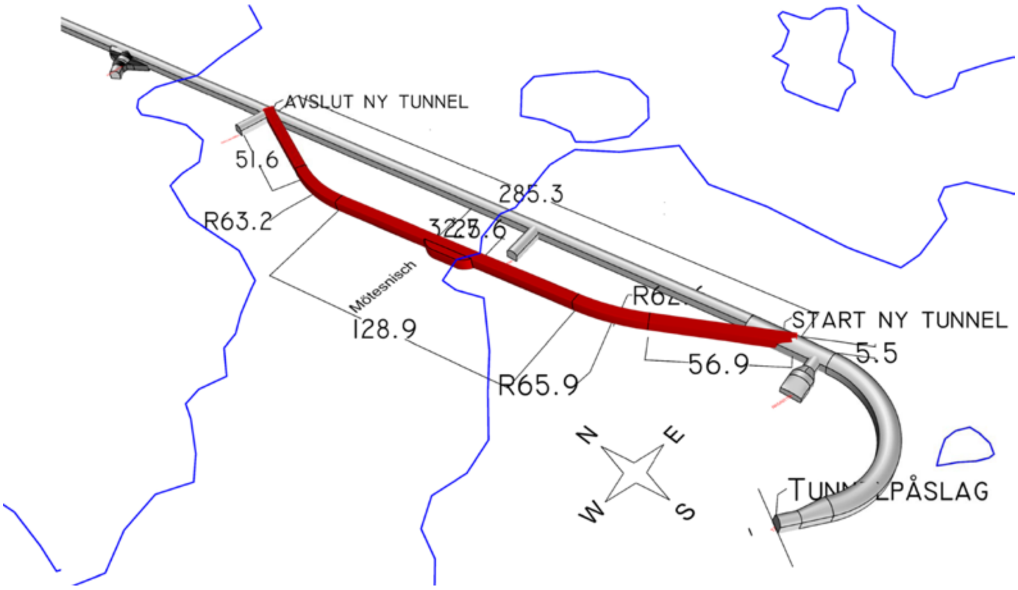

Figure 3-4. *Preliminary design of the 300 m TBS-Test tunnel.*

3.3 Dismantling of dome plug

Background

In a few years, SKB plans to start construction of the Spent Fuel Repository in Forsmark. Approximately 200 horizontal deposition tunnels, each with up to 40 vertical deposition holes for canisters, will be needed in the Swedish KBS-3 programme, and each tunnel will be sealed by an end plug. Between 2010 and 2015, SKB and Posiva (Finland) conducted system design development of the dome plug and a full-scale experiment (DOMPLU) was installed in the Äspö HRL during 2013 (Grahm et al. 2015).

The deposition tunnel end plug consists of an arched concrete dome, a bentonite seal, a filter zone and material delimiters between each layer. Furthermore, a backfill transition zone has been introduced to moderate the swelling pressure from the backfilling in the tunnel, with the purpose of attaining a predetermined load from swelling pressure on the plug. The different construction materials can be seen in Figure 3-5.

The main goal of the full-scale test DOMPLU is to determine leakage through the plug (and the contact surfaces between the rock and the concrete) at a water pressure representative to the hydrostatic groundwater pressure in the repository. Accordingly, water has been injected inside the plugged volume since 2014 at a pressure of 4 MPa and more than 100 sensors have monitored the plug. This part of the experiment was completed in 2017 and a new phase of the full scale test was initiated with the new project *Dismantling and evaluation of Dome plug*.

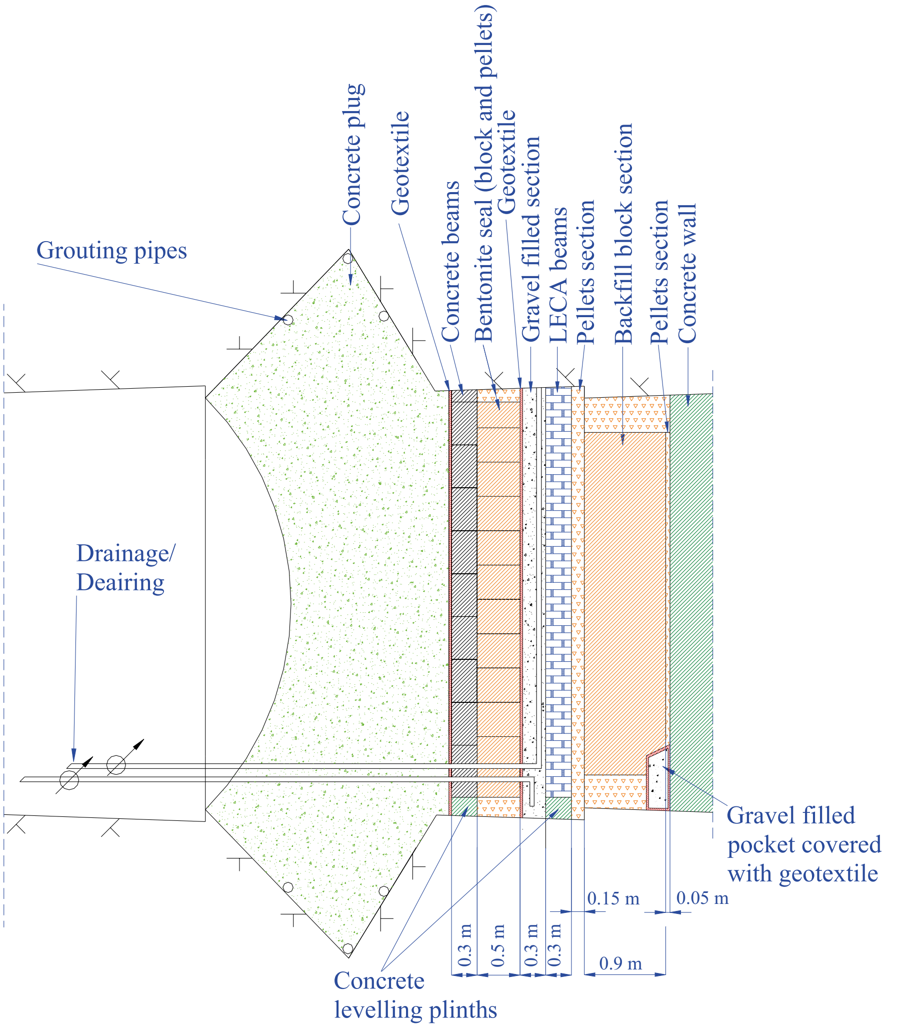

Figure 3-5. *DOMPLU design.*

Objectives

This new phase of the DOMPLU project aims to ensure that the reference design of the KBS-3V deposition tunnel end plug works as intended. By doing tests and analysis on the installed components, hopefully it will be proven that the method for sealing of a deposition tunnel is feasible and controllable.

The main objectives for the dismantling part of the DOMPLU project are to:

- dismantle and evaluate the full scale test that was installed in previous design and installation project,
- contribute to increased knowledge about how to close deposition tunnels and to develop the detailed design,
- analyze the construction during dismantling to see if there are any parts of the Dome plug that can be improved.

Experimental concept

The following activities were planned for analyzing and dismantling of the dome plug:

Gas tightness test

This test was planned to verify if the dome plug is gas tight since gas tightness is a design requirement.

Pressurisation test

The goal was to stress test the dome plug to 9 MPa which is the design pressure (500 m/50 MPa water column +2 MPa swell pressure with 2 as a safety factor). This test is only a strength test and any increased water leakage above 5 MPa is irrelevant since the hydrostatic pressure cannot reach above this level at a depth of 500 m.

Non destructive testing (NDT)

Plausible NDT methods were tested to see if any of them could be used as a control method during manufacturing.

Destructive testing of the concrete dome

Several samples from the concrete dome were taken by core drilling and material properties and interfaces are to be analysed. Interfaces between rock and concrete dome are extra interesting since that could be a potential leak path.

Dismantling the concrete dome

The concrete will be breached with a hydraulic hammer. To get started, a 1×1 m opening will be created in the center of the plug by stitch drilling.

Dismantling and sampling of bentonite and filter components

To determine water saturation and density, a large numper of bentonite samples from the sealing- and backfill section are planned.

Results

Gas tightness test

The test was initiated by lowering the pressure to atmospheric level and draining the filter section of water.

The upstream side of the plug was then pressurized with helium to approximately 0.4 bar(e), after this the pressure source was shut off. During the test a sophisticated helium leak detector was used. The test lasted for 24 h and during this time there was no leakage detected, instead the pressure increased slightly, this was probably due to natural inflow of water on the upstream side of the concrete dome. Due to these results, the plug was considered gas-tight.

Pressurisation test

Despite serious concerns that it would be difficult to achieve the design pressure, the test was considered very successful. After the gas test, the plug was again pressurized to 4 MPa and this pressure was held for about 5 weeks to see if the pressure drop during the gas test had affected the sealing of the plug. After it was found that the sealing was not affected, the pressure was increased gradually, and for a few days the dome plug was pressurized to 9 MPa (8 MPa water pressure +1 MPa swelling pressure).

Non destructive testing (NDT)

Four NDT methods were tested.

- GPR (Ground Penetration Radar).
- IE (Impact Echo).
- IR (Impulse Response).
- MIRA A1040 (Ultrasonic tomography for imaging of concrete structures).

Although GPR seemed to be the most useful method, the results are to be analyzed further.

One factor of interest to the project was if the NDT had detected the cavity found in the upper part of the slit, as described below and showed in Figure 3-6. NDT has not detected this defect. This may be due to the geometry of the plug which made it difficult for the NDT methods to reach this area.

Destructing testing of concrete dome

Approximately 20 cores have been taken from the concrete structure by core drilling. The cores are to be analyzed at an external laboratory.

During sampling, a cavity was discovered in the upper part of the concrete structure, as seen in Figure 3-6. Preliminary results indicate that the cavity was caused by the fact that the mould was not top filled during casting.

Although the dome plug has worked well during the test period, this cavity probably contributed to some increased leakage. The discovery of the cavity is an opportunity to improve the installation sequence and avoid this type of manufacturing defect in the future.

Dismantling the concrete dome

To breach the Dome plug, a square opening was created by stitch core drilling. After removing the centre block, work began on breaching the concrete dome. An electric hydraulic demolition machine was used for the task, see Figure 3-7.

Although the concrete dome is not reinforced, it proved quite difficult to remove. Despite this, the work was completed according to plan in late 2017 and this means that the entire tunnel profile plus the upper part of the slot is exposed.

Dismantling and sampling of bentonite and filter components

This activity is planed to be performed during 2018 and will start with removal of the concrete beams that can be seen to the right in Figure 3-7.

In addition to the tests mentioned above, photography and visual inspection have been performed throughout the dismantling process.

All results from this part of the DOMPLU project shall be evaluated and reported in late 2018.

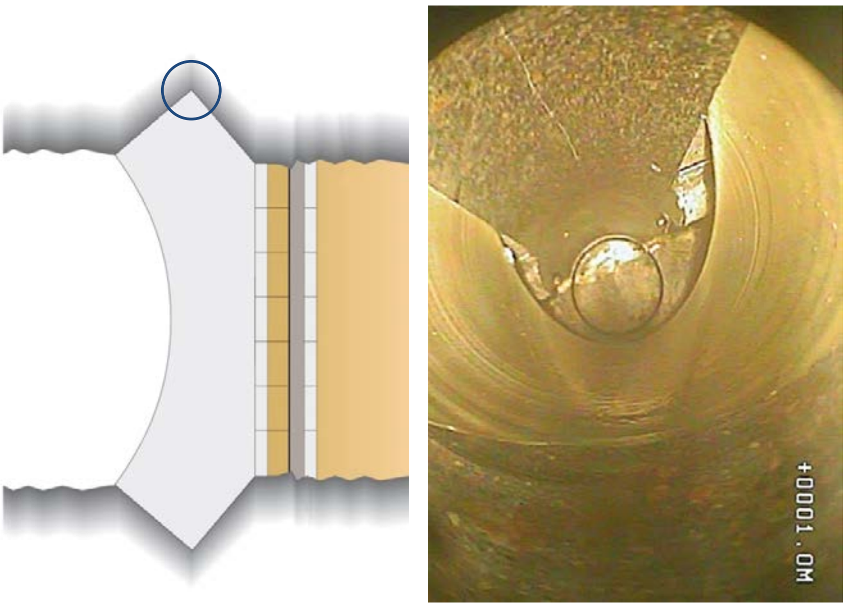

Figure 3-6. *A cavity in the upper part of the concrete was discovered in drill cores in the interface between concrete and rock. The image to the right is taken with a camera inside the bore hole.*

Figure 3-7. Machine for breaching (left) and result after removal of the concrete dome (right).

3.4 System design of buffer and backfill

As reported in last years annual report two full scale buffer installation tests were conducted at Äspö during 2015 and 2016. Based on the results from these tests, laboratory tests and modelling of the early THM (Thermal, Hydraulic and Mechanical) evolution the buffer and backfill designs, the installation method and sequence were updated (Luterkort et al. 2017).

For the new installation method and sequence the buffer blocks and pellets are installed in a direct sequence in conjuction with the installation of the canister. Buffer and canisters are installed in all relatively dry deposition holes in a deposition tunnels and after this the backfilling starts. As the backfilling front approaches one of the remaining relatively wet deposition holes the buffer and canister are installed in this deposition hole. After the buffer is in place the backfilling starts over and the buffer will in a short time period gain support of the backfill material. This reduces the upward heaving of the buffer in the wetter deposition holes.

During 2017 handling of remaning issues concerning buffer and backfill design have been planned and a new project initiated. No practical work has been performed.

The planned work will include a full scale installation test as a part of determining the limit between what is defined as a relatively wet and a relatively dry deposition hole. Tests to give bases for optimising the buffer pellets will also be performed.

3.5 Developing, testing and application of improved models for bentonite expansion and erosion (POSKBAR)

Background

The formation and stability of colloids from the clay Engineered Barrier System (EBS) may have a direct impact of assessed risk from the repository in two aspects:

- Generation of colloids may degrade the engineered barrier (Figure 3-8).
- Colloid transport of radionuclides may reduce the efficiency of the natural barrier.

There is a large pool of knowledge about colloid stability both from the general scientific literature and from national and international projects within the nuclear waste management community. However, there is still a gap of knowledge in the ability to transfer the scientific understanding into a useful abstraction for long term performance assessment for real systems. The recent EC project BELBaR focused on closing this gap by increasing the knowledge about bentonite colloid stability in realistic systems and by developing tailor-made experimental programmes focused on resolving the issues that are important in safety assessment. The quantitative models for the assessment of erosion and radionuclide transport were also further developed in BELBaR.

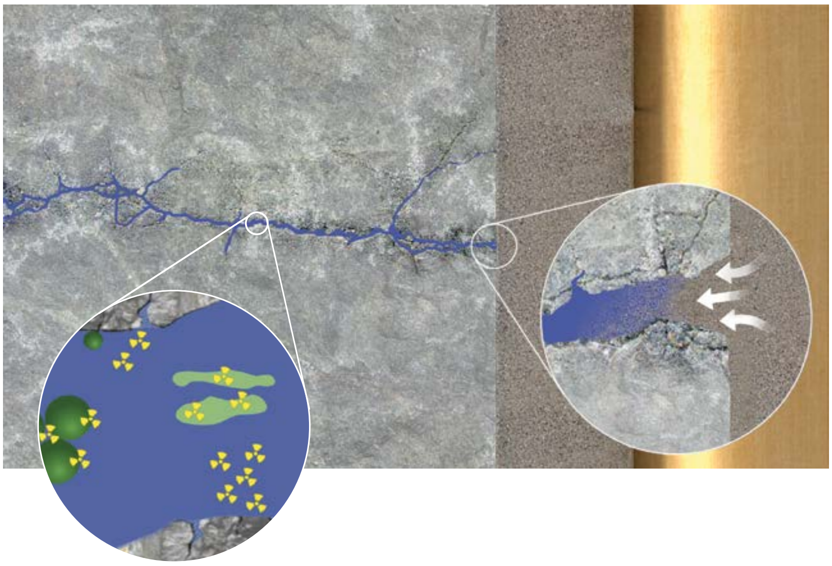

Figure 3-8. *Colloid formation and radionuclide transport from a bentonite barrier.*

The following key points reflect a summary of the conclusions from the BELBaR project:

- In general, erosion/colloid generation is rapid initially, but decreases with time and in some cases stops altogether.
- In static experiments – equilibrium is reached – the maximum quantity of colloids generated depends on initial conditions but erosion is not continuous and chemical forces driving dispersion processes are considered to be more important than mechanical forces even in the dynamic system.
- There is a potential connection between flow rate and erosion when ionic strength of groundwater is below the critical coagulation concentration (CCC).

With respect to the safety assessment, these results suggest that the assumptions related to the mass loss rate's dependency on groundwater flow velocity could potentially be reviewed under no highly "erosive" conditions. The conclusions have demonstrated that the mechanism for bentonite erosion overall is driven more significantly by chemical forces rather than mechanical forces. This may be particularly relevant when considering the differences reported in the experimentally derived, or numerical modelling derived values for n within the equation: mass loss scales with flow velocity u as $k \cdot u^n$ and that potentially the coupling between mass loss and groundwater velocity alone is overestimated in the numerical models.

The POSKBAR project is SKB's continuing work after the BELBaR project and while erosion is still in focus, the expansion and sedimentation of bentonite is more in focus in this new project which includes both experimental work and model development.

Objectives

The overall project goal is to produce a model, or expression, that can be used to quantify the mass loss of bentonite from the buffer and also the backfill due to colloid formation/gel destabilization in a situation with dilute groundwaters in the repository. The model will be used in the future assessments for the long term performance of the KBS-3 Spent Fuel Repository.

Experimental concept

The project includes three main parts:

- Fracture geometries.
- Erosion and stability experiments.
- Model development.

Fracture geometries

Knowing the geometry of the fractures that intersect the deposition holes is key input for the experimental setup and model development. It is clear that the fracture width will have a significant impact on the erosion process. It is also possible that the fracture shape, meaning the variability of the width will have an impact.

The project thus assesses what type of fractures that may intersect a deposition hole; their geometries (i.e. distribution of width, length, volume, direction, etc) and statistical occurrence.

Erosion and stability experiments

Although a large set of experiments was carried out in BELBaR there are still large uncertainties concerning the details on how the erosion process should be described. The focus of the experimental work within POSKBAR will be directed towards simulation of "real" systems.

A set of 7 tasks have been defined in order to get further data in support for the "erosion by flow"-model in more realistic aperture sizes and flows. The work is primarily carried out with Nanocor®, MX-80, Ca-MX-80 and MCA-C (saponite) and a water chemistry of 1 mM NaCl. Figure 3-9 provides an illustration of the basic experimental setups used by the current contractor, CIEMAT, in Spain.

