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Äspö Hard Rock Laboratory
Annual Report 2018

SVENSK KÄRNBRÄNSLEHANTERING AB

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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 2018 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 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.

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.

As prospective alternatives to drilling and blasting, SKB is studying different available methods for excavating a deposition tunnel, for example *mechanical excavation*. SKB follows the development of methods in this area.

A project on *Drilling of deposition holes* has been initiated, developing the techniques for producing deposition holes.

The project *Dismantling of dome plug* has been responsible for the excavation and analysis of the full-scale deposition tunnel plug installed in 2012–2013. The plug was excavated during the end of 2017, and analysis and reporting has been ongoing in 2018.

Several projects are ongoing with focus on *System design of buffer and backfill*. During 2018 tests have been performed on bentonite pellets to find optimisations in both material and pellet type.

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's in the repository. The model will be used in the future assessments for the long term performance of the KBS-3 repository.

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.

Long-term studies of steel corrosion in low-pH concrete. On behalf of SKB, Swerea KIMAB AB and The Swedish Cement and Concrete Research Institute (CBI) have carried out studies on corrosion in the Äspö HRL's underground environment. The final phase of the study was carried out in 2018 with retrieval and analyses of 12 concrete blocks with embedded test bars of carbon steel and four approximately four-meter-long rock bolts embedded in low-pH grout in the roof and wall of a tunnel niche in Äspö HRL.

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 2018, 2 concrete cylinders containing organic material representative of low- and intermediate-level radioactive waste were retrieved and segmented.

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 KBS-3H Multi Purpose Test (MPT) is a down-scaled (length-wise and temporal) non-heated installation of the KBS-3H reference design, and includes the main KBS-3H components in full scale. The MPT has been in monitoring phase since installation in 2013.

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 2018 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 2018, including development of equipment for milling of buffer blocks and development of equipment for backfill 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 2018 include materials testing and preparation of bentonite for several projects.

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 2018, much focus has been on the *Material Science project.*

The Water Chemistry Laboratory at Äspö HRL perform the sampling and analyses on water samples collected in streams, lakes and boreholes in the surrounding area and the tunnel. For the moment the Chemistry Laboratory can perform 14 different analyses for water samples.

The operation of the facility during 2018 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 2018, 3 091 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 2018 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. These services give the organisations and companies the opportunity to save time and cost and minimise risk. During October 2018 SKB International and SKB organised a scientific training course covering important issues governing a national nuclear waste disposal programme, with 30 participants from organisations world-wide attending.

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 2018.

Äspö platsbeskrivande modell

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 platsbeskrivande modell* är att beskriva Äspölaboratoriets geologiska, hydrogeologiska och grundvattenkemiska förhållanden, inklusive uppdaterade geometriska och numeriska modeller för de olika geovetenskapliga diciplinerna.

Programmet för hydroövervakning utgör en grundsten i Äspölaboratoriets hydrogeologiska undersökningar, och stödjer olika experiment som genomförs. Övervakningssystemet baseras på cirka 1 500 mätpunkter för olika hydrogeologiska variabler.

Programmet för hydrokemisk övervakning 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.

Som ett alternativ till traditionell sprängning studerar SKB olika metoder för produktion av deponeringstunnlar, så som *mekanisk brytning*. SKB följer utvecklingen av teknik och metoder på området.

Ett projekt har initierats inom *Borrning av deponeringshål*, vilket ska utveckla tekniker för produktionen av deponeringshål.

Projektet *Brytning av valvplugg* har ansvarat för brytning och analys av den fullskaliga plugg för deponeringstunnlar som installerades i Äspötunneln 2012–2013. Pluggen bröts under slutet av 2017, och analys och rapportering har fortsatt under 2018.

Flera projekt pågår med fokus på *Systemkonstruktion av buffert och återfyllnad*. Under 2018 har tester genomförts på bentonitpellets för att identifiera optimiseringar i både materialval och pellettyp.

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.

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.