Task 1. "Erosion under flow"-experiments in horizontal **narrow fractures (slots)** with apertures of 0.1, 0.2 and 0.4 mm.

Task 2. "Erosion under flow"-experiments in **variable aperture fractures (i.e. more realistic fractures)** with sodium-dominated smectite. An average aperture width of around 0.2 mm will be used.

Task 3. Experimental validation of **sedimentation of sodium-dominated smectite flocs in narrow vertical/sloping fractures**, **slots**, with an aperture of 0.2 mm.

Task 4. Experimental validation of **sedimentation of calcium-dominated smectite flocs in narrow vertical/sloping fractures**, **slots**, with apertures of 0.1, 0.2 and 0.4 mm.

Task 5. Experiments of **sedimentation in vertical/sloping variable aperture fractures (i.e. more realistic fractures)**. An average aperture width of around 0.2 mm will be used.
  a. of sodium-smectite dominated flocs,
  b. of calcium-smectite dominated flocs,
  c. of "as-is" bentonite with accessory minerals.

Task 6. **Expansion experiment** at different water compositions in narrow slots as well as in variable aperture fractures. The water composition is varied from 1 mM NaCl to "higher than CCC". With apertures of 0.1, 0.2 and 0.4 mm.

Task 7. Expansion and erosion experiments with **synthetic clays** (e.g. laponite and saponite) with an aperture of 0.2 mm. These tests are primarily performed in the same manner as Task 1.

The original 7 tasks were also complemented by the repetition of a few BELBaR experiments relating to the effect of fracture slope angle at larger apertures, 1 mm, as well as by some experiments set up to help in understanding how and why montmorillonite sols separate into a gel and practically colloidal free water after some time. This happens also in very dilute waters.

Model development

The erosion model that was used in SR-Site has been further developed and refined in the BELBaR project (Neretnieks et al. 2017) and this is the current model.

The model development in POSKBAR was initiated with the compilation of experimental data, mainly from BELBaR, but also from other sources; this was followed by verification of the current model, using the experimental data. Possible improvements and alternative methods were compiled and model development was subsequently carried out using these conclusions. Two modelling teams were dedicated to tackling the same questions in parallel.

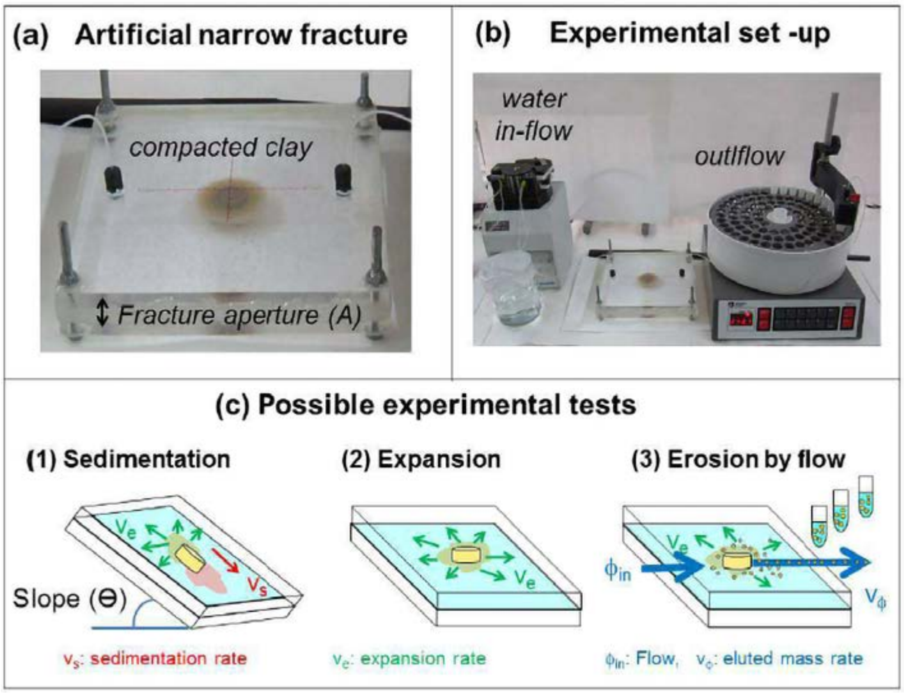

Figure 3-9. *(a) Artificial narrow fracture, (b) Experimental set-up; (c) Scheme of experimental tests: (1) Sedimentation, (2) Expansion and Erosion by flow.*

A second model development step has been initiated for one of the modelling teams, now supported by POSKBAR experimental data. This part aims at developing a POSKBAR model and simplified expressions that can be used to quantify the mass loss of bentonite from the buffer and also the backfill due to colloid formation/gel destabilization in a situation with dilute groundwater's in the repository.

Results

Fracture geometries

To verify that the fracture geometries in the Ciemat experiments are relevant for the situation in Forsmark a DFN model has been used to estimate fracture apertures. The model used is Model: DFN PFM 2.2.xls, v4.3, 2009-05-12 (Fox et al. 2007). The model volume is 10 × 10 × 15 m (Figure 3-10), centred on DH8 of Hyposite (random choice). 100 realisations were performed and the output was traces and fractures intersecting the deposition hole. The geometric aperture is estimated according to (Klimczak et al. 2010). Out of 28 161 simulated fractures intersecting the deposition hole only 102 had an aperture larger than 0.4 mm (largest 1 mm) while the rest were between 0.04 to 0.4 mm. This shows that the experimentally used apertures are relevant for a deposition hole in Forsmark.

Erosion and stability experiments

During 2017 the tasks without a variable fracture aperture have been initiated (1, 3, 4, 6 and 7) and the results supports the BELBaR conclusions that chemical forces driving dispersion processes are more important than mechanical forces even in the dynamic system. Figure 3-11 provides an example of preliminary results from the expansion experiments carried out by CIEMAT.

Preliminary results also indicate that the expansion in the fractures slows down/even stops at concentrations below CCC which is in contrast to the current model.

During 2018 the tasks with variable fractures will be carried out. Äspö will also initiate in-house experiments in the laboratory to further support model development.

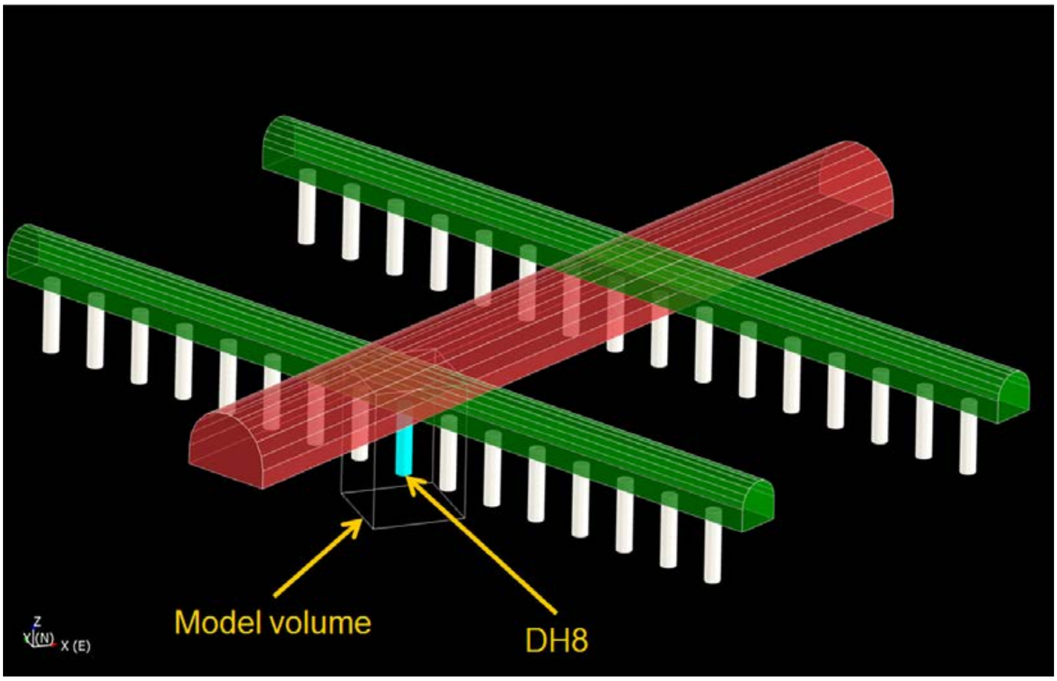

Figure 3-10. *Model volume.*

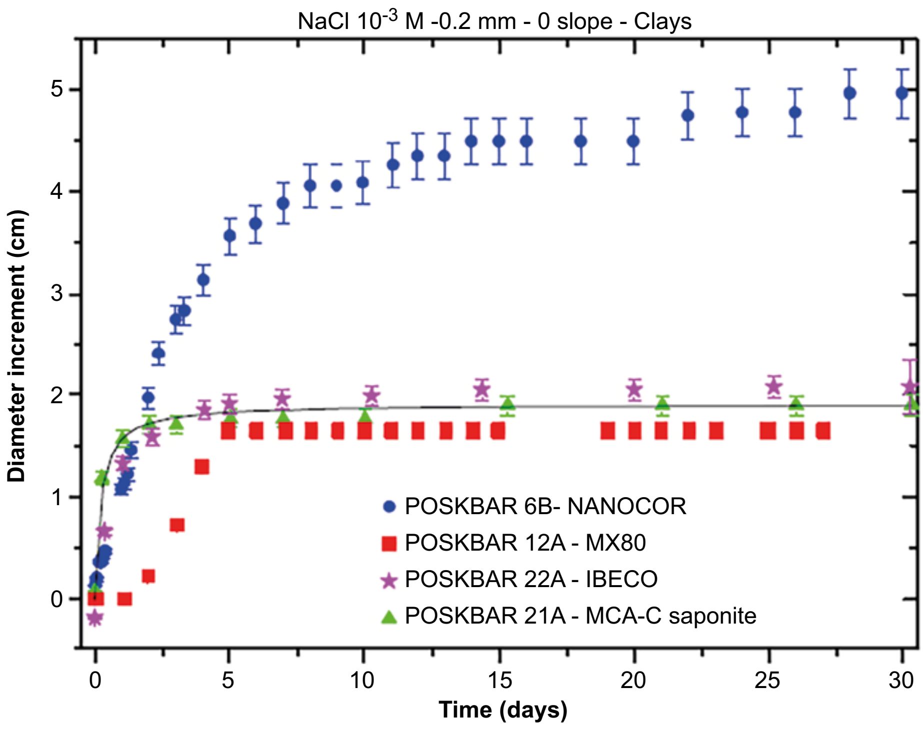

Figure 3-11. *Expansion (diameter increment, in cm) of different clays (NANOCOR, Mx-80, IBECO and MCA-C) compacted at 1.4 g/cm^3, within artificial fracture placed horizontally (slope 0°) of fixed aperture (0.2 mm), filled with NaCl 10^{-3} M. Line is included to guide the eye.*

Model development

The current model (Neretnieks et al. 2017) has been tested with the compiled experimental data and it has been concluded that it does not underestimate the mass losses and it is deemed quite conservative.

The eroded montmorillonite forms flocs that sediment in sloping fractures. This is accounted for in the model. The rate of transport of the flocs is modelled as a flow of an agglomerate fluid with a viscosity like water. Experiments from the BELBaR project and information in literature suggest that the sedimenting agglomerate fluid becomes so much more viscous with time that it may slow down the erosion because of fracture clogging by a gel-like sediment.

In large aperture sloping fractures that are not rapidly clogged the sedimenting clay will collect at the bottom of the fracture. Intersecting fractures can allow the sediment to migrate further into the fracture network when the next fracture has a slope steeper than the angle of repose (friction angle). For the accessory minerals this is expected to be on the order 25–45°, whereas it can be lower for the smectite agglomerates. This suggests that there is a possibility that the accessory minerals will fill the fracture network below the tunnel and/or deposition hole after some initial loss of clay and may constrain further erosion. The effects of the accessory minerals are not included in the present model. It may also be possible to support such clogging of fractures by modelling. The main weaknesses in the present model are that:

- The viscosity of the sedimenting agglomerate fluid is probably underestimated as the effect of aging is not accounted for.
- The potential clogging of fractures by accessory minerals is not accounted for.

There is a potential that both these effects independently may decrease the erosive loss by several orders of magnitude.

The second modelling team assessed a Code_Bright model (Laviña et al. 2018) and it handles the initial swelling well, but currently faces challenges at high porosity which is the case at erosion, there are also numerical challenges. A particle based: Discrete element model was also worked on, and tools developed to adapt it to the current problem, however, it also faced numerical challenges and would need more work before it could be used. A final, multi-phase modelling based on macroscopic models also handled the initial swelling well but could currently not address the transformation between gel and sol.

The first team will continue the model development in 2018 with the aim of achieving an updated model that can be used in the future assessments for the long term performance of the KBS-3 Spent Fuel Repository. The current plan is to publish the work of both teams in 2018/2019, (Neretnieks et al. 2018) and (Laviña et al. 2018).

3.6 Pre study on drilling of deposition holes

Background

In the late 1990s a total of 13 deposition holes were drilled by SKB. The deposition holes were drilled with a modified TBM to drill vertical shaft (Andersson and Johansson 2002). The TBM machine used for these tests is no longer available.

During the period 2012–2015, Posiva drilled a total of 10 deposition holes with a new drilling machine from the company Tamrock in Finland (Railo et al. 2015, 2016).

The drillings of deposition holes carried out by Posiva have taken longer than expected and the drill holes do not meet the tolerance requirements. The reason for this is mainly due to the problem of handling drill cuttings and poor equipment stability.

After these drillings were carried out, some tolerance requirements have been tightened further which will lead to even greater demands on the equipment used in the repository.

For the Spent Fuel Repository in Forsmark, SKB plans to drill about 6 000 deposition holes with a capacity of up to 200 holes per year. SKB also needs to drill 4–6 deposition holes in the beginning of the 2020s as a part of the integration tests for the entire KBS-3V system.

SKB is now interested in re-reviewing the market to see if there is new technology available for this type of drill activities.

Figure 3-12. *Prototype deposition hole drilling machine used by Posiva.*

Objectives

The purpose of this preliminary study is to find a suitable method for producing deposition holes and to provide recommendations on how SKB should proceed in the work of testing and/ or acquiring such drilling equipment.

In order to have an efficient drilling method, the goal is that the equipment being developed shall drill vertical deposition holes with a flat bottom surface. The tolerances of the hole, including the bottom surface, are an important aspect that affects the whole installation of bentonite and canister.

After a market research and consideration of previous studies, it has been estimated that mechanical drilling with push reaming or boxhole drilling technique has the potential to meet the requirements.

The overall requirements for the deposition holes are as follows:

- The drilling machine shall be able to produce deposition holes that comply with SKB's functional and quality requirements.
- The equipment shall be robust and cost effective.
- The equipment must be service- and maintenance friendly.
- Productivity shall be high with short times for setup, drilling and moving between deposition holes.
- The equipment must be designed to minimize the risk of contamination the deposition hole with oil, grease or other unwanted substances.
- The goal is that the production speed should be at least one deposition hole per day.

Experimental concept

In this study these potential and well known suppliers where contacted to investigate the technical feasibility:

1. Sandvik Mining and Construction/TBR Raise Borer Ltd with vertical push-reaming.
2. Atlas Copco with vertical push-reaming.
3. Herrenknecht with box drilling machine.

Results

All three of the contacted suppliers showed potential concepts to drill deposition holes. All the presented concepts are based on existing technique that needs modifications to be able to drill straight downwards. Development of new drilling equipment will require in-depth studies of, among other things, the drill head and its system for handling of drill cuttings.

One important aspect from the time for this study was that the requirements for the deposition holes were not fully defined by SKB and the preliminary requirements as stated were considered challenging to fulfil, regardless the choice of production method.

Future plans

The requirement on the deposition holes must be evaluated and finally determined if they are to be used as an input to a technical specification for a new drilling machine.

In the next stage, a further collaboration with suppliers is recommended to investigate the possibility to meet SKB's capacity and dimensional requirements.

3.7 Investigation methods for ramp and shaft

Background

Detailed studies are necessary to characterize and document the Forsmark bedrock before the production of the Spent Fuel Repository so that it is constructed in accordance with conditions in the bedrock, and construction requirements regarding rock can be verified.

During autumn 2016 it was decided that technology project DETUM-1 should be discontinued and the remaining work within DETUM's subproject *Methods and Instruments (M & I)* would be transferred into the new project KBP5003 Methods for investigations, for further development.

The project will complete technology development of methods for investigations for the Spent Fuel Repository accesses (ramp and shaft) in accordance with established list of investigation equipment.

Developed methods will ensure that detailed investigations are carried out efficiently with regards to cost and time.

The project will develop documentation for methods that will guide the performance of investigations in the Spent Fuel Repository (ramp and shaft).

Output targets

The target is to ensure that all survey methods, document management and instruments needed to implement detailed investigations for the Spent Fuel Repository accesses are presented, described, quality assured and approved when it is time for the operational programs being submitted to the Swedish Radiation Safety Authority, this in connection with the application to commence construction of the Spent Fuel Repository.

Results

During spring/summer 2017, the project has identified and analysed methods and investigations that have to be produced.

3.8 Work on concrete barrier

Background

The Final Repository for Short-Lived Radioactive Waste, SFR, located in Forsmark, has been in operation since 1988 and has been operated since 1 July 2009 by Svensk Kärnbränslehantering AB, SKB. The repository is located in rock vaults 50 meters below the sea bed of the Baltic Sea, and stores waste from Swedish nuclear power plants as well as from health care and industry.

The existing facility is designed for final disposal of mainly operational waste from the Swedish nuclear power plants. At present, an extension of the repository is being planned for disposal also of the waste that will arise during the dismantling of the Swedish nuclear power plants, SFR3. In this extension, a rock vault for intermediate-level radioactive waste, 2BMA, will be included, Figure 3-13. The repository structures in 2BMA consist of unreinforced concrete caissons, Figure 3-14.

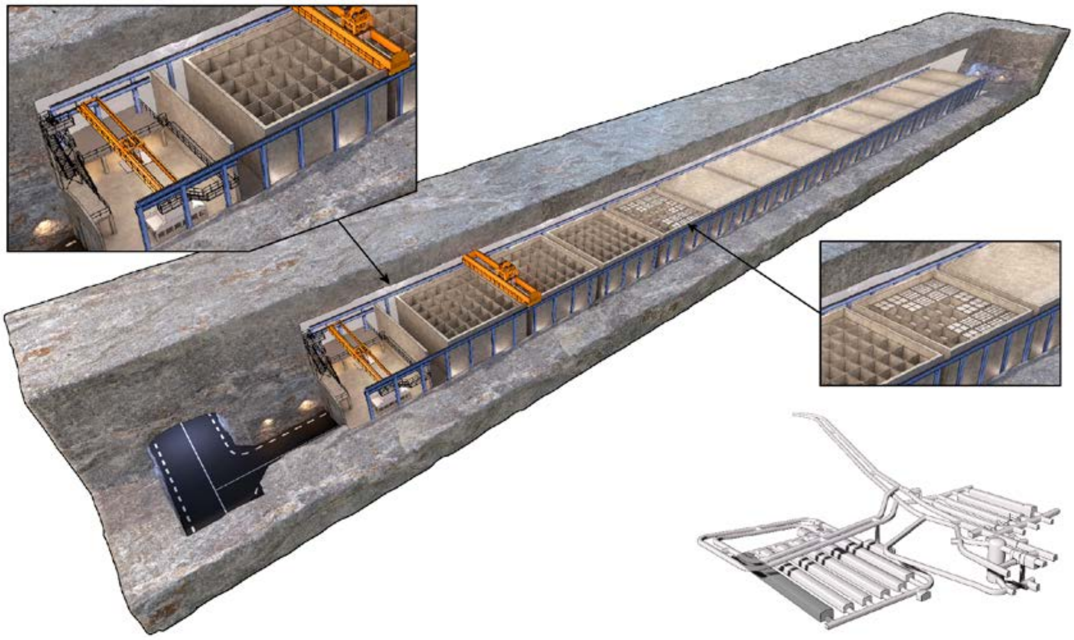

Figure 3-13. *The rock vault for intermediate level radioactive waste.*

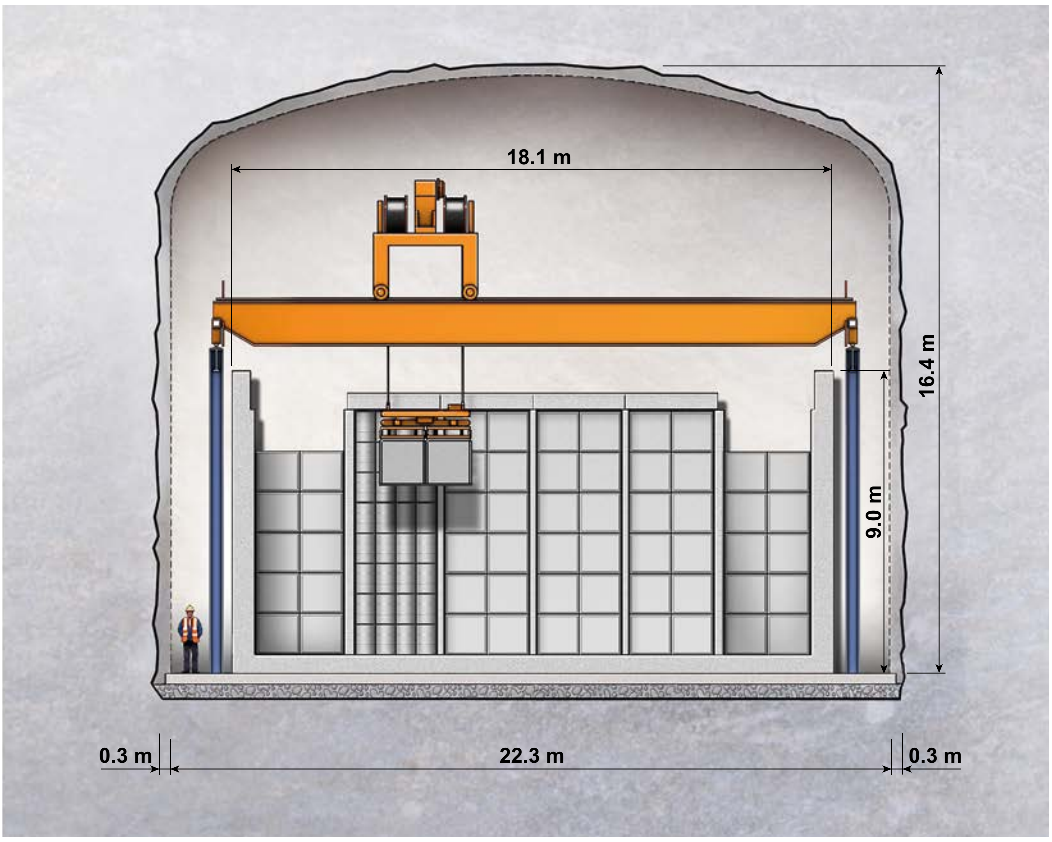

Figure 3-14. *A schematic illustration of a cross section of a concrete caisson for 2BMA.*

In order to demonstrate that SKB is able to construct the concrete caissons in accordance with requirements under current prerequisites a development program comprising a number of different development and verification steps has been initiated. This development program includes the steps from material development through casting of a representative section of a concrete caisson in the Äspö Laboratory and monitoring of its properties.

Objectives

The main objective of this development programme is to demonstrate that SKB is able to construct the concrete caissons in accordance with requirements under current prerequisites.

Experimental concept

The program includes the following main steps:

- Characterization of the bedrock in the area of the future SFR3 and identification of suitable quarries that can be used for ballast production during the material development work. Previously reported in Lagerblad et al. (2016).
- Material development, including laboratory work, up-scaling to production scale, transport simulations and pump tests. Prevoiusly reported in Lagerblad et al. (2017).
- Casting of a representative section of a concrete caisson in TAS05 in the Äspö HRL according to the reference method as well as according to a more standardised method and long-term monitoring of its properties. This part also includes a stress test where the concrete structure is covered in a tent-like strucure and dehumidifyers installed to reduce the humidity in the atmosphere surrounding the concrte structure.
- Casting of a down-scaled caisson according to the new reference design adopted in 2017 in TAS08 in the Äspö HRL and long-term monitoring of its properties.

Results

Material development

For results from the first two parts of the material development programme, please refer to Lagerblad et al. (2016, 2017).

Casting of a representative section of a concrete caisson in TAS05

During late 2016 and early 2017 casting of a representative section of a concrete caisson was commenced in TAS05 in the Äspö HRL. As indicated, this comprised one initial casting according to the present reference concept and a second casting aimed at investigating the possibility of introducing a new reference casting concept.

Section 1

Section 1 comprised a base slab with the dimensions 13 × 3 metres on which an L-shaped wall with a height of about 3 meters was cast in one uninterrupted sequence according to the reference concept.

In order to facilitate the casting, the formwork was erected using traditional techniques rather than the suspended system required in the reference design. This was motivated by the fact that construction of a suspended form work system would not be possible in the limited space available in TAS05. Also, the main focus of this experiment was on material properties rather than on construction method. For that reason also form rods were accepted, both to ensure the stability of the formwork but also for suspension of the sensor system. Form rods were also not expected to influence the material properties or the results from the long-term monitoring programme.

Casting was done according to standard procedures and after curing for about one week the form work was disassembled.

Immediately after demoulding, an inspection was carried out where the physical result of the casting was investigated. The focus was on surface fineness, occurrence of air blisters or other surface imperfections, adhesion to joint seals and finally mould filling. An overview image is shown in Figure 3-15. The inspection showed that the concrete was of good quality and that no fractures could be identified. The long term monitoring of section 1 has also showed a very limited shrinkage and still a year after casting no fractures have been identified.

Section 2

Section 2 comprised an L-shaped wall of identical dimensions as the wall of section 1 which was cast on the base slab of section 1 according to standard procedures for concrete casting.

Immediately after demoulding, an inspection was carried out where the physical result of the casting was investigated. The focus was on surface fineness, occurrence of air blisters or other surface imperfections. An overview image is shown in Figure 3-16. The inspection showed that the concrete was of good quality and that no fractures could be identified. The long term monitoring of section 2 has also showed a very limited shrinkage and still 10 months after casting of section 2 no fractures have been identified.

***Figure 3-15.** Section 1 just after demoulding.*

***Figure 3-16.** An overview image of section 1 (left part) and section 2 (right part) just after demoulding of section 2. The horizontal joint seal in the bottom slab and the vertical joint seal in the wall of section 2 are clearly visible.*

Stress test

Four months post casting of section 2 the stress test was initiated. This test was in principle a continuation of the long-term monitoring programme but it also comprised monitoring the long-term properties of the concrete in an environment with a reduced relative humidity. The main purpose of the stress test was to serve as a background to future decisions on climate control in 2BMA. Further, the stress test also aimed at studying the rate with which the concrete dries out in a very dry environment and its effect on the levels of internal strain, dimensional changes and formation of fractures.

Erection of the tent was commenced beginning mid July 2017, i.e. just below 4 months post casting of section 2 and about 8 months post casting of section 1, Figure 3-17 left image. The tent covered the entire concrete structure and the use of roof trusses allowed the formation of a slit of about 0.5 meters on all sides of the concrete structure, Figure 3-17 right image. This permitted the air to flow freely around the structure and ensured a homogeneous drying of the concrete.

The follow-up of the stress test has shown:

- No fractures have been identified in or adjacent to the joint between section 1 and 2 or in any other part of any of the two sections or its bottom slab.
- The total shrinkage in the walls is approximately 1 mm (corresponding to 0.08 ‰) and for the bottom slab 0.4 mm (corresponding to 0.03 ‰). The shrinkage difference between walls and bottom slab is calculated to 0.6 mm (corresponding to 0.046 ‰).
- The relative humidity of the concrete's outer parts has decreased from close to 100 % in connection with the start of dehydration to 80 % just over 4 months later. In the inner parts of the concrete structure, relative humidity has decreased by 1–2 % during the corresponding period.
- Mainly increased compressive stresses have been measured, but also increased tensile stresses have been noted for a sensor in the bottom slab. The increased compressive stresses can probably be explained by the shrinkage that occurs in the outer parts of the structure, creating a pressure in the inner parts where the drying and thus the shrinkage is more limited.

In summary, the analysis of data from the first 4 months of the dehydration of the concrete structure shows that the dehydration takes place only very slowly and that the overall shrinkage has been very limited.

A full report covering this work will be published during 2018.

Figure 3-17. *The tent-like structure covering the concrete structure during the stress test.*

3.9 Sealing of boreholes

Background

A large number of investigation boreholes have been drilled in both the area for the planned Spent Fuel Repository and for the Final Repository for Short-Lived Radioactive Waste (SFR) which are both located in Forsmark in Östhammar municipality. While some of these boreholes will be used for monitoring during the construction others need to be sealed before the start of the construction of the above ground facilities and the start of the excavation work.

The present reference method for sealing these investigation boreholes (SKB 2010) is to install highly compacted bentonite plugs placed in perforated copper tubes in the main part of the borehole while the parts of the borehole that includes water bearing fracture zones will be filled with quartz based concrete plugs that prevents erosion of the clay. This method has been tested and calculations show that it fullfills our previous requirement where the sealing should restore the hydraulic conductivity of the rock. The drawback with this method is that it is very expensive and labour intensive. A new technology development project was therefore initiated in 2015 with the goal to optimize the sealing of SKB's investigation boreholes in Forsmark. The main changes in pre-conditions compared to previous work done was:

1. The current reference method was mainly developed for sealing of deep investigation boreholes with a hydraulic connection to the repositories.There is a need for a diversified sealing methodology as most of the investigation boreholes are short and/or located far from the repository area. Any new method developed therefore needs to be optimized for managing both deep boreholes and the many shorter boreholes in an efficient manner.
2. The design requirement is at present that a hydraulic conductivity of less than 10^{-8} m/s should be achieved along the whole borehole length. However, analyses performed within SR-Site regarding the Spent Fuel Repository (SKB 2011) shows that the present requirement on the hydraulic conductivity of the sealing can be mitigated.
3. The effect of nearfield hydrology for SFR has been studied with hydraulic modelling of (Abarca et al. 2013). The conclusion of this modelling is that a boreholes sealed with a method resulting in a hydraulic conductivity of 10^{-6} m/s or lower creates a situation where the water flow through the repository is the same as if no boreholes where present.
4. A study regarding closure of ramp, shafts and investigation boreholes for the spent fuel repository has shown that the current requirement that the sealing needs to restore the hydraulic conductivity of the rock is unnecessarily high. A new design requirement regarding borehole sealing at the Spent Fuel Repository in Forsmark has therefore been recommended where the hydraulic conductivity of the sealing along the borehole length is less than 10^{-6} m/s (Luterkort et al. 2012).

A new modular design for sealing of deep boreholes has been developed based on the updated design requirements. This method, refered to as the "The sandwich concept" (Figure 3-18), is developed for sealing of deep investigation boreholes with a hydraulic connection to the repositories. The method is however modular and can easily be adapted to any of the different type of boreholes commonly seen in Forsmark:

- Short investigation bore holes not penetrating the rock will only use the top most part of the concept; the Bentonite pellets.
- Regular bore holes without a hydraulic connection to any of the repositories will be sealed using either sandfilling or quartz concrete filling combined with the upper end seal and bentonite pellet.
- Boreholes with a hydraulic connection to any of the repositoris will be sealed with the complete sandwich concept including at least one bentonite seal.

The sandwich concept, see Figure 3-18, is based around a sand section covering the main part of the borehole. The purpose of the sand filling is to ensure the mechanical and chemical stability of the borehole and create a solid foundation for the rest of the sealing components. The sealing of the borehole is done by installing highly compacted bentonite in strategically selected sections with good rock i.e. no fractures or rock fallouts. Quartz-based concrete plugs are placed as separators between the different materials. This material is also placed in borehole sections passing close to the repository and as an upper end sealing. Copper expanders are placed at all material transitions in order to prevent interaction between the materials and to ensure long-term stability. Finally, the upper part of the borehole passing the top soil is filled with pellets of bentonite.

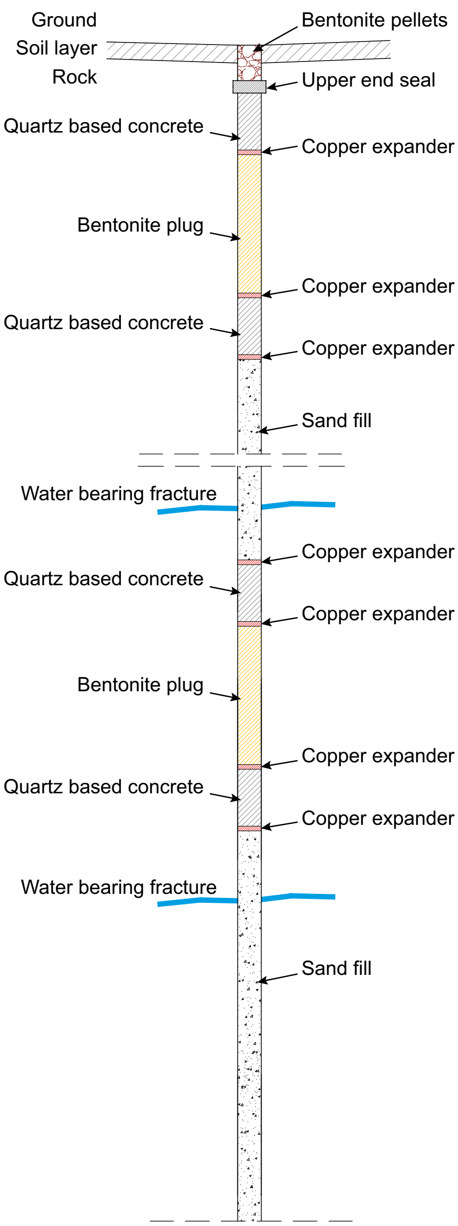

Figure 3-18. *Schematic drawing of the suggested principle for sealing of deep investigation boreholes, the so called "Sandwich concept". The design includes dense bentonite plugs positioned in sections with good rock. Permeable sand is filling up the main part of the borehole. Quartz based concrete is positioned in the transition zones between bentonite and sand. Copper expanders are positioned at all transitions between different materials.*

Objectives

The objectives of the work done at Äspö include:

- To develop and test methods for installing sand and bentonite pellets in both dry and water filled boreholes as a part of the sandwich concept but also as a part of the concepts for more simple sealing methods.
- To verify the Sandwich concept. This is done by laboratory tests on the different parts of the concept but also by installing all the components in a so called mock-up test.
- To verify the possibility of installing the Sandwich concept in a 250 m deep borehole.

Experimental concept

The project will make a number of preparatory tests followed by a full scale installation of the sandwich concept in the borehole KAS013 at Äspö.

Results

The different components included in the sandwich concept, the sand, bentonite, concrete and the copper expander have been tested at the Multi-purpose test facilities in Äspö and at Clay Technology during 2017. The results from these investigations are reported in Sandén et al. (2017). The results from these laboratory tests were then used as input for the design of both a mock-up test and the upcoming field test at Äspö.

The mock-up test, which includes all the components in the sandwich concept, see Figure 3-19, were installed and retrieved during 2017. This test was preceded by tests made in the laboratory where the homogenisation of the bentonite was studied. The saturation and the hydraulic conductivity of the installed bentonite were measured. This information was complemented with measurement of the achieved final density of the installed bentonite after the dismantling of the test. The result of the mock-up test will be reported in a public report during 2018.

An inventory of a suitable boreholes for the installation tests at Äspö was made in 2016. The decision was to use the borehole KAS013 which has a diameter of 75 mm with a total length of ca 250 m.