Långtidsstudier av stålkorrosion i låg-pH betong. Swerea KIMAB AB och Betonginstitutet (CBI) har på uppdrag av SKB utfört studier på korrosion i Äspös underjordsmiljö. Den sista fasen i studierna genomfördes under 2018 med återtag och analys av 12 betongblock med prover av kolstål och fyra stycken ca fyra meter långa bergbultar inbäddade i låg-pH bruk i taket och väggen av en tunnelnisch i Äspötunneln.

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 2018 återtogs och segmenterades två betongcylindrar innehållande organiskt material.

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. KBS-3H Multi Purpose Test (MPT) är en nedskalad (i längd och tid) testinstallation av referensdesignen med fullskalekomponenter. Försöket har övervakats sedan installationen under 2013.

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 2018 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 2018, däribland framtagande av teknik för att fräsa buffertblock och teknik för att installera återfyllnad.

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 under 2018 inkluderar materialtester och produktion av bentonitmaterial för ett flertal projekt.

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 2018 har fokus legat på studier inom *Materialstudieprojektet.*

Vattenkemilaboratoriet på Äspö HRLgenomför provtagning och analys av vattenprover insamlade från vattendrag, sjöar och borrhål i omgivande områden och Äspötunneln. För nuvarande kan Kemilaboratoriet utföra 14 olika analyser på vattenprover.

Driften av anläggningen under 2018 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 2018 besöktes Äspölaboratoriet av 3 091 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 2018 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 till besparingar både i tid och i pengar, samt en möjlighet att minimera risker. Under oktober 2018 arrangerade SKB och SKB International en vetenskaplig kurs i viktiga frågor kring utveckling och genomförande av ett nationellt slutförvarsprogram, med 30 deltagare från organisationer över hela världen.

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 planning for design and construction of deep geological repositories for radioactive waste.

The Äspö HRL is not only an underground laboratory. On the surface lies Äspö Research Village with laboratory areas for accredited hydrochemical analyses, research activities and advanced bentonite clay examinations. 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 2018.

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 ramp 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 system is connected to the ground surface through a hoist shaft and two ventilation shafts. Thanks to the available 20 passenger elevator, easy access to the underground laboratory is offered from the office building at the Äspö Research Village.

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.

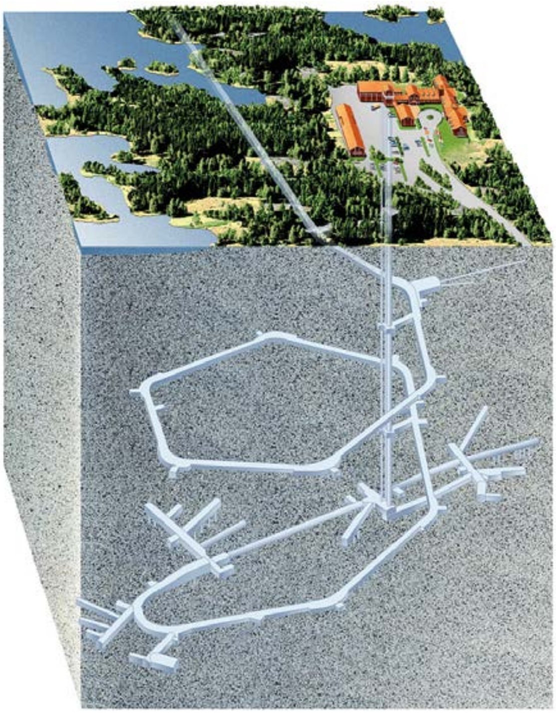


Figure 1-1. Overview of the Äspö HRL facilities.

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.

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 2020–2025 is described in SKB's RD&D-Programme 2019 (SKB 2019a).

After the start of operation in 1995, experiments began gradually to investigate how the engineered barriers (canister, buffer, backfill and closure) of the Spent Fuel Repository could be designed and managed in order to provide optimal functionality and safety. 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 post closure 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 caissons will be demonstrated in large scale under realistic conditions. In addition, research projects are carried out for future analyses of post closure safety for SFR and SFL (the Swedish repository for Long-Lived Radioactive Waste) focused on studies of interactions between different types of barrier materials relevant to these repositories and for different types of materials that are representative of low- and intermediate-level waste.