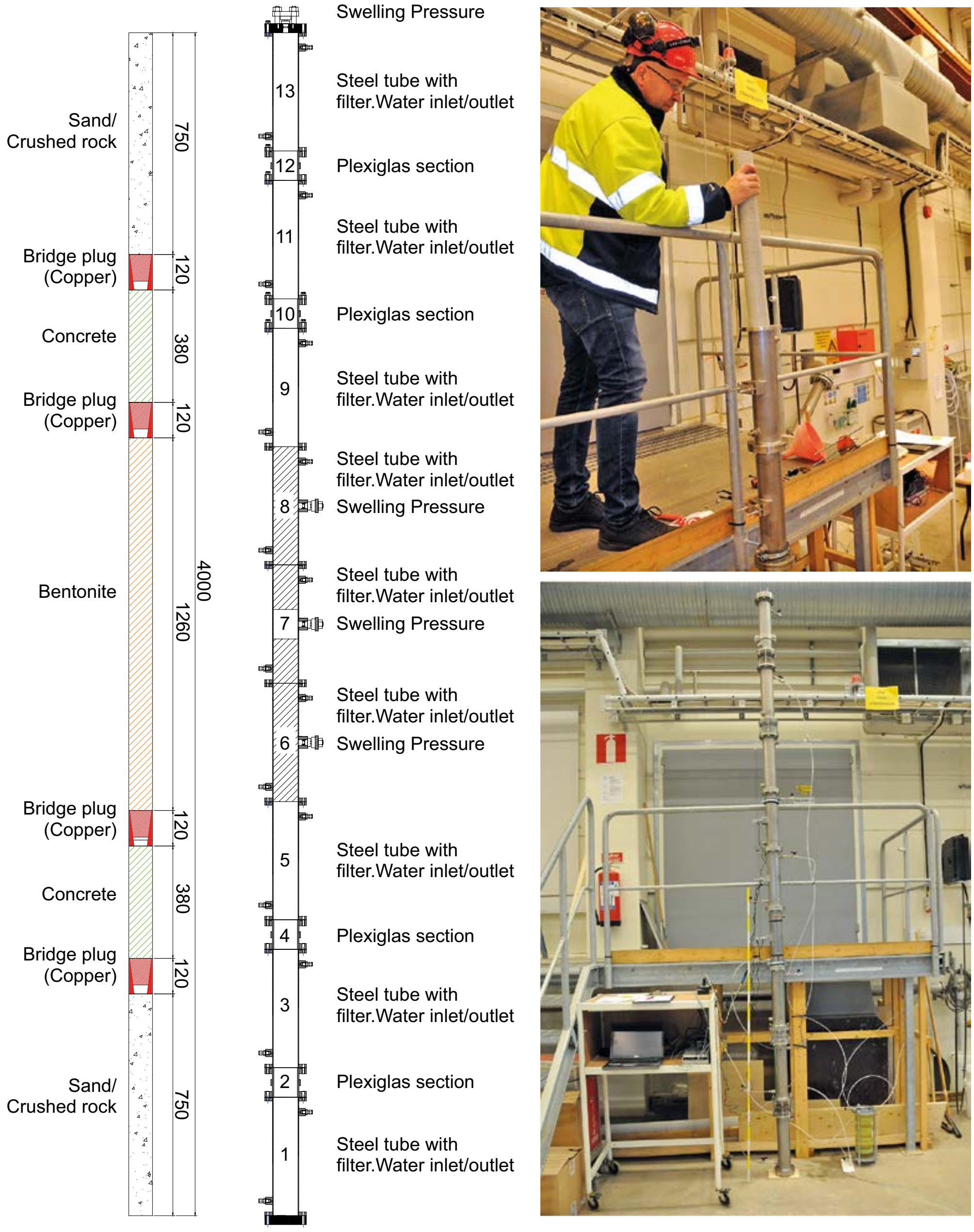

Figure 3-19. *Schematic drawing of the mock-up test and some photos from the installation.*

The borehole starts at the island Äspö and ends at the −220 m level in the Äspö tunnel. The choice to use a hole that is open in both ends was made to support future tests and possible overcoring of the installed lower parts of the borehole seal. The preparation of the hole was made at the end of 2017 which included changing of the casing in the upper part, reaming and cleaning of the hole. This work was made with a drilling machine from the ground level.

The installation of the sandwich concept will be done before the summer of 2018. All key components of the Sandwich Concept will be installed under realistic conditions to verify that the design can be efficiently installed. The project will in addition to testing the installabillity of the concept also develop and test the quality assurance concept for borehole sealing including calculations of the density of the installed components i.e. the sand, bentonite and concrete.

Concrete will be installed at the bottom of the borehole and samples will be taken afterwards on the concrete by overcore drilling from below at the −220 m level. The strength and the friction between the concrete and the wall of the borehole will be investigated on these samples.

3.10 Bentonite material studies

Background

SKB has developed methods and techniques for acquisition and quality control of bentonite for a long time (Svensson et al. 2017). The work is currently conducted in the Material science project.

The long term safety requirements on the bentonite used for buffer are quantified into a number of parameters; swelling pressure, hydraulic conductivity, shear strength, thermal conductivity and limitations in sulphide, total sulphur and carbon (harmful substances) (Posiva SKB 2017).

In order to develop in-house knowhow, improve flexibility and make cost efficient bentonite sampling and characterisation, SKB has opted to set up its own laboratory at Äspö. The laboratory is planned to be able to analyse all parameters in the technical design requirements except for the total sulphur, sulphide and carbon analyses which can be obtained from commercial laboratories. Once the planned methods are established the techniques for analysing the harmful substances may eventually also be included in-house.

In addition to the requirement parameters, several supporting methods are also being established; cation exchange capacity (CEC), powder X-ray diffraction (XRD), X-ray fluorescence spectroscopy (XRF), exchangeable cations (EC), water content, bulk density, granule size distribution, compaction properties and a sampling instruction.

A large benefit in establishing analysis methods for the suggested parameters at Äspö and in SKB's central management system is that when a laboratory is built in Forsmark, the methods will already be available in the management system and verified in the laboratory and it will be possible to apply plenty of knowledge and routines from Äspö to establish selected methods in a new facility.

The extensive material characterisation is essential for the approach of an adaptive buffer and backfill design, where the dry density and water content of the blocks and pellets are designed based on the material characteristics, in order to fulfil the in situ requirements and allow for efficient industrial production, see Chapter 3.4.

Objectives

The objectives of the Material science project are:

- To ensure that SKB has the material knowhow and measurement technology needed in order to conform to the safety functions, performance targets and technical design requirements.
- To develop and test the adaptive buffer and backfill design methodology.
- To verify that a quality controlled buffer and backfill manufacturing can be accomplished with different bentonite materials.
- To deliver basic data and requirements to the detailed planning of Hargshamn and to the production facilities regarding the handling and quality assurance of buffer and backfill components.

Experimental concept

The project is updating and adding the methods listed above. The updates also include measurement uncertainty calculations. When finalised, the methods will be transferred to the chemistry laboratory for continuous application and administration within SKB's management system.

In parallel with the method development, the project is also assessing and updating the adaptive design methodology by analysing 5 different bentonites as potential buffer and/or backfill materials. All steps, from assessing the mines capabilities, full characterisation of a 20–200 kg sample, preliminary design, purchase and confirming analyses of 20 tons followed by full scale production and detailed design.

Other key areas of research are to study how the swelling pressure and hydraulic conductivity correlates with the content of the material and how well contaminations or other deviations can be detected. These studies are done by adding controlled amounts of sand to the bentonite and measuring the swelling pressure and hydraulic conductivity as well as other key parameters.

Several of the measurements are quite time-consuming which puts practical limitations on how many samples that can be analysed. SKB's strategy is to do an initial, full characterisation, of a given material, and then, based on this, define limits for some key parameters that can be continuously monitored (Svensson et al. 2017). Measurements in the laboratory will be required; however, measurements that have the potential to be automated, such as XRF analyses, component dimensions and weights, are of highest interest.

The current sampling strategy for a full scale test production, material purchase (20 tons), is presented in Figure 3-20. It involves 20 samples of which the smaller parts are kept separate and analysed for variability using XRF while the larger parts are combined into a cumulative sample that in turn is separated into one part for laboratory analyses and one for archiving. If the purchase is 20 big-bags, each of them are sampled, while if it is 40 big-bags every other big-bag is sampled.

Results

During 2017 the methods have been updated and analyses of the 5 selected materials; Milos clay, a Moroccan clay, Bulgarian clay, Turkish clay and Indian clay have been initiated. The data is being compiled and assessments have been initiated. Preliminary assessments indicate that several of the materials are possible to use both as buffer and backfill. The larger 20 tons purchases and test compactions are planned for 2018–2019.

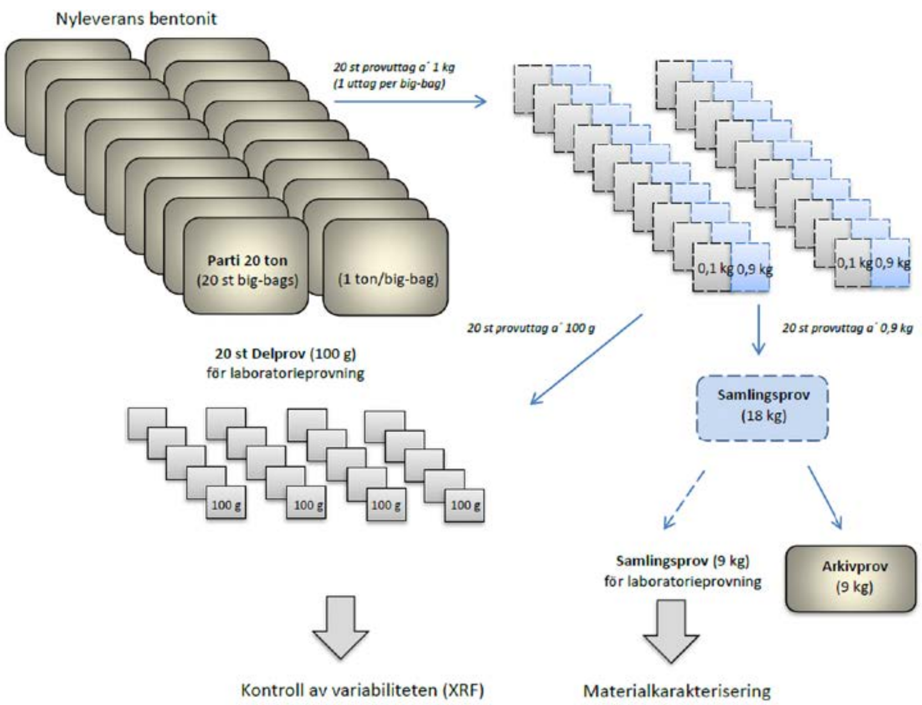

Figure 3-20. *Sampling strategy for a 20 ton material purchase.*

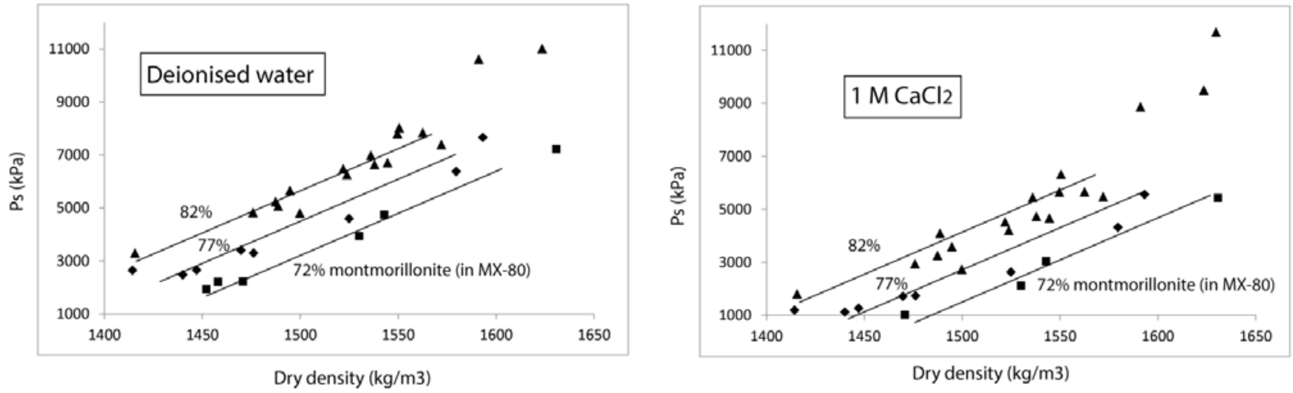

Figure 3-21. *The swelling pressure as a function of montmorillonite content and density using deionised water and 1 M CaCl2 solution.*

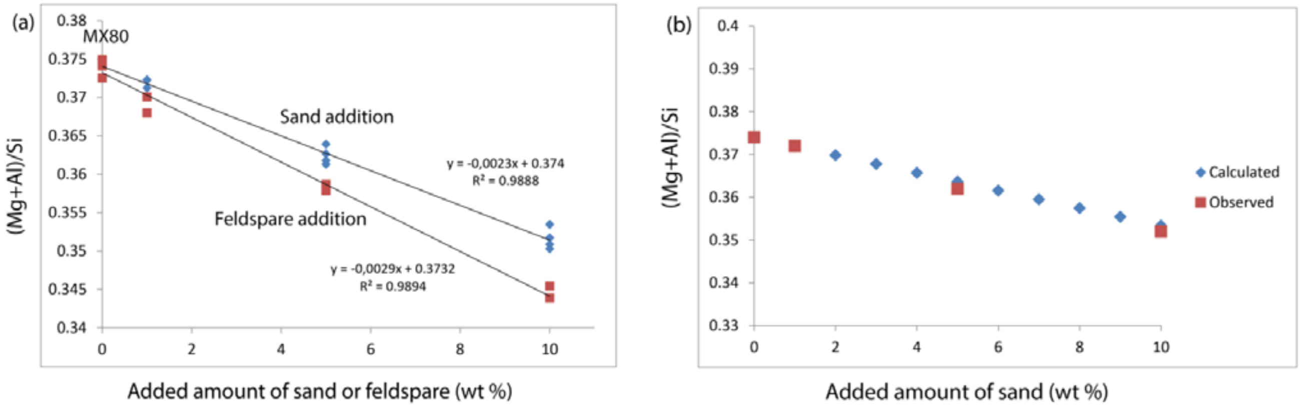

Figure 3-22. *Chemical data (XRF) vs montmorillonite content (specific dilutions).*

The sand additive measurements have been carried out and results are presented in Figure 3-21 and Figure 3-22. Figure 3-21 illustrate that a 5 % change in the montmorillonite content can be detected in the swelling pressure measurements, and actually has a non-trivial effect on the swelling pressure. Figure 3-22 illustrates that by studying the ratio (Mg + Al)/Si measured with XRF, which is sort of representation the materials montmorillonite content divided by its accessory minerals allows for a detection of sand additions of as little as 1 %. The results demonstrates that there is good potential in using XRF as one component for monitoring that there are no critical changes in an industrial flow of bentonite material.

3.11 Projects in a monitoring phase

This section describes projects that have been previously installed in the underground laboratory. Most of these are in a monitoring phase, while two projects – Concrete & Clay and Alternative Buffer Materials – have had retrieval of experiments during 2017.

3.11.1 Prototype Repository

Background

Many aspects of the KBS-3 repository concept have been tested in a number of in situ and laboratory tests. Models have been developed that are able to describe and predict the behaviour of both individual components of the repository, and the entire system. However, processes have not been studied in the complete sequence, as they will occur in connection to repository construction and operation. In addition, it is needed to demonstrate that it is possible to understand the processes that take place in the engineered barriers and the surrounding host rock.

The Prototype Repository provides a demonstration of the integrated function of the repository and provides a full-scale reference for test of predictive models concerning individual components as well as the complete repository system. The Prototype Repository should demonstrate that the important processes that take place in the engineered barriers and the host rock are sufficiently well understood.

The installation of the Prototype Repository has been co-funded by the European Commission with SKB as co-ordinator. The EC-project started in September 2000 and ended in February 2004. The continuing operation of the Prototype Repository is funded by SKB. The retrieval of the outer section, which started in 2011 and was finalized at the end of 2013, was made in cooperation with Posiva. Furthermore, the following organisations were participating and financing the work with the dismantling; NWMO (Canada), ANDRA (France), BMWi (Germany), NDA (United Kingdom), NAGRA (Switzerland) and NUMO (Japan). The reporting of the retrieval of the outer section started during 2013 and was finalized during 2014.

Objectives

The main objectives for the Prototype Repository are to:

- Test and demonstrate the integrated function of the final repository components under realistic conditions in full-scale and to compare results with model predictions and assumptions.
- Develop, test and demonstrate appropriate engineering standards and quality assurance methods.
- Simulate appropriate parts of the repository design and construction processes.

Experimental concept

The test is located in the innermost section of the TBM-tunnel at the −450 m level. The layout involves altogether six deposition holes, four in an inner section and two in an outer, see Figure 3-23. Canisters with dimension and weight according to the current plans for the final repository and with heaters to simulate the thermal energy output from the spent nuclear fuel have been positioned in the holes and surrounded by bentonite buffer. The deposition holes are placed with a centre distance of 6 m. This distance was evaluated considering the thermal diffusivity of the rock mass and the maximum acceptable temperature of the buffer. The deposition tunnel is backfilled with a mixture of bentonite and crushed rock (30/70). A massive concrete plug, designed to withstand full water and swelling pressures, separates the test area from the open tunnel system and a second plug separates the two sections. This layout provides two more or less independent test sections.

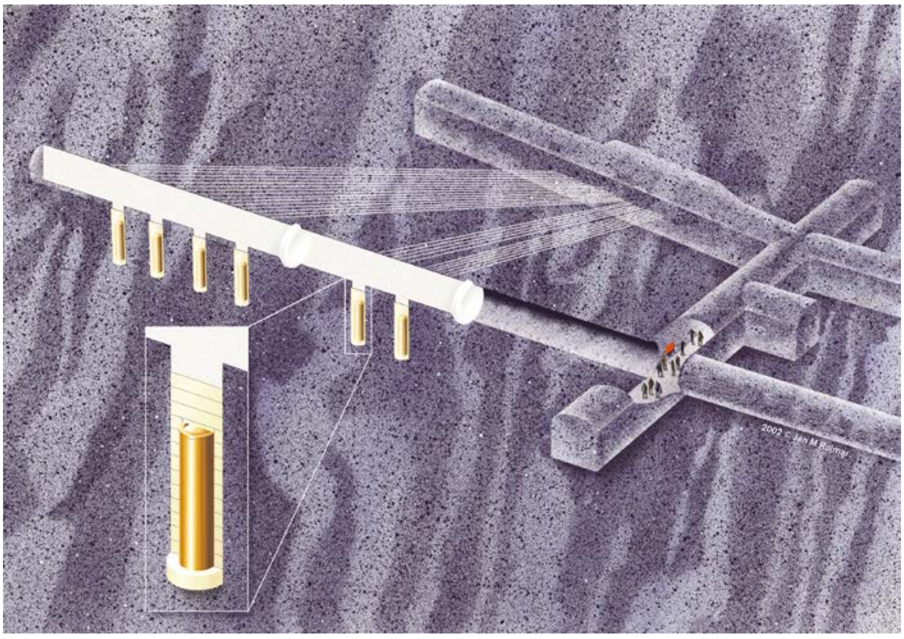

Figure 3-23. *Schematic view of the layout of the Prototype Repository (not to scale).*

Instrumentation is used to monitor processes and evolution of properties in canister, buffer, backfill and near-field rock. Examples of processes that are studied include:

- Water uptake in buffer and backfill.
- Temperature distribution (canisters, buffer, backfill and rock).
- Displacement of canister.
- Swelling pressure and displacement in buffer and backfill.
- Stress and displacement in the near-field rock.
- Water pressure build up and pressure distribution in rock.
- Gas pressure in buffer and backfill.
- Chemical processes in rock, buffer and backfill.
- Bacterial growth and migration in buffer and backfill.

The outer test section was retrieved during 2011 after approximately eight years of water uptake of the buffer and backfill.

3.11.2 Concrete and Clay

Background

In the present SFR and future repositories for low-and intermediate level radioactive waste, SFL and SFR 3, interaction will occur between the barriers (mainly comprising different forms of cementitious materials but also bentonite clay) and the waste. These interactions will affect the barriers chemical, physical and mechanical properties and their ability to prevent the release of radio nuclides.

The project Concrete and Clay was initiated in 2009 with the aim of increasing the level of understanding of processes that may occur in SKB's repositories for low- and intermediate level waste, the Final Repository for Short-Lived Radioactive Waste, SFR, and the future Final Repository for Long-Lived Radioactive Waste, SFL.

Objectives

The objective of this project is to increase the understanding of the processes occurring in repositories for low- and intermediate level waste. Three main fields of interest have been identified:

- Decomposition of different waste form materials and transport of the degradation products in a cement based matrix.
- Mineral alterations in the concrete itself and at the interface between concrete and different types of bentonite in the presence of degradation products.
- Transport of degradation products in bentonite under natural conditions and mineral alterations in the bentonite.

Experimental concept

The experiments comprise a total of 12 concrete cylinders containing materials representative for low- and intermediate level waste which are deposited in four different deposition holes in NASA0507A and NASA2861A respectively. Further also a total of 150 bentonite blocks in 5 different packages are deposited in TAS06. In each bentonite block (∅ 270 mm and height 100 mm) 4 different material specimens have been placed.

As a complement to the large scale experiments, also reference experiments have been prepared. These comprise different types of waste form materials which are placed in steel containers filled with a mixture of Äspö ground water and hardened and crushed cement paste. The objective of these experiments is to serve as a guide for the decision on when to retrieve the large scale experiments.

Experiments will be retrieved at regular intervals and the last will be left until the closure of the Äspö HRL.

Results

Installation of the experiments

During 2010 and 2011 a total of 12 concrete cylinders containing different waste form materials were prepared and deposited in two holes in each of NASA0507A and NASA2861A respectively. During 2010 also 20 steel containers containing cement buffered Äspö water and material specimens representative of low- and intermediate level waste were prepared. About half of these containers were stored at 50 °C in a temperature controlled water bath and the remaining simply under a protective roof in the Äspö tunnel at a temperature of about 13 °C.

During 2014 the bentonite experiments were prepared. A total of 150 bentonite blocks, each also containing 4 different material specimens, were manufactured from MX-80, Asha, Febex and Ibeco RWC. The experiments are now deposited in 5 different deposition holes in TAS06. The preparation of the specimens and the installation procedure is described in Mårtensson (2015).

Retrieval of experiment #20

During 2017 experiment #20 was overcored and retrieved. Overcoring was initially planned to be done by removing the sand between the titanium cage containing the bentonite blocks and the walls of the deposition hole. However, as that method was not successful, traditional overcoring was instead used.

About 20 holes was drilled at a distance of about 100 mm from the periphery of the deposition holes, Figure 3-24, left image. Due to fracturing of the bedrock and jamming of the package caused by lose pieces of rock; the entire package could not be lifted at once. Instead the lose rock pieces had to removed one by one (Figure 3-24, right image) until the package could be lifted, Figure 3-25.

The packages was then wrapped in plastic and transported to the bentonite hall where the individual bentonite blocks were segmented, packed in vacuum sealed aluminium bags, labelled and finally shipped for laboratory analysis, Figure 3-26. Each segment contained ¼ of a block in which a specimen made of ordinary cement paste or low-pH cement paste had been placed. Each specimen also contained a metal powder or a powder of a metal chloride representative for low- and intermediate level radioactive waste as described in Mårtensson (2015). The analysis is planned to be ready by mid 2018. A full report covering retrieval and analysis is planned for 2019.

Figure 3-24. Over coring of experiment #20 and removal of the fractured rock from the deposition hole.

Figure 3-25. Lifting of the bentonite package.

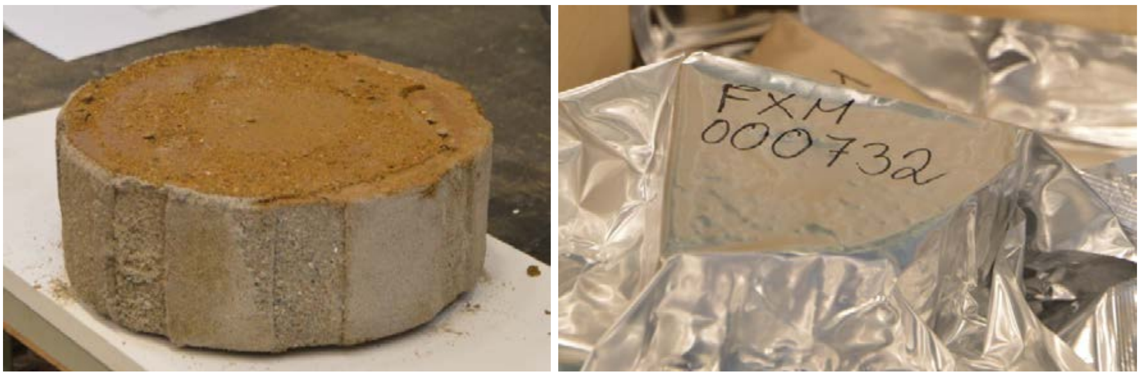

Figure 3-26. *One of the bentonite blocks, prior to segmentation (left image) and after sementation and packaging (right image).*

3.11.3 Alternative Buffer Materials

Background

The Alternative Buffer Materials (ABM) project was started in 2006 with the purpose to evaluate different bentonites as possible buffer candidates, as up this point mainly the Wyoming MX80 bentonite had been in focus.

Objectives

The objectives are to (i) characterise different bentonites regarding composition and properties, (ii) to evaluate their long term performance during realistic conditions, and (iii) to identify and study processes that may occur in the bentonite buffer during special conditions.

Experimental concept

The ABM project consists of a combination of field experiments at the Äspö HRL and laboratory studies of the bentonites performed at a varity of laboratories, including both SKB and external partners.

The field test include more than ten different compacted bentonites, typically heated at 130 °C, the bentonite block outer diameter is 3 dm, and the central heater has a diameter of 1 dm and the heater material is iron based. The selection of bentonites corresponds to typical commercially relevant bentonite types as well as scientifically more exotic variants.

In recent years the ABM project has been partly overlapping with other SKB projects called the material science projects (KBP 1009, Svensson et al. 2017; KBP1015). In the ABM project the focus is on the scientific difference between the bentonites composition and performance, while in the material science projects the focus is much more on the technical industrialisation process of how to industrialise the analytical and sampling techniques in order to achieve an effective quality control of the buffer and backfill bentonites.

Results

In 2006 three experiments were started (ABM 1-3) and in 2012 three additional packages were installed (ABM 4-6). The ABM1 was excavated in 2009 after 2½ years of heating in the rock (e.g. Svensson et al. 2011, Svensson and Hansen 2013), and in 2013 the ABM2 was excavated after 6½ years of heating (e.g. Svensson 2015). The bentonites in ABM1 and ABM2 were typically highly ion exchanged and equilibrated with the Äspö ground water, making the distribution of ions in the different blocks more even, and the salt content typically also increased somewhat. Precipitates (e.g. Ca carbonates/sulphates and NaCl) and iron corrosion products typically formed locally. The integrity of the montmorillonites was typically fairly intact, with only some minor formation of trioctahedral smectite (saponite/ferrosaponite) very close to the corroding iron heater, however, with no expected impact on the buffer performance (Svensson 2015).

Since the start annual ABM meetings has been held for discussing results and collaboration between the many international groups, and every year a number of presentations of the different groups have been held on a selection of international clay conferences, making the ABM experiment a very important and central experiment for bentonite long term performance studies, as well as Round Robin tournaments with the purpose of investigating and increasing the performance of selected laboratory analytical techniques.

In 2017 the ABM5 was excavated. The ABM5 experiment was different from the others, as it was water saturated at a lower temperature of 80 °C, and during its final year it was heat shocked at 150–200 °C in order to study effects from temperatures much higher than the expected boiling point (as a higher design temperature of the buffer would be economically very beneficial if possible). The ABM5 bentonite blocks were upon excavation highly fractured due to the very high temperature (Figure 3-27), detailed analysis of the blocks are to be performed in the coming years.

3.11.4 KBS-3 Method with Horizontal Emplacement

Background

The KBS-3 method is based on the multi-barrier principle and constitutes the basis for planning the final disposal of spent nuclear fuel in Sweden. The possibility to modify the reference design, which involves vertical emplacement of singular canisters in separate deposition holes (KBS-3V), to consider serial disposal of several canisters in long horizontal drifts (KBS-3H) has been considered since the early 1990s, see Figure 3-28.

***Figure 3-27.** Highly fractured bentonite blocks from the very high temperature experiment ABM5 excavated in 2017.*

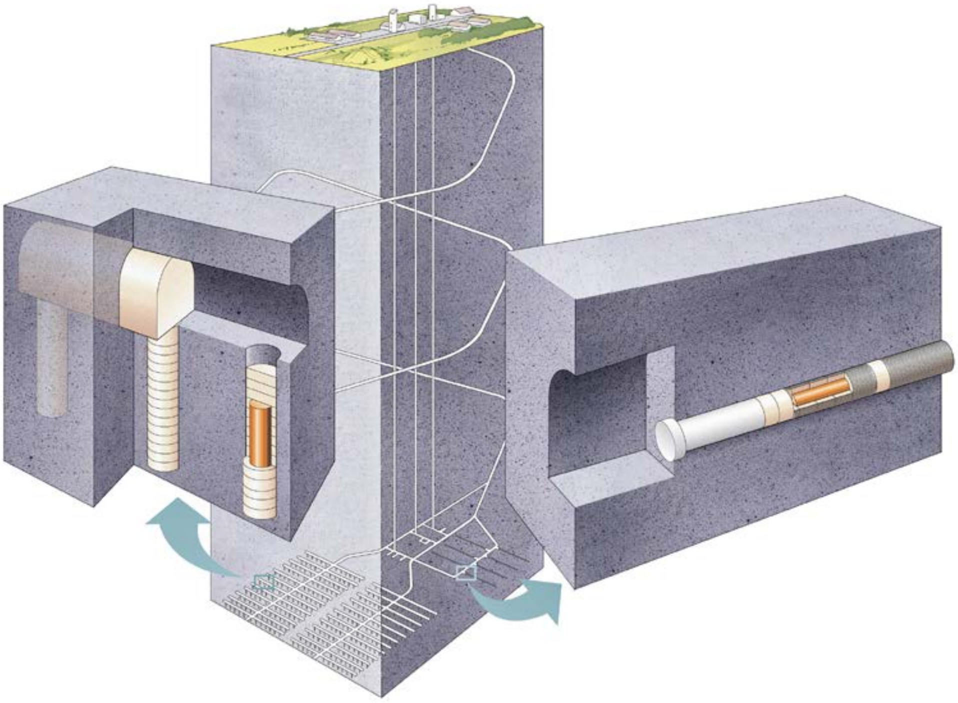

***Figure 3-28.** Schematic drawing of the KBS-3V reference design (left) and KBS-3H (right).*

In 2001 SKB published a RD&D programme (SKB 2001) for the KBS-3H variant with four phases. The current joint (SKB/Posiva) project phase, KBS-3H System Design, was initiated in 2011 and it will be concluded end 2016. All development steps have been made in close cooperation between SKB and Posiva. The current project phase covers all areas of the KBS-3 method but the focus is on the KBS-3H specific issues.

Objectives

The final goal of the KBS-3H System Design phase is to bring KBS-3H design and system understanding to such a level that a PSAR can be prepared and that a subsequent comparison between KBS-3V and KBS-3H is made possible. For components and sub-systems this will be achieved by assessing the design premises/basis, updating the requirements, verifying that the design solution meets and can be manufactured according to the requirements and based on this, reaching the system design level in accordance with SKB's model of delivery. The system design level also includes devising plans for industrialisation/implementation including control programs and risk assessments.

Vital in reaching the project´s main objective is to produce the basis and carry out long-term safety evaluation. The safety evaluation will be done for Olkiluoto site only. The work for Olkiluoto is deemed to provide results that will indicate if KBS-3H is also applicable to Forsmark site. This work will be based on earlier safety assessment work and will make use of Posiva´s safety case "TURVA-2012" for KBS-3V (produced by SAFCA) for Olkiluoto and SR-Site for Forsmark. This is expected to be achieved by the end of 2016.

Experimental concept

The DAWE (Drainage, Artificial Watering and air Evacuation) design alternative has been chosen as the reference design for the KBS-3H concept. Consequently, the deposition drift is divided into two compartments with an approximate length of 150 m each.

In the KBS-3H concept, the canisters are placed in long horizontal deposition drifts, see Figure 3-29. Unlike the KBS-3V concept (reference design), the KBS-3H concept utilises a prefabricated installation package called Supercontainer that is assembled in an industrial process at the canister reloading station before disposal, thus reducing the possibility of human error. The Supercontainer consists of a perforated protective shell made of metal with bentonite buffer and copper canister installed inside the buffer. Several Supercontainers are installed into each deposition drift. The drifts are almost horizontal, and their maximum length is 300 metres. The drifts have a diameter of c. 1 850 mm, and they have a slight upward inclination (c. 2°), which is why water is removed from the drifts by gravity along the bottom of the deposition drift during installation. The Supercontainers and the bentonite blocks installed in the drift stand on parking feet between which the inflow water can flow out of the drift. The gap between the Supercontainer and the drift wall is 44.5–48 mm.

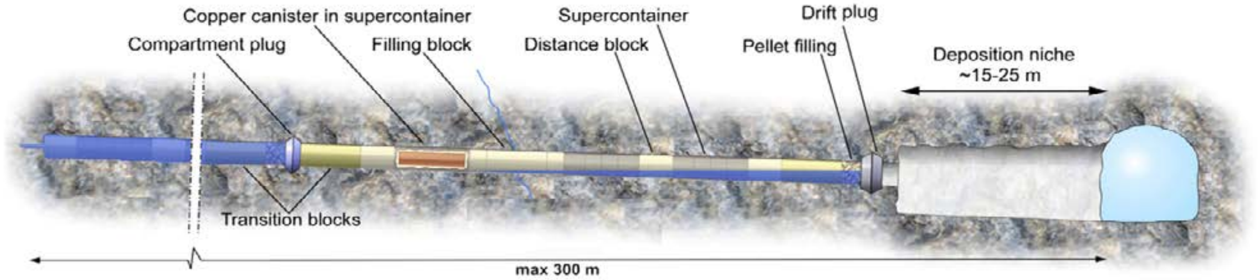

Figure 3-29. *KBS-3H reference design DAWE with its main components; the plugs with their transition zones, the Supercontainers, and the distance and filling blocks. The illustration shows an ongoing artificial water filling procedure of the second compartment.*

Differences between KBS-3V and KBS-3H

The main differences between the two concepts: the horizontal and the vertical emplacement can be divided in the following aspects when comparing the two options from the angle of KBS-3H:

- Cost aspect
  - Less costly mainly due to lower volumes of excavation and backfilling.
- Environmental aspect
  - Less excavation (no deposition tunnels).
  - The volume to be backfilled much smaller.
  - Smaller clay production facility needed.
- Operational safety
  - No risk of canister falling during installation.
  - Risk of fire is smaller due to less amount of vehicles and machines which form the most significant fire load.
- Occupational safety
  - Less traffic in the repository.
  - The number of work phases smaller.
  - Less tunnel reinforcement needed during installation phase (reinforcement structures need to be dismantled before deposition).
  - Less explosives will be stored underground since mechanical excavation used for drifts.
  - Less risks for being exposed to radiation.
- Long-term safety
  - The most important of all aspects.
  - Currently disadvantageous for 3H due to the issue of chemical erosion entailing the so-called "domino effect".
  - The definition of initial state better due to artificial wetting.

3.11.5 Large scale gas injection test

Background

The large-scale gas injection test (Lasgit) is a full-scale in situ test designed to answer specific questions regarding the movement of gas through bentonite in a mock deposition hole located at 420 m depth in the Äspö Hard Rock Laboratory (HRL).

The multiple barrier concept is the cornerstone of all proposed schemes for the underground disposal of radioactive wastes. Based on the principle that uncertainties in performance can be minimised by conservatism in design, the concept invokes a series of barriers, both engineered and natural, between the waste and the surface environment. Each successive barrier represents an additional impediment to the movement of radionuclides. In the KBS-3 concept, the bentonite buffer serves as a diffusion barrier between the canister and the groundwater in the rock. An important performance requirement of the buffer material is that it should not cause any harm to the other barrier components. Gas build-up from, for example, corrosion of the iron insert, could potentially affect the buffer performance in three ways:

- Permanent pathways in the buffer could form at gas breakthrough. This could potentially lead to a loss of the diffusion barrier.
- If gas cannot escape through the buffer, the increase in pressure could lead to mechanical damage of other barrier components.
- The gas could de-hydrate the buffer.

Knowledge pertaining to the movement of gas in initially water saturated buffer bentonite is largely based on small-scale laboratory studies. While significant improvements in our understanding of the gas-buffer system have taken place, laboratory work highlighted a number of uncertainties, notably the sensitivity of the gas migration process to experimental boundary conditions and possible scale dependency of the measured responses. These issues are best addressed by undertaking large scale gas injection tests. Additionally, a full-scale experiment designed to identify gas pathway formation is suited to study the hydration of the bentonite buffer over a 10+ year time-scale.

The experiment has been in continuous operation since February 2005. The first two years (Stage 1, up to day 843) focused on the artificial hydration of the bentonite buffer. This was followed by a year-long programme of hydraulic and gas injection testing in filter FL903 (Stage 2, day 843 to 1 110). A further year of artificial hydration occurred (Stage 3, day 1 110 to 1 385), followed by a more complex programme of gas injection testing in filter FL903 (Stage 4, day 1 430–2 064). In late 2010 attention moved from the lower array filter (FL903) to the upper array (FU910). Stage 5 started on day 2 073 and was completed on day 2 725. Focus then returned to the lower array (FL903) in late 2012 and involved a gas injection test throughout 2013. In 2014, the focus of the experiment was to determine the hydraulic properties of the bentonite buffer at all measurable locations by means of two-stage hydraulic head tests. In 2015, the experiment returned to a period of prolonged natural and artificial hydration.