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 at least until 2024.

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

1.3 Organization

The Äspö HRL is included in the department Research and Development (R) at SKB.

The Research and Development department comprises four units; Repository Technology (RD), Encapsulation Technology (RI), Site Modelling and Monitoring (RP) together with Research and Post-closure Safety (RS).

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 deposition tunnels, production and installation methods for the engineered barriers, transport and logistics as well as all necessary quality control methods.

- 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 that additional research and development activities can use the underground laboratory in the future.

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

- *Technology Development (RDT)*, 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.
- *Operations and technical support (RDD)*, responsible for the operation and maintenance of the Äspö HRL offices, workshops and underground facilities and for development, operation and maintenance of supervision systems. The group is also responsible for the preparations and practical coordination of projects undertaken at the Äspö HRL, providing services (design, site selection, installations, measurements, field equipment, monitoring systems etc) and workers safety to the experiments.
- *Chemistry (RDK)*, responsible for water sampling and accredited chemical water analysis and bentonite material analysis. The group coordinates all activities inside the research laboratory.

Each major research and development task, ordered by SKB and carried out in Äspö HRL, is organised as a project or assignment 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 2018 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 openings are allocated for the different experiments so that optimal conditions are obtained for each purpose, see Figure 1-2.

1.5 Reporting

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

For the coming period, 2020–2025, the RD&D-Programme 2019 has recently been presented (SKB 2019a).

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 2018.

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.