Objectives

The aim of Lasgit is to perform a series of gas injection tests in a full-scale KBS-3 deposition hole. The objective of this experimental programme is to provide data to improve process understanding and test/validate modelling approaches which might be used in performance assessment. Specific objectives are:

- Perform and interpret a series of large-scale gas injection test based on the KBS-3 repository design concept.
- Examine issues relating to up-scaling and its effect on gas movement and buffer performance.
- Provide additional information on the processes governing gas migration.
- Provide high-quality test data to test/validate modelling approaches.
- Provide data on the hydration of a full-scale KBS-3 system.

Experimental concept

Lasgit is a full-scale demonstration project conducted in the assembly hall area in Äspö HRL at a depth of −420 m (Figure 3-30). A deposition hole, 8.5 m deep and 1.8 m in diameter, was drilled into the gallery floor. A full-scale KBS-3 canister (without heater) has been emplaced in the hole. Thirteen circular filters of varying dimensions are located on the surface of the canister to provide point sources for the injection of gas to mimic canister defects. Pre-compacted bentonite blocks with high initial water saturation have been installed in the deposition hole. The hole has been capped by a conical concrete plug retained by a reinforced steel lid capable of withstanding over 5 000 tonnes of force.

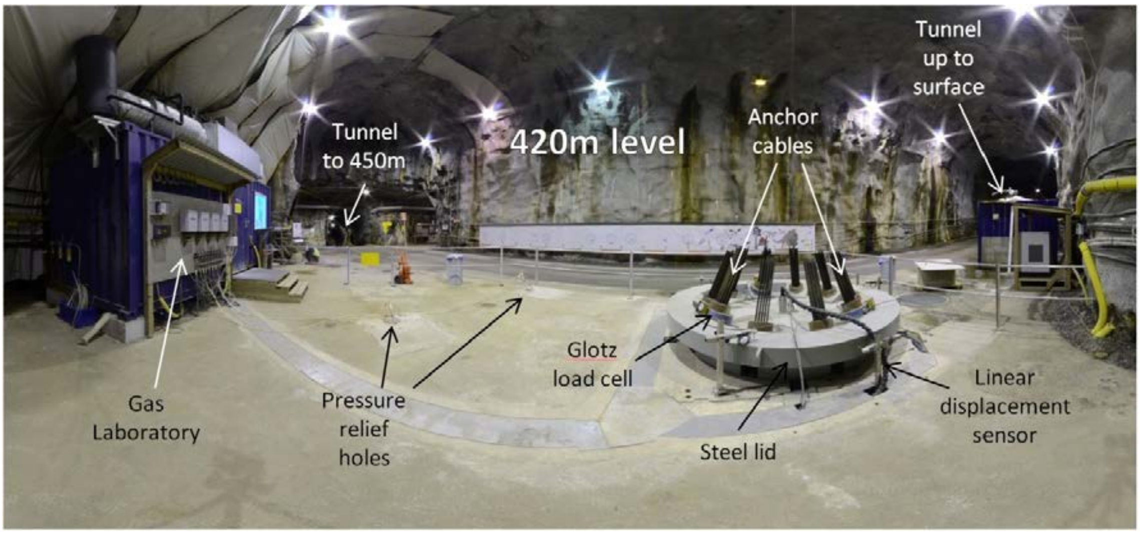

Figure 3-30. *The Large scale gas injection test at the -420 m level in Äspö HRL.*

In the field laboratory instruments continually monitor variations in the total stress and porewater pressure at the borehole wall, the temperature, any upward displacement of the lid and the restraining forces on the rock anchors. The experiment is a "mock-up test" which does not use any radioactive materials.

Lasgit has consisted of four operational phases: the installation phase, the hydration phase, the gas injection phase, the homogenisation phase. The installation phase was undertaken from 2003 to early 2005 and consisted of the design, construction and emplacement of the infrastructure necessary to perform the Lasgit experiment.

The hydration phase began on the 1st February 2005 with the closure of the deposition hole. The aim of this phase of the experiment was to fully saturate and equilibrate the buffer with natural ground-water and injected water. The saturation and equilibration of the bentonite was monitored by measuring pore pressure, total pressure and suction at both the buffer/rock interface and key locations within individual clay blocks. The hydration phase provided an additional set of data for (T)HM modelling of water uptake in a bentonite buffer.

3.11.6 In situ corrosion testing of miniature canisters

Background

The post-failure evolution of the environment inside a copper canister with a cast iron insert is important for the assessement of the release of radionuclides from the canister in a failure scenario. After failure of the outer copper shell, the course of the corrosion in the gap between the copper shell and the cast iron insert will determine the subsequent release of radionuclides. A possible scenario is that the formation of solid iron corrosion products could exert an internal load on the copper shell, which could lead to deformation. This process has been studied earlier both in laboratory experiments (Bond et al. 1997) and by modelling (Smart et al. 2006).

In the MiniCan in situ test, five miniature copper-cast iron canisters have been exposed to the groundwater flow in boreholes in the Äspö HRL since late 2006. In order to model failure and allow corrosion of the iron insert, millimetre defects were introduced into the outer copper shell. Corrosion will take place under saline, eventually oxygen-free and reducing conditions in the presence of the microbial flora in the Äspö groundwater; such conditions are very difficult to create and maintain for longer periods of time in the laboratory. Consequently, the MiniCan experiment will be valuable for understanding the microbiological influences on canister corrosion and degradation, as well as for the understanding the development of the environment inside the canister after penetration of the outer copper shell.

Objectives

The main objectives of the experiment are to provide information about: 1) how the environment inside a copper-cast iron canister would evolve if failure of the outer copper shell was to occur, and 2) how microbiological activity affects canister corrosion. The results of the experiment will be used to support process description in the safety assesment.

The following specific issues are being addressed:

- Does water penetrate through a small defect into the annulus between the cast iron insert and the outer copper canister?
- How does corrosion products spread around the annulus in relation to the leak point?
- Does the formation of anaerobic corrosion product in a constricted annulus cause any expansive damage to the copper canister?
- Is there any detectable corrosion at the copper welds?
- Are there any deleterious galvanic interactions between copper and cast iron?
- Does corrosion lead to failure of the lid on the iron insert?
- What are the corrosion rates of cast iron and copper in the repository environment?
- What is the risk of stress corrosion cracking of the copper?
- How does the microbial flora of the deep ground water influence the development of canister corrosion?

Experimental layout

In late 2006, five experimental packages containing miniature copper-cast iron canisters were mounted at a depth of 450 m in the Äspö HRL (Smart and Rance 2009). The model canister design simulates the main features of the SKB reference canister design. The cast iron insert contains four holes simulating the fuel assembly channels, together with a bolted cast iron lid sealed with a Viton O-ring. The copper lid and base is electron beam welded to the cylindrical body. The annulus between the cast iron insert and the outer copper body is < 30 μm wide. All the canisters have one or more 1 mm diameter defects in the outer copper shell.

The canisters are mounted in electrically insulated support cages (Figure 3-31), which contain bentonite clay of two different densities. There is no direct electrical contact between the copper canister and the stainless steel support cages. One miniature canister does not have any bentonite, to investigate the effect of direct groundwater flow on the corrosion behaviour.

Cast iron and copper corrosion coupons are mounted inside the support cages of each experimental package and corrosion behaviour is monitored electrochemically. Cast iron and copper weight loss specimens are also present. Each support cage contains a "sandwich type" copper-cast iron specimen to investigate oxide jacking effects and galvanic corrosion. U-bend and wedge open loading stress corrosion specimens are mounted in one of the boreholes in direct contact with the groundwater, to assess the possible risk of stress corrosion cracking of copper. In addition, two of the canisters will be monitored using strain gauges to detect any expansion in the copper shell. The redox potential, E_h, is being monitored using a combination of metal oxide, platinum and gold electrodes.

The boreholes are located in a region with many fractures, leading to a plentiful supply of groundwater to the canisters. The experiments are continuously monitored to measure the following parameters:

- Corrosion potential of the model canister, cast iron and copper.
- Electrochemical potential of gold, platinum and a mixed metal oxide Eh probe.
- Corrosion rate of cast iron and copper, using linear polarisation resistance (LPR), AC impedance (ACI), electrochemical noise (ECN), and the electric resistance in a copper wire.
- Strain on the surface of two of the model canisters.
- Hydrostatic pressure in the boreholes.

Water samples are taken regularly from the support cages as weel as from the boreholes to monitor the development of the local water chemistry. The experiments will remain in situ for several years, after which they will be retrieved, dismantled and the evolution of the corrosion front inside the canister will be analysed. Further details on experimental concept are presented in Smart and Rance (2009).

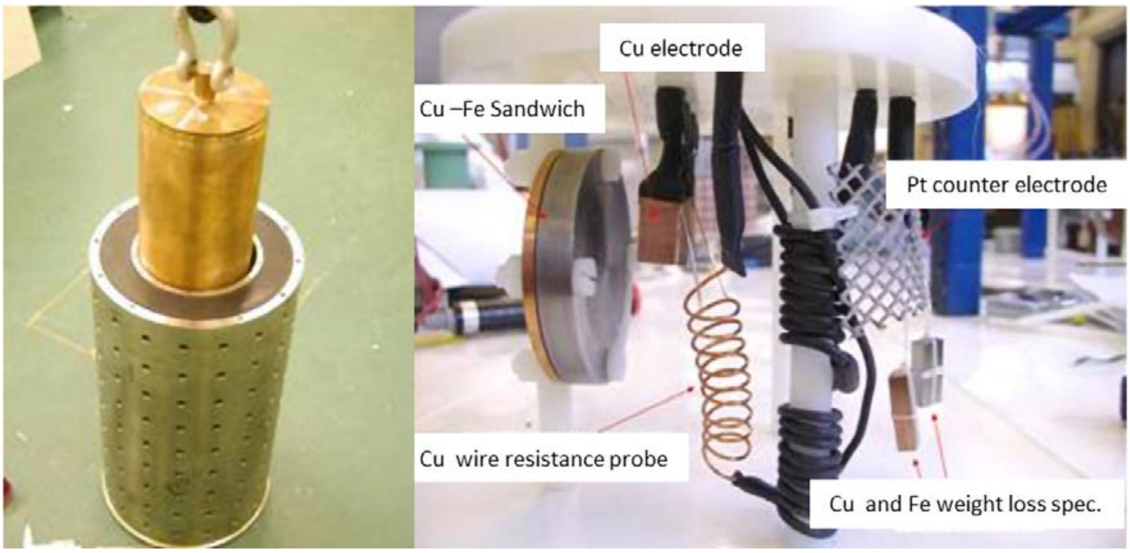

Figure 3-31. *Model canister being lowered into support cage containing bentonite pellets in annulus (left). Test electrodes inside support cage around model canister experiments (right).*

Background

Comprehensive research and development work has been carried out during the last thirty years in order to determine the basic behaviour of unaltered bentonite material. The results have been reported in technical reports, scientific articles, and models concerning both unsaturated and saturated buffer conditions. The models are believed to well describe the function of an unaltered MX-80 bentonite buffer after water saturation with respect to physical properties, e.g. swelling pressure, hydraulic conductivity and rheological behaviour.

In a HLW repository, there will be a temperature increase and a thermal gradient over the bentonite buffer as a result of the decaying spent fuel. Original water in the bentonite will thereby be redistributed parallel to an uptake of water from the surrounding rock. The Long Term Test of Buffer Material (LOT) project aims at studying possible alteration of the bentonite as a result of the hydro-thermal evolution, both with respect to mineralogy and to sealing properties.

Objectives

The general objectives in the LOT test series may be summarized in the following items:

- Collect data for validation of models concerning buffer performance under quasi-steady state conditions after water saturation, e.g. swelling pressure, hydraulic conductivity and rheological properties.
- Check of existing models concerning buffer degrading processes, e.g. mineral redistribution and montmorillonite alteration.
- Check of existing models concerning cation diffusion in bentonite.
- Collect information concerning survival, activity and migration of bacteria in bentonite under repository-like conditions.
- Check of calculated data concerning copper corrosion, and collect information regarding the character of possible corrosion products.
- Collect information, which may facilitate the realization of the full-scale test series, e.g. the Prototype project, with respect to preparation, instrumentation, retrieval, subsequent analyses, evaluation and data handling.

Experimental concept

The LOT test series includes seven test parcels, which all contain a heater, central tube, clay buffer, instruments and parameter controlling equipment. The test parcels have been placed in boreholes with a diameter of 300 mm and a depth of around 4 m. The test concerns realistic repository conditions except for the scale and the controlled adverse conditions in four parcels. Temperature, total pressure, water pressure and water content, are measured during the heating period. At termination of the tests, the parcels are extracted by overlapping core-drilling outside the original borehole. The water distribution in the clay is determined and subsequent well-defined mineralogical analyses and physical tests of the buffer material are made, see Table 3-1.

Table 3-1. Test program for the LOT project.

Type	No.	max T (°C)	Controlled parameter	Time (years)	Remark
A	1	130	T, [K^+], pH, am	1	Reported, TR-00-22
A	0	120–150	T, [K^+], pH, am	1	Reported, TR-09-31
A	2	120–150	T, [K^+], pH, am	6	Reported, TR-09-29
A	3	120–150	T	>10	Ongoing
S	1	90	T	1	Reported, TR-00-22
S	2	90	T	9	Ongoing
S	3	90	T	>10	Ongoing

A = adverse conditions, S = standard conditions, T = temperature, [K^+] = potassium concentration, pH = high pH from cement, am = accessory minerals added.

4 Mechanical- and system engineering

4.1 General

At SKB, techniques for the final disposal of spent nuclear fuel are under development. A total of over 200 different products and components known today are to be developed for the Spent Fuel Repository. Both well established existing technologies and new technologies will be used. As far as possible standard equipment, modified and adapted to the activity, will be used. Where no standard equipment is available new objects must be developed.

Assessment has been made of when the production of machines must begin and when they need to be completed, as well as whether production of prototypes is necessary. The number of objects and affiliated information are due to change since the specifications are working documents.

Newly developed and modified equipment are primarily tested at Äspö HRL and the Canister Laboratory in Oskarshamn. At these sites, facilities suitable for testing are available.

During 2017, two projects within mechanical- and system engineering have been active at Äspö:

- Equipment for milling of buffer blocks.
- Backfill pellet installation equipment.

These projects are described in the following sections.

4.2 Equipment for milling of buffer blocks

Background

In the repository for spent nuclear fuel, the copper canister will be deposited in deposition holes. The canister will be set down on a bentonite block belonging to the buffer. For the canister to be completely vertical in the deposition hole the bottom of the hole must be completely horizontal, or, the buffer block must be levelled after installation in the hole.

The work presented here describes the work aimed at proposing and testing a concept for milling the bottom bufferblock in order to find an alternative to levelling the bottom of the deposition hole, so that the overall deposition process in the repository is rational and robust.

Objectives

The objective of the work is to design, construct and test a prototype for milling the bottom buffer block so that a canister can be vertically emplaced in a deposition hole where the bottom is not completely horizontal.

Experimental concept

The concept for the design is to mill the track for the bottom flange of the canister so that the canister can stand vertically. The circular equipment rests on the periphery of the bottom buffer block.The prototype is leveled horizontally using a gyro and three different motors. The milling tool is a standard tool for milling. The motor spindle is installed on an axis that spans the diameter of the equipment. The motor spindle can move along the length of the axis.The axis is mounted on the circular frame and can be rotated in the horizontal plane around its center. The two movements together allow the motor spindle to mill the block in the area of interest. A prototype of the equipment has been produced, see Figure 4-1.

The testing is divided into two phases where a number of cases have been tested during 2017 and some will be tested during 2018. The tests carried out in 2017 concerned the linear motor together with the motor spindle. The remaining work is to integrate and test the circular drive and to test the milling of a buffer block in full scale.

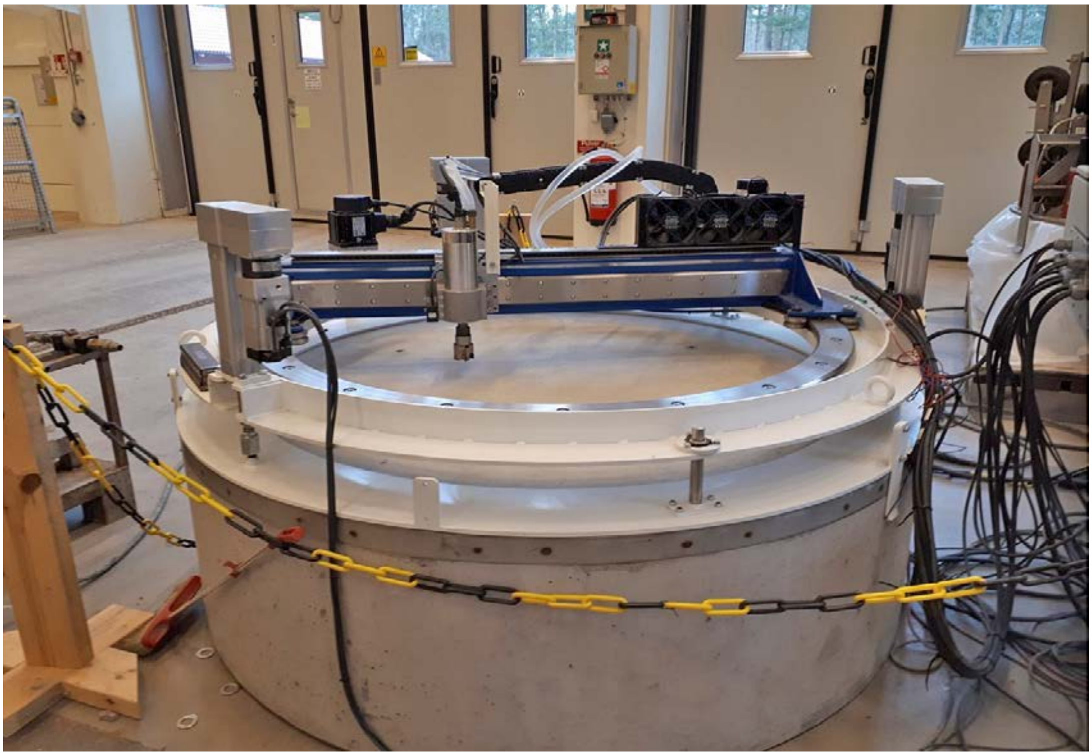

Figure 4-1. *The prototype equipment.*

Results

During 2017, a test rig for the motor spindle and the linear drive was built in the Multi-purpose test facilities at Äspö, see Figure 4-2.

The milling of bentonite with the motor spindle was tested with good results, see Figure 4-3 and Figure 4-4. Tests of the drive of the linear movement was also successfully carried out, showing that the integration of software and hardware is functional and that the linear parts of the equipment works as expected.

Figure 4-2. *Test rig for the linear motor and the motor spindle.*

Figure 4-3. Motor spindle milling in bentonite.

Figure 4-4. Milled track in bentonite.

4.3 Backfill pellet installation equipment

Background

The deposition tunnels are to be backfilled with bentonite blocks, while the gap between blocks and the rock wall will be filled with bentonite pellets. The blocks will also be stacked on a layer of pellets on the floor. Equipment is being developed for the installation of pellets, and during 2017 tests have been performed with equipment for creating the bottom pellet layer.

Objectives

The aim of the project is to produce a concept for pellet installation that can fulfill the requirements on quality, control and capacity. Method and equipment for installation of pellets on the floor has been developed.

Experimental concept

The choosen concept is to distribute pellets on the tunnel floor using a screw, see Figure 4-5. This method fulfils requirements such as:

- Low dust generation.
- Careful handling of pellets.
- Capable of handling uneven surfaces.
- Energy effective.
- Compact, should be able to fit on backfill machine.

The prototype has the dimensions 4 500 mm × 3 500 mm, and weighs around 800 kg.

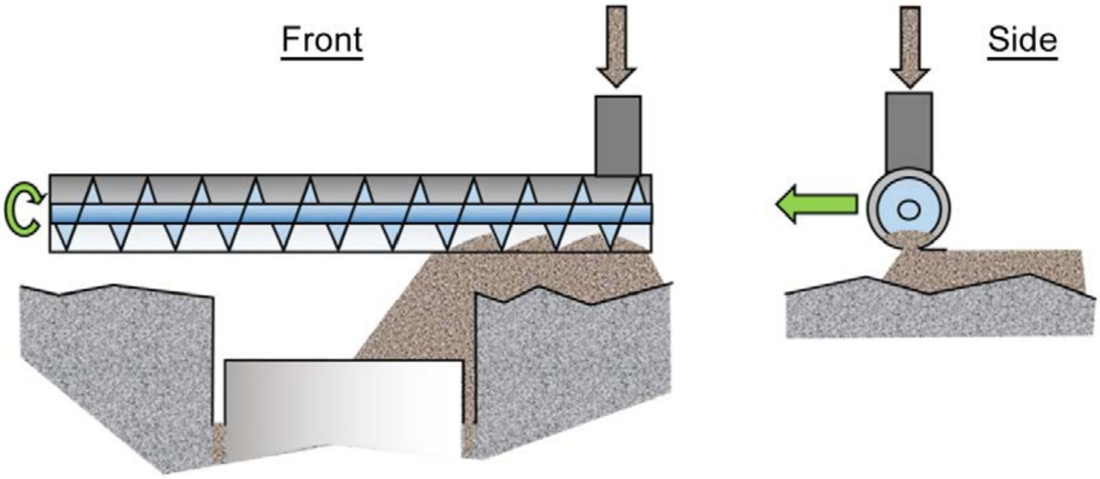

Figure 4-5. Pellet screw concept.

When the space between screw tube and floor is filled with pellets a signal is sent to stop the screw, which is then moved sideways 125 mm. The sensor senses that more pellets are needed and the screw starts up again. This is repeated until the length of the pellet layer is 1 000 mm.

The tests were designed to verify the equipment's ability to create an even pellet layer. The width of the layer, as well as dust generation and time consumption was measured and estimated.

Results

The equipment worked as planned, see Figure 4-6. After the layer was completed the surface for stacking blocks was measured to 1 000 mm × 4 000 mm, with a depth of 100 mm. This corresponds to ca 400 kg pellets, and such an area can be produced in 5–8 minutes. Horisontalness and evenness was measured, and was found to be very good. Dust generation was moderate and mainly occured during filling of the open pellet storage.

Some observations were made which will be considered in the continued development of the equipment, but that had no affect on the test results.

Figure 4-6. Pellet layer being produced during test.

5 Äspö facility

5.1 General

The Äspö facility comprises the Äspö Hard Rock Laboratory and the above ground Research Village.

During 2011–2012 new tunnels and experiment sites were constructed. In total about 300 m new tunnel meters were excavated.

Äspö HRL is the residence of the unit Repository Technology but the unit includes employees in both Äspö, Stockholm and Forsmark. The main responsibilities of the unit are to:

- Develop, demonstrate and streamline repository technology for nuclear waste, including installation methods, transport- and handling techniques.
- Develop, administer and operate Äspö HRL as an attractive resource for experiments, demonstration tests and visitor activities.
- Actively work for a broadened use of Äspö HRL, with the aim to turn the facility over to future research- and development parties.

The organisation of the Repository Technology (TD) unit is described in Section 1.3 in this report.

5.2 Multi-purpose test facilities

Before building a Spent Fuel Repository, further studies of the behaviour of the buffer and backfill materials under different installation conditions are required. SKB has constructed Multi-purpose test facilities at Äspö, designed for studies of buffer and backfill materials. The laboratory has been in operation since spring 2007, and was previously called the Bentonite Laboratory. The name has been changed to reflect the bredth of research that is and can be performed in the facilities. The Multi-purpose test facilities enables full-scale experiment under controlled conditions and makes it possible to vary the experiment conditions in a manner which is not possible in the Äspö HRL.

The laboratory, a hall with dimensions 15 × 30 m, includes two deposition holes where the emplacement of buffer material at full scale can be tested under different conditions. The hall is used for testing of different types of backfill material and the further development of techniques for the backfilling of deposition tunnels.

Other equipment in the laboratory includes an Eirich bentonite mixer with a load capacity of 1 000 kg to allow mixing of bentonite with desired water ratio, and a KAHL press for fabrication of extruded pellets combined with a Baron CXL 4500 transporter and a CZ Multiscreen. The press produces extruded pellets with a diameter of 6 mm and a length of 20 mm. The production capacity is approx. 700 kg/h. A self cleaning filter system ensures a good working environment with low dust emissions.

In 2017 the focus has been on preliminary tests with different materials such as bentonite, sand and concrete. These materials are the components of the borehole seal concept that SKB will test in 2018 (Sandwich model).

5.3 Material Science Laboratory

A research laboratory for bentonite analysis and experiments has been established on the Äspö facility, and is hosted by the department of research and safety analysis at SKB.

The purpose of the laboratory is to act as a research infrastructure for internal bentonite investigations, supporting the research and technical development at SKB, including the very important internal competence buildup.

The laboratory is used in a number of projects and activities including technological development in (i) the material science projects (KBP1009 and KBP1015), and for various research studies such as (ii) the Alternative Buffer Material (ABM), (iii) chemical erosion properties of bentonite, (iv) microbiological activity of sulphate reducing bacteria (SRB) at unsaturated conditions, (v) evolution of gases in bentonite during unsaturated conditions, (vi) impact of reducing conditions on the bentonite swelling pressure, and (vii) high pH effects on montmorillonite stability. During 2017 activity (i), (iii; Figure 5-1) (iv; Figure 5-2), (vi) and (vii) had the highest activity.

The infrastructure consists of equipment allowing handling, preparation, purification and analysis of bentonites, or investigation of important properties. This includes classical wet chemical analysis such as cation exchange capacity (CEC), exchangeable cations (EC), chemical reduction of iron (CBD), geotechnical measurements such as water content, density, swelling pressure and hydraulic conductivity, and solid state investigations using non destructive techniques such as X-ray diffraction (XRD) for mineralogy, X-ray fluorescence (XRF) for chemical content, infra red spectroscopy for detailed investigations of the clay mineral crystal structure, and µ-raman spectroscopy for investigations requiring high spatial resolution. A very large glovebox is also available for anaerobic studies or sampling of oxygen sensitive field samples, such activity (iv) and (vi).

Figure 5-1. *Experimental cell for measuring of chemical erosion of different bentonites.*

Figure 5-2. *Sulphide (in the form of CuS) formed by microbiological activity of sulphate reducing bacteria from gypsum in the presence of liquid water. Gypsum is a common mineral in bentonite, and this sulphate to sulphide transformation is the subject of the study.*

5.4 Facility Operation

Background and objectives

The main goal for the operation of the rock laboratory is to provide a facility which is safe for everybody working in, or visiting it, and for the environment. This includes preventative and remedial maintenance in order to ensure that all systems such as drainage, electrical power, ventilation, alarmand communications are available in the underground laboratory at all times.

Results

The facility has had a stable operation during 2017.

The external Rock inspectation, which was carried out in 2016, has led to some focus activities in different areas in the tunnel:

- Inventory of rock bolts based on previous choice of material.
- A plan for exchange of rock bolts has been developed.
- Rock maintenance at the elevator shaft.
- Reinforcement in the rescue chamber.

Extensive ventilation work has been performed at the −460 m level in the tunnel, as old ventilation ducts have been replaced with new ones.

A new, more energy efficient, heat pump has been installed for heating the office buildning.

Mostly of the luminaires in the tunnel has been replaced to LED lights. This is a better working environment and reduces energy consumtion.

Some improvemets in the maintenance system has been carried out. The form has got a new content and the instruction, which controls the maintenance, has been updated.

5.5 Communication Oskarshamn

General

The main goal for the Communication unit in Oskarshamn is to create public acceptance for SKB. This is done by presenting information and showing SKB's facilities and the RD&D work e.g. at Äspö HRL, often in cooperation with other departments at SKB. Furthermore the unit is responsible for visitor services at Clab and the Canister Laboratory as well. In addition to the main goal, the Communication unit takes care of, and organises visits for international guests every year. The international visits are mostly of technical nature, but increasing interest is shown regarding societal consensus questions. The Communication unit has a booking team which books and administrates all visitors at SKB. The booking team also work for Oskarshamn NPP's service according to agreement. In addition to above, the unit also is responsible for school information in Oskarshamn, press release matters locally and internal as well as external communication on site at the different facilities.

During 2017 the Communication Oskarshamn consisted of eight persons.

Special events and activities

During 2017, 4 522 persons visited the Äspö HRL and with the visitors at Clab and the Canister Laboratory included, it resulted in a total of 6 300 persons. The total number of visitors to SKB's facilities in both Oskarshamn and Forsmark/Östhammar was 9 413 persons. The visitors represented the general public, students, professionals, politicians, journalists and international visitors. The total number of international visitors to the Äspö HRL was 656.

The special summer arrangement "Berg500" was arranged during six weeks and 1 146 people visited the underground laboratory. Tours for the general public also took place some Saturdays during the year.

During 2017, the school information officer visited schools and high schools within the Municipality of Oskarshamn to inform about SKB's work. The school information officer was part of "Innovation Camp" for second year students at the high school, arranged by "Ung Företagsamhet" (Young Enterprise). All 9th grade students in Oskarshamn are offered a day with lego robot programming and a visit to the Äspö HRL. Students in the 3rd grade of high school are offered a visit to Clab. Newsletters and targeted invitations are sent out to teachers every year.

To celebrate the national event "Geologins Dag" (The Geological Day), the unit a arranged a field day on Öland on September 8, for 40 local high school students to teach them about the typical geology on Öland and also about the stone industry.

On November 27, "Äspö Miljöforskningsstiftelse" handed out awards to two persons/organziations/companies that have contributed to increase the public knowledge and awareness about the environment. Winners 2017 were Anna Augustsson, Linneaus university, for her research on environmental risks from contaminated land and for her pedagogic and enthusiastic way on which she tells pupils and other visitors about why we need a non-toxic environment and Strandnära AB that in every way in their workmanship show that you can work in an environmental-friendly way.

As a part of external information efforts, the unit arranges lectures on different themes related to SKB's work. During 2017 two lectures were arranged, one on how other countries take care of their radioactive waste and one on how SKB has used an old canon in the research on copper corrosion and also the story of the warship Kronan that carried the canon when she sank in 1676.

On November 25, nearly 100 competitors participated in "the Äspö Running Competition" held in the Äspö tunnel.

Every year members from the unit participate in "Almedalsveckan" in Visby.

5.6 Future use of Äspö HRL

SKB is conducting work with the intent to seek alternative possibilities for adaptation of the Äspö Hard Rock Laboratory into a national research and innovation infrastructure. The work is being spurred both by an active external interest in the planning for the future use of Äspö HRL and by internal long term strategic reasons. First of all the efforts are focused on finding out if there are external parties willing to individually or together with other parties financially support the operations of the Äspö underground laboratory. If such interest exists, SKB will continue to operate and use the Äspö underground laboratory. Otherwise, SKB will start cease of the operations.

5.6.1 Planning prerequisites for Äspö HRL

The planning prerequisites for the current and future use of Äspö HRL are based on the strategic decisions that formed the basis of the latest reference cost calculations (Plan 2016). The strategic decisions were:

- SKB will have completed its ongoing and planned RD&D work in the Äspö underground laboratory by 2023.
- SKB has a continued need for the Äspö HRL offices, conference rooms, laboratories, workshops, etc above ground after 2023.

The first planning prerequisite (1) is a consequence of SKB intending to carry out the final tests of the repository technology at repository depth in Forsmark. The remaining time until 2023 has been deemed sufficient for the remaining RD&D work in the Äspö underground laboratory. The second planning prerequisite (2) concerns SKB's long term facility needs in Oskarshamn and a need of above ground laboratory resources and infrastructure past 2023.

5.6.2 Continuation or cease of operations in the Äspö underground laboratory

Given the planning prerequisites, work has been initiated to begin preparing and investigating two alternatives: a shift of operations in the Äspö underground laboratory, or alternatively a cease of operations in the Äspö underground laboratory.

It has been decided that a choice between the two alternatives will be made in 2020 to have enough time for adaptation before the implementation in 2023. The following preliminary descriptions of situations will be used as basis for the choice between the two alternatives.

- The continuation of operations is carried out if it has developed in a positive way and is deemed feasible until 2023. A positive development includes one or more organisations (universities, institutes, WMOs or companies) that are willing to financially contribute to the operational cost of the Äspö underground laboratory after 2023. In this case SKB would continue to be responsible for the operation after 2023.
- Ceasing operations is carried out if no new possible managing party or parties has shown the ability and interest to durably operate the underground laboratory after 2023. In this alternative, the Äspö underground laboratory is closed after SKB's RD&D work is completed in 2023.

5.6.3 Status of the continuation of operations alternative

SKB has chosen to prioritise the continuation of operations alternative. Both SKB and SKB International are searching for organisations for financial long term support of the operations of the Äspö underground laboratory. During 2017 work has been carried out within the following development activities which have been initiated.

Competence centre CRUST including National Geosphere Laboratories (NGL)

SKB and the municipality of Oskarshamn decided in 2011 to investigate the potential of Äspö Hard Rock Laboratory as a national resource for research and development in an underground environment. This was the first proactive step to finding other uses for the laboratory with respect to a future reduction of SKB's activity. Discussions were initiated with KTH Royal Institute of Technology which resulted in KTH recommending the direction to qualify Äspö HRL as a national research infrastructure funded by the Swedish Research Council (VR).

Stockholm University became lead part in the NGL initiative, in cooperation with Uppsala University (UU), Lunds University (LU), Linnaeus University (LNU), Royal Institute of Technology (KTH), Chalmers University of Technology (CTH), Luleå University of Technology (LTU), Geological Survey of Sweden (SGU), Swedish University of Agricultural Sciences (SLU), SKB and Nova in Oskarshamn.

A nomination for NGL as a national research infrastructure was submitted in spring of 2015. The application was well received by the Swedish Research Council, and was graded A2 (second highest) meaning "Has relevance to be considered a research infrastructure of national interest, but not yet ready for application period 2017".

Strengthened by the A2 grade, the parties proceeded with the NGL initiative, now led by KTH. A new yearly scientific meeting was held in 2016 with the heading "NGL – The Underground Space Challenge". Preparations for a new application were initiated and was submitted to the Swedish Research Council in October of 2017. The evaluation process will take about half a year and the decision will be announced in May 2018.

Baltic Sea Underground Innovation Network (BSUIN)

Since October 2017 SKB is participating in an international cooperation named Baltic Sea Underground Innovation Network (BSUIN). The cooperation runs for three years and is funded to 75 % by the EU Interreg BSR (Baltic Sea Region). Oulu University in Finland is lead part for the cooperation.

There are 14 cooperating partners, with 6 of them representing underground laboratories in Finland (1), Russia (2), Poland (1), Germany (1) and Sweden (1, Äspö HRL). For more information about the project and the participating partners, see Section 5.6.4 below.

Pre study – Test bed for development and innovation in rock engineering

In the spring of 2016, SKB and KTH Royal Institute of Technology initiated a meeting with Skanska to discuss if there was any interest from the construction industry to use Äspö HRL as a test bed for development and innovation in rock engineering. The discussion was positive and it was decided to, if possible, fund a feasibility study with cofounding from InfraSweden2030 (funded by Vinnova (Sweden's Innovation Agency)).

An application was submitted to the board of InfraSweden2030 in November of 2016. The board recommended Vinnova to co-finance the study, which was started in the beginning of 2017. The study was completed in the fall of 2017. The result of the study was used as basis for a new application to the board and Vinnova to perform a deeper study (stage 2) including interested parties from other business areas such as geoenergy. This new application got a positive reception and the study will be initiated with a planning meeting in March of 2018. The study will be carried out until the end of June 2019.

Smart integrated test environment for the mining industry (SMIG)

In the SMIG project, innovation leaders among mining companies, equipment and system suppliers, specialized enterprises and universities are together developing a test bed for testing of systems, technologies and functions. Organisation, technical integration and system technology will be developed and several pilot tests will be performed.

The project is carried out to meet mining industry's need of a test bed where systems and functions can be tested on the path towards the vision of "A fully automated mining process".

SKB's interest in the project lies in creating connections with the mining industry to make them aware and interested of Äspö HRL as a facility for testing and demonstration. The aim is to make Äspö HRL a part of the mining industry's test environment.

5.6.4 EU project BSUIN

Baltic Sea Underground Innovation Network (BSUIN) is an Interreg-project within the European Union's Baltic Sea Region programme, which started in October of 2017. In the project, six underground facilities are cooperating for increased innovation, business development and science. The methods used are by improving the information about the underground laboratories, the operation, user experiences and safety. The result of the project is to develop and market a mutual and comprehensive offer to potential customers of the underground laboratories in the Baltic Sea region. This is intended to strengthen the innovation potential in the Baltic Sea Region.

BSUIN is also intended to become a viable network to be continued after the project end in September of 2020, likely in the form of a common association. Establishing the forms of cooperation is one of the activities in the project. Äspö HRL participates as one of the six underground facilities.

SKB is leading the work package focussing on Service Design and is active within all five work packages. Initial activities include composing and delivering information regarding geophysical studies and investigations that have been performed at Äspö HRL. Work is also ongoing with answering surveys on work environment, pricing and business prerequisites. These are areas where SKB is already active, but hope to develop further through the project while getting inspirations and input from other facilities.