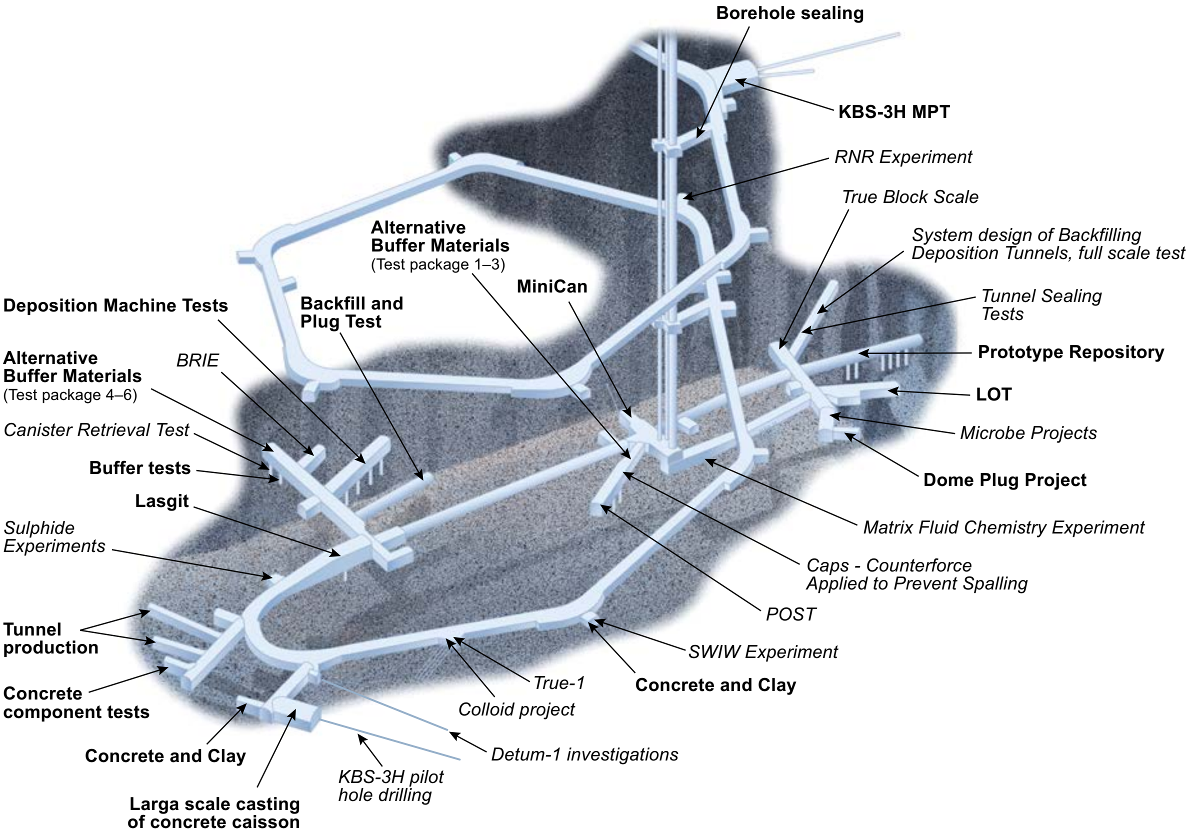


Figure 1-2. *Allocation of experiment sites from −220 m to −460 m level. Ongoing experiments in bold text.*

1.6 Structure of this report

The achievements obtained at Äspö HRL during 2018 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 – laboratories, operation and maintenance, communication activities and future plans.
- SKB International – services and support related to Äspö HRL.

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 available data 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 multidisciplinary modeling,
- in further development of the modeling 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, has had lower acitivity during 2018. Work with the RoCS technology has been performed within the project Investigation methods for ramp and shaft, see Section 3.7.

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.

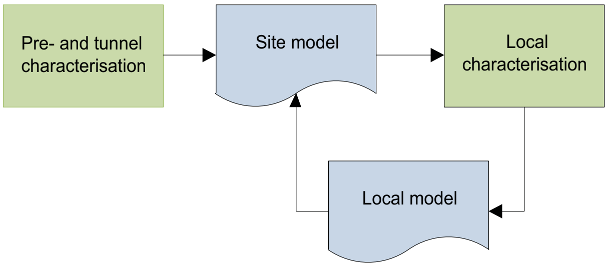


Figure 2-1. *Evolution of local- and site descriptive model.*

Objectives

The major aims of the site descriptive modell and modelling are to:

- Maintain and develop the understanding of the hydrogeological properties of the Äspö HRL rock mass.
- Support of experiments and measurements in the hydrogeological field.
- Maintain and develop the methodology for site descriptive modelling.

Experimental concept

The concept is to recurrently compile and evaluate new hydrogeological along with the previous data as a base for revising and updating the modelling/model and the geoscientific understanding of the site. And develop the internal expertise in site descriptive modelling.

Results

The hydrogeological component of the Äspö SDM progressed with the data compilation and evaluation as well as with the hydrogeological parameter assignment to the rock and deformations zone units of the single hole interpretations. Work is on-going.

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 2-2. 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.

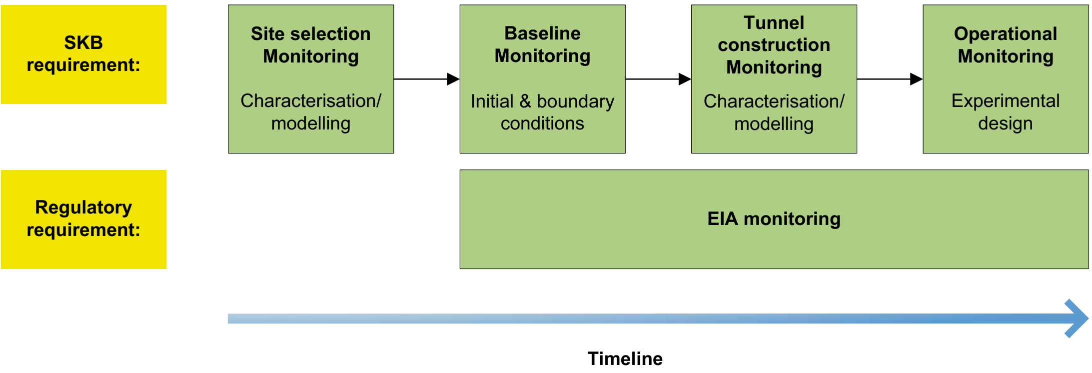


Figure 2-2. *The staged approach of monitoring at Äspö.*

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 conjunction 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.

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 coming nuclear waste repository, a transfer of knowledge and know-how from Äspö Hard Rock Laboratory to Forsmark Site administration on all aspects of hydrogeological monitoring continued. This is sustained on a structured and recurrent basis comprising technical, organisational and Q/A & Q/C issues.

2.4 Geochemistry

Background

A general understanding of the current hydrogeochemical conditions in deep crystalline bedrock is crucial when predicting future changes in groundwater chemistry (i.e. climatic cycles).

Through different experiments and projects undertaken in the tunnel, additional data is collected and deeper understanding is gained, for example in groundwater composition, origin and evolution in the area, together with active major processes, primarily flow/mixing related, in order to explain the groundwater chemistry and its distribution.

Objectives

The major aims of the hydrogeochemical activities are to:

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

Results

Hydrogeochemical resources were largely provided to the following major projects and activities:

- Chemical characterization of organic material in deep groundwater in Äspö HRL.
- Chemical characterization of rare earth elements in deep groundwater in Äspö HRL.
- The Detailed investigation methodology project for developing hydrogeochemical methodology and instrumentation required for the construction of the Spent Fuel Repository in Forsmark.

A number of groundwates from different locations where analysed for organic material with FT-ICR-MS. The samples depicted a very terrestrial signature with, for example, low contribution of N- and S-bearing molecular formulas, a high modified aromaticity index and low H/C ratio.

Rare earth elements (REEs) were studied in groundwater using both diffusive gradients in thin-films (DGT) and with convential filtration (0.45 µm membrane filters). Among 14 studied groundwaters there was a huge range in REE_{DGT}-fractionation patterns, ranging from enrichment to a nearly three-order-magnitude depletion of the heavy REEs.

2.4.1 Hydrochemistry monitoring program

Background

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:

- The surface environment – precipitation, stream, lake and sea water (i.e. surface water).
- The near surface environment – regolith aquifer (i.e. near surface water).
- 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.

The monitoring program is designed as monthly to annual 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.

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.

Results

All analytical data from 2018 are quality assured and stored in SKB database. Groundwater from Äspö HRL was sampled in series; after three, five and seven section volumes. In addition to the usual analyses, also acetate, organic material and C-13/C-14 in the organic phase were performed.

Figure 2-3. *The simple and robust DGT device is deployed for a known time in deep groundwater and provides the time weighted average concentration for the REEs.*

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 are 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 2018 the following experiments and projects concerning the engineered barriers were ongoing, either in active or in monitoring stage:

- Tunnel production.
- Drilling of deposition holes.
- Dismantling of the dome plug.
- System design of buffer and backfill.
- Developing, testing and application of improved models for bentonite expansion and erosion.
- Investigation methods for ramp and shafts.
- Development of concrete barriers.
- Overcoring of rock bolts.
- 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 Mechanical excavation

Background

Considering the deposition sequence in the Spent Fuel Repository, where several different machines and equipments are used, the tunnel floor needs to be sufficiently level in order to be easily accessible and also to reduce maintenance and wear of the installation machines. As prospective alternatives to drilling and blasting, SKB is studying different available methods for excavating a deposition tunnel, for example mechanical excavation and wire sawing. The ambition is to create a deposition tunnel with minimized EDZ and even tunnel contour, efficiently produced at a competitive cost.

Results

In order to increase the understanding of mechanical excavation SKB participated in a Swedish cooperation project with the goal to test mechanical excavation with a Mobile Miner 55V. The assembly work took place in the vicinity of the tunnel entrance to Äspö HRL, at the Simpevarp peninsula.

Due to delays in the assembly of the machine and cutter head modifications the time slot for excavating the tunnel was passed. The project participants agreed to close the project without any tunnel being constructed.

A photo from assembly site can be seen in Figure 3-1:

In the coming years SKB will follow the development of methods for mechanical excavation. A strategic decision must be made on the best suitable method. In addition, SKB has agreed upon the possibility to volunteer Äspö HRL as a national test bed for mechanical excavation, see further Section 5.7.3 Status of the continuation of operations alternative.