The project is also planning for project meetings at each facility. The programme for these meetings includes project board meeting, participant workshops and smaller group meetings, and guided tours of the facility. The project meeting at Äspö HRL is scheduled for 18–20th of June, 2018.

More information can be found at http://bsuin.eu.

Cooperating underground facilities

In addition to Äspö HRL, the following five facilities are participating in the project. Callio Lab in central Finland is situated in a 1 440 metres deep mine for copper, zink and pyrite mining. Experiment niches for other purposes are available at several depths in the tunnel. The mining operation is planned to be ended after 2019. There are plans to facilitate for other organisations and businesses to perform experiments and development work in the facility.

Ruskela Lab in Russian Karelia is an older mining environment where marble has been mined since the 1700s. The facility runs from the surface down to 36 metres, and consists of several underground halls and open casts. In later years the area has become a tourist attraction and a site for testing and development of technology and methods for determining the strength of the rock and identifying weak rock zones. The goal is to use this knowledge to inform and guide other historical mining environments and to raise safety for staff and visitors.

Russian Underground Low Background Laboratory of the Khlopin Radium Institute is an underground laboratory at 120 metres depth under the St Petersburg subway. The laboratory makes continuous measurements of tritium. The laboratory also has three gamma ray spectrometers with shielding from background radiation.

Lab development by KGHM Cuprum Research and development Centre. The company KGHM Cuprum provides a comprehensive research and design service for mining industry. It operates in all service areas linked with mining activity, from project evaluation, through research and development, to project management and supervision of the implementation stage. The copper and salt mines owned and operated by the company are situated in the south west Poland. The largest and deepest (1 300 m) mine is situated in the vicinity of the town Polkowice, and has been in operation for 60 years. Areas where mining has ceased are available for experiments and testing and it is here an underground laboratory is planned. There is also an above ground laboratory for rock mechanical testing.

Reiche Zeche in Saxony, Germany was originally a silver mine first taken in operation in 1839. It has for a long time been used as an educational site within mining technology and also for research. Today the facility is used by several institutions and companies to develop technology, production methods and materials for the mining industry. It is still used to train students in practical mining and investigation methods.

6 SKB International

6.1 Background history

SKB organised NWM, Nuclear Waste Management, at a department in SKB in order to manage international requests for consultations and transfer of methodology and technology in an efficient way. The international operation was in 2001 transferred to a separate company, SKB International Consultants AB, a wholly owned subsidiary of SKB. The name was changed in 2010 to SKB International AB. SKB International is the commercial arm of SKB and cannot draw any funds from the nuclear waste fund as the mother company SKB. SKB International offers technology, methodology and expert resources to international clients.

SKB International has access to all expertise, experience and technologies that SKB has acquired and developed in its programme. SKB International provides services to organisations and companies in spent nuclear fuel and nuclear waste management and disposal and hence provides the opportunity to save time and cost and minimise risk. SKB International is committed to the safe disposal of spent nuclear fuel and radioactive waste generated in the operation and decommissioning of nuclear power reactors. The company has full access to SKB's experts, operating facilities, laboratories and intellectual property. SKB International's services are based on the knowhow and hands-on experience accumulated by SKB in the development and operation of the Swedish nuclear waste management system.

SKB International makes available SKB's special purpose vessel m/s Sigrid at times she is not involved in SKB's programme. m/s Sigrid is roll-on/roll-off, lift-on/lift-off vessel with XX3 classification allowing transports of the highest class of radioactive cargo.

SKB International's main areas of operation are:

- Consulting services.
- Technology transfer.
- Laboratory services.
- Transports with m/s Sigrid.

6.2 Support and services related to Äspö

Äspö HRL is a unique research facility and there are only a few like it in the world. Almost 500 metres underground, SKB conduct experiments in collaboration with Swedish and international experts. The facility includes also the Äspö Village at surface with office spaces, different laboratories, a Multi-purpose test facility, etc.

Äspö HRL enables us to study the interaction of bentonite clay and copper canisters with the rock in realistic conditions. Here experiments are made to identify the role of the rock as a barrier. This can, for instance, concern how the rock slows down the movement of radioactive substances or how microbes affect conditions at this depth. It is possible for other organisations to carry out their own research and experiments at the Äspö HRL. This can be organised through SKB International.

6.2.1 Underground facility with available experiments sites

The underground part of Äspö Hard Rock Laboratory (Figure 6-1) consists of a 3 600 metre long tunnel. It starts on the Simpevarp peninsula, where the Oskarshamn nuclear power plants are located.

Under Äspö, the main tunnel descends in two spiral turns down to a depth of 460 metres. Along the main tunnel there are connecting tunnels and niches where experiments and tests are conducted. In total, the tunnels are about five kilometres long. From Äspö Research Village there is also an elevator for passenger transport down into the underground tunnel system.

Figure 6-1. Äspö HRL underground tunnel system.

Multi-purpose test facilities

Multi-purpose test facilities (Figure 6-2, see also Section 5.2) has been in operation since 2007. It includes two stations where the emplacement of buffer material at full scale can be tested under different conditions. The laboratory has also been used for continued testing of different types of backfill material and the further development of techniques for the backfilling of deposition tunnels. A wood frame mock-up of a deposition tunnel in full scale in the laboratory has been used in such testing. Other equipment in the laboratory includes an Eirich bentonite mixer with a load capacity of 1 000 kg to allow mixing of bentonite with desired water ratio, and a press for production of extruded bentonite pellets.

Water chemistry laboratory

The Chemistry Laboratory (Figure 6-3) was built in the late 1990s. The main purpose is to perform the sampling and analyses on water samples collected in streams, lakes and boreholes in the surrounding area and the tunnel. In combination with groundwater flow, groundwater composition is of great importance for repository performance in both the short and long term. Before the site investigations started in 2002, a decision was made to accredit the chemistry laboratory. This was fulfilled in 2003. The laboratory serves all of SKB and its projects, not only Äspö HRL. In 2011 new laboratory areas was built and this makes it possible for external organisations to use the laboratory for sample preparations and other laboratory work while performing experiments at Äspö HRL.

Figure 6-2. Äspö HRL Multi-purpose test facilities.

Figure 6-3. *Äspö HRL Chemistry laboratory.*

Material science laboratory

There are many current and future challenges regarding the bentonite buffer and backfill materials related to long term safety assessment, as well as industrial scale quality control. As a part of the needed infrastructure, a material science laboratory has been constructed at Äspö, with focus on material chemistry of bentonite issues and competence development (Figure 6-4, see also Section 5.3). The key focus areas are long term safety related research and development of methods for quality control.

Wet chemical methods such as cation exchange capacity (CEC) and exchangeable cations (EC), X-ray diffraction (XRD) for the determination of crystalline solids, X-ray fluorescence (XRF) spectroscopy for elemental compositon, Fourier Transformed IR (FT IR) spectroscopy for detailed analysis of the clay mineral structure and amorphous material, and UV/Vis for the CEC method are examples of equipment.

Borehole deviation facility

Drilling in conjunction with construction and operation of a repository for spent nuclear fuel at Forsmark requires careful control of borehole geometry in various applications. Foreseen pilot holes for deposition tunnels, up to 300 m long, where the boreholes are required to stay within the tunnel perimeter calls for careful control of the drilling process. This requires development not only of drilling methodology but also of instruments and methodology for providing the necessary steering and successive verification of borehole geometry. To this end SKB has devised a facility where indirect deviation measurements can be verified relative to the known geometry of a simulated borehole on ground surface (Figure 6-5).

The 300 m long near horizontal simulated borehole was constructed during 2013 on the Äspö island. The equipment consists of a tube anchored to the rock. The tube, which essentially follows ground surface topography, has been carefully surveyed geodetically. SKB use the facility to test borehole deviation equipment of different types, including magnetic tools, gyro based tools.

Office space

The Äspö village (Figure 6-6) accommodate office space in a unique and lovely environment for up to 100 people with access to conference rooms, video connections, internet, and other support and equipment necessary for an efficient working place.

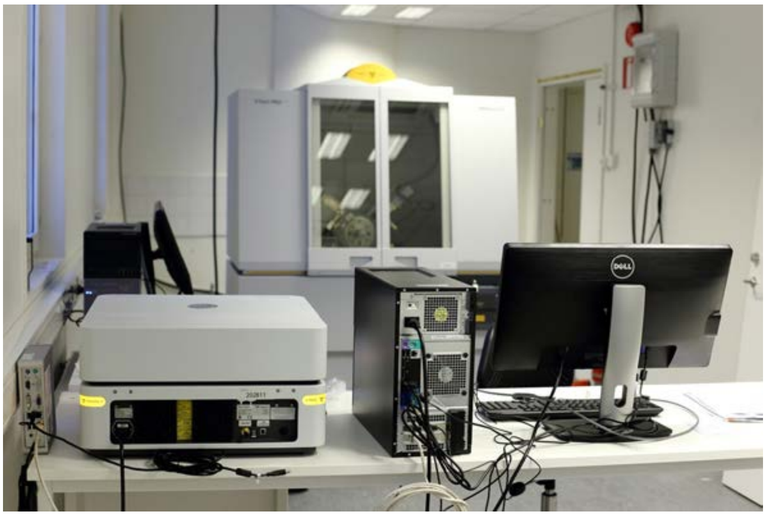

Figure 6-4. *Äspö HRL Material science laboratory.*

Figure 6-5. *Äspö HRL Borehole deviation facility.*

Figure 6-6. *Äspö HRL above ground office buildings.*

6.2.2 SKB International can customise following services:

Participation in SKB's experiments

SKB is using Äspö HRL for testing and verifying different technical solutions for the KBS-3 method at full scale under realistic conditions. In this report several experiments and demonstrations gives examples of activities which can be followed or joined by other organisations.

On the job-training

It is possible to arrange specific on the job-training activities for competence building of other organisations' staff.

Access to field data from 1986 up until today

SKB has produced data from the site investigations around the Äspö island back in the mid 1980s, from the construction phase of the Äspö HRL between 1990 to 1995 and from activities accomplished up until today. Most of this field data can be available for other organisations, who perhaps have no access to own field data and would like for instance do site descriptive modelling.

Support to your organisation with tests and experiments

The staff at Äspö has long experience in planning, accomplishing and analysing tests and experiments. They are prepared to support other organisation which would like to perform own tests or experiments at Äspö HRL.

Workshops and training courses

SKB International has good experiences in arranging customised workshops and training courses in different topics. Experts from SKB covering different disciplines, e.g. long term safety, site investigations and selections, public relations, construction of URL, etc can be involved.

Äspö International partnership

SKB International offers a unique partnership to organisations where they can get information from SKB's ongoing work accomplished at Äspö HRL. Meetings and workshops with SKB experts are annually organised specially for the partners. At these occations partners get good insite in the work and experiences SKB has developed over 40 years. The partners can also follow the work and activities on site at Äspö.

A specific web based site, the Äspö International Web Portal, is available for the partners. Information about the Äspö HRL, including the Äspö village with the Bentonite, the Chemistry and Material Science laboartories as well as the underground laboratory is presented. Also accomplished, ongoing and planned projects/experiments are presented. This gives the partners great possibilities continuously to follow planned and ongoing work and also to prepare for own experiments.

Field data measured from the site investigations of the Äspö HRL during 1986 to 1990, field data from the construction of Äspö HRL during 1990 to 1995 and extensions done at site and in the underground facility accomplished until today.

6.3 Activities and support during 2017

Äspö International partnership

For the Äspö International partners SKB International arranged different events during 2017. Two **topical workshops** were organised. The first regarding development of borehole sealing of investigation boreholes drilled from the surface. In the second workshop ongoing and planned modelling based on Äspö data was presented by one of the Äspö International partners. SKB presented the DFN-R project.

The specific **Äspö International Web Portal** was updated with updated information of different SKB projects.

The annually **Technical Information Meeting**, TIM, presented the latest updates from the technical development work accomplished. Examples of topics covered at the meeting were:

- Overall Äspö information.
- Dismantling of the dome plug (DOMPLU).
- Sealing of investigation boreholes.
- Buffer and backfill development.
- Glacial effects on bentonite.
- KBS-3H project.
- Tunnel and deposition hole production.
- Underground characterisation of ramp and shaft.

At the annually **International Joint Committee meeting** SKB presented planned activities during 2018 and coming years. One new event is to arrange a training course *"Overview of geological nuclear waste disposal – based on Swedish experiences (KBS3) – for implementers and researchers"* at Äspö during autumn 2018.

Training course

During late autumn a customized training course in planning, construction and operation of an underground research laboratory was organised.

6.4 Contact information

Are you interested in our assistance or do you need more information? Just contact us and we will help you out.

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More information available at:

www.skbinternational.se

References

SKB's (Svensk Kärnbränslehantering AB) publications can be found at www.skb.com/publications.

Abarca E, Idiart A, de Vries L, Silva O, Molinero J, von Schenk H, 2013. Flow modelling on the repository scale for the safety assessment SR-PSU. SKB TR-13-08, Svensk Kärnbränslehantering AB.

Andersson C, Johansson Å, 2002. Boring of full scale deposition holes at the Äspö Hard Rock Laboratory. Operational experiences including boring performance and a work time analysis. SKB TR-02-26, Svensk Kärnbränslehantering AB.

Bond A E, Hoch A R, Jones G D, Tomczyk A J, Wiggin R M, Worraker W J, 1997. Assessment studies for a copper canister with cast steel inner component. SKB TR-97-19, Svensk Kärnbränslehantering AB.

Fox A, La Pointe P, Hermanson J, Öhman J, 2007. Statistical geological discrete fracture network model. Forsmark modelling stage 2.2. Updated 2008-12. SKB R-07-46, Svensk Kärnbränslehantering AB.

Grahm P, Malm R, Eriksson D, 2015. System design and full-scale testingo f Dome Plug for KBS-3V deposition tunnels. SKB TR-14-23, Svensk Kärnbränslehantering AB.

Klimczak C, Schultz R A, Parashar R, Reeves D M, 2010. Cubic law with aperture-length correlation: implications for network scale fluid flow. Hydrogeology Journal 18, 851–862.

Lagerblad B, Golubeva M, Cirera Rui J, 2016. Lämplighet för krossberg från Forsmark och SFR att användas som betongballast. SKB P-16-13, Svensk Kärnbränslehantering AB.

Lagerblad B, Rogers P, Vogt C, Mårtensson P, 2017. Utveckling av konstruktionsbetong till kassunerna i 2BMA. SKB R-17-21, Svensk Kärnbränslehantering AB.

Laviña M, Idiart A, Molinero J, 2018. POSKBAR project – Development, testing and application of altenative models for bentonite expansion and erosion. SKB TR-17-13, Svensk Kärnbränslehantering AB.

Luterkort D, Gylling B, Johansson R, 2012. Closure of the Spent Fuel Repository in Forsmark. Studies of alternative concepts for sealing of ramp, shafts and investigation boreholes. SKB TR-12-08, Svensk Kärnbränslehantering AB.

Luterkort D, Johannesson L-E, Eriksson P, 2017. Buffer design and installation method. Installation report. SKB TR-17-06, Svensk Kärnbränslehantering AB.

Mårtensson P, 2015. Äspö Hard Rock Laboratory. Concrete and clay. Installation report. SKB P-15-01, Svensk Kärnbränslehantering AB.

Neretnieks I, Moreno L, Liu L, 2017. Clay erosion – impact of flocculation and gravitation. SKB TR-16-11, Svensk Kärnbränslehantering AB.

Neretnieks I, Moreno L, Liu L, 2018. Revisiting bentonite erosion understanding and modelling based on the BELBaR project findings. SKB TR-17-12, Svensk Kärnbränslehantering AB.

Railo A, Laitinen I, Mustonen S, Kosunen P, Joutsen A, Mellanen S, Nuijten G, 2015. Design and construction of equipment and experimental deposition holes, in ONKALO demonstration tunnel 1. Posiva Working Report 2015-25, Posiva Oy, Finland.

Railo A, Laitinen I (ed), Mustonen S, Kosunen P, Joutsen A, Mellanen S, Ikonen A, Hollmen K, Nuijten G, 2016. Design and construction of equipment and experimental deposition holes, in ONKALO demonstration tunnel 2. Posiva Working Report 2016-27, Posiva Oy, Finland.

Sandén T, Dueck A, Åkesson M, Börgesson L, Nilsson U, Goudarzi R, Jensen V, Johannesson L-E, 2017. Sealing of investigation boreholes. Laboratory investigations of sealing components. SKB P-17-10, Svensk Kärnbränslehantering AB.

SKB 2001. RD&D programme 2001. Programme for research, development and demonstration of methods for the management and disposal of nuclear waste. SKB TR-01-30, Svensk Kärnbränslehantering AB.

SKB 2009. Site description of Laxemar at completion of the site investigation phase. SDM-Site Laxemar. SKB TR-09-01, Svensk Kärnbränslehantering AB.

SKB, 2010. Design, production and initial state of the closure. SKB TR-10-17, Svensk Kärnbränslehantering AB.

SKB, 2011. Long-term safety for the final repository for spent nuclear fuel at Forsmark. Main report of the SR-Site project. SKB TR-11-01, Svensk Kärnbränslehantering AB.

SKB, 2016. RD&D programme 2016. Programme for research, development and demonstration of methods for the management and disposal of nuclear waste. SKB TR-16-15, Svensk Kärnbränslehantering AB.

Smart N R, Rance A P, Fennell P A H, 2006. Expansion due to the anaerobic corrosion of iron. SKB TR-06-41, Svensk Kärnbränslehantering AB.

Smart N R, Rance A P, 2009. Miniature canister corrosion experiment – results of operations to May 2008. SKB TR-09-20, Svensk Kärnbränslehantering AB.

Svensson D, 2015. The bentonite barrier – Swelling properties, redox chemistry and mineral evolution. PhD thesis. Centre for Analysis and Synthesis, Lund University.

Svensson P D, Hansen S, 2013. Redox chemistry in two iron-bentonite field experiments at Äspö hard rock laboratory, Sweden: an XRD and Fe K-edge XANES study. Clays and Clay Minerals 61, 566–579.

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

Svensson D, Lundgren C, Johannesson L-E, Norrfors K, 2017. Developing strategies for acquisition and control of bentonite for a high level radioactive waste repository. SKB TR-16-14, Svensk Kärnbränslehantering AB.

Woodcock N H, Rickards B, 2003. Transpressive duplex and flower structure: Dent Fault System, NW England. Journal of Structural Geology 25, 1981–1992.

Arkitektkopia AB, Bromma, 2019

SKB is responsible for managing spent nuclear fuel and radioactive waste produced by the Swedish nuclear power plants such that man and the environment are protected in the near and distant future.

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