3.3 Drilling of deposition holes

Background

SKB has followed Posiva's development work for deposition holes, where Posiva has drilled ten vertical experimental holes in Onkalo, distributed between two demonstration tunnels (Railo et al. 2015, 2016). The deposition holes were drilled with a prototype machine of type Rhino HSP500 manufactured for the purpose. SKB has previously drilled around 15 deposition holes in the Äspö HRL with a different machine during 1998–1999 (Andersson och Johansson 2002).

There is still a need for further development and evaluation of the drilling of of deposition holes with the new prototype machine. A new project will start during 2019 and the first results are estimated during 2020–2021. The principle layout of a deposition hole is diameter 1 750 mm and depth ca 8 000 mm as seen in Figure 3-2.

***Figure 3-1.** Assembly of the main body of the Mobile Miner.*

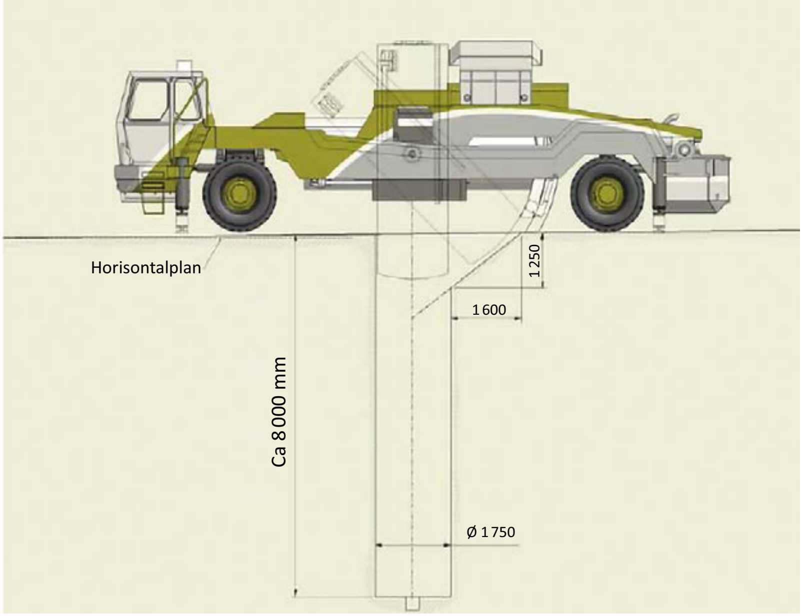


Figure 3-2. *Cross section of a reference design KBS-3 deposition hole.*

Objectives

SKB will borrow Posivas prototype machine for drilling deposition holes, evaluate and if possible further develop the equipment, and attempt to have it CE certified. After that SKB will drill a new set of experimental holes at Äspö HRL.

In addition to evaluating development of the machine, the drilling of deposition holes will also be a good opportunity to update and expand SKB's experience in drilling of deposition holes as this has not been done in some time. The drilling activities will also give improved basis for calculations on cost for wear on drilling equipment.

This project will start during 2019 and the first results are estimated during 2020–2021.

3.4 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 a dome plug, and a full-scale experiment (DOMPLU) was installed in the Äspö Hard Rock Laboratory during 2013 (Grahm et al. 2015).

After installation a test period started 2014 with the main goal to determine leakage past the plug. Such a leakage could be through the plug itself or past the contact surfaces between the rock and the concrete. To achieve a water pressure representative to the hydrostatic groundwater pressure in the repository, water was injected inside the plugged volume at a pressure of 4 MPa. 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.*

In the new project a number of tests were performad before breaching the plug. For example, a gas tightness test was performed to evaluate the gas tightness of the plug. The last test was a strength test intended to test the load carrying capacity of the concrete dome during high pressure loads. In the end of 2017, the dome plug was dismantled and the test design was evaluated.

To evaluate the dome plug, monitoring has been performed since construction when about 100 sensors were installed in the different material zones in the dome plug. Besides this, other types of measurements have also been conducted such as; leakage measurements, non-destructive test methods and a large amount of material tests on concrete and bentonite. As a complement to all these measurements, numerical analyses have also been performed to predict and to obtain greater understanding of the results (Enzell and Malm 2019).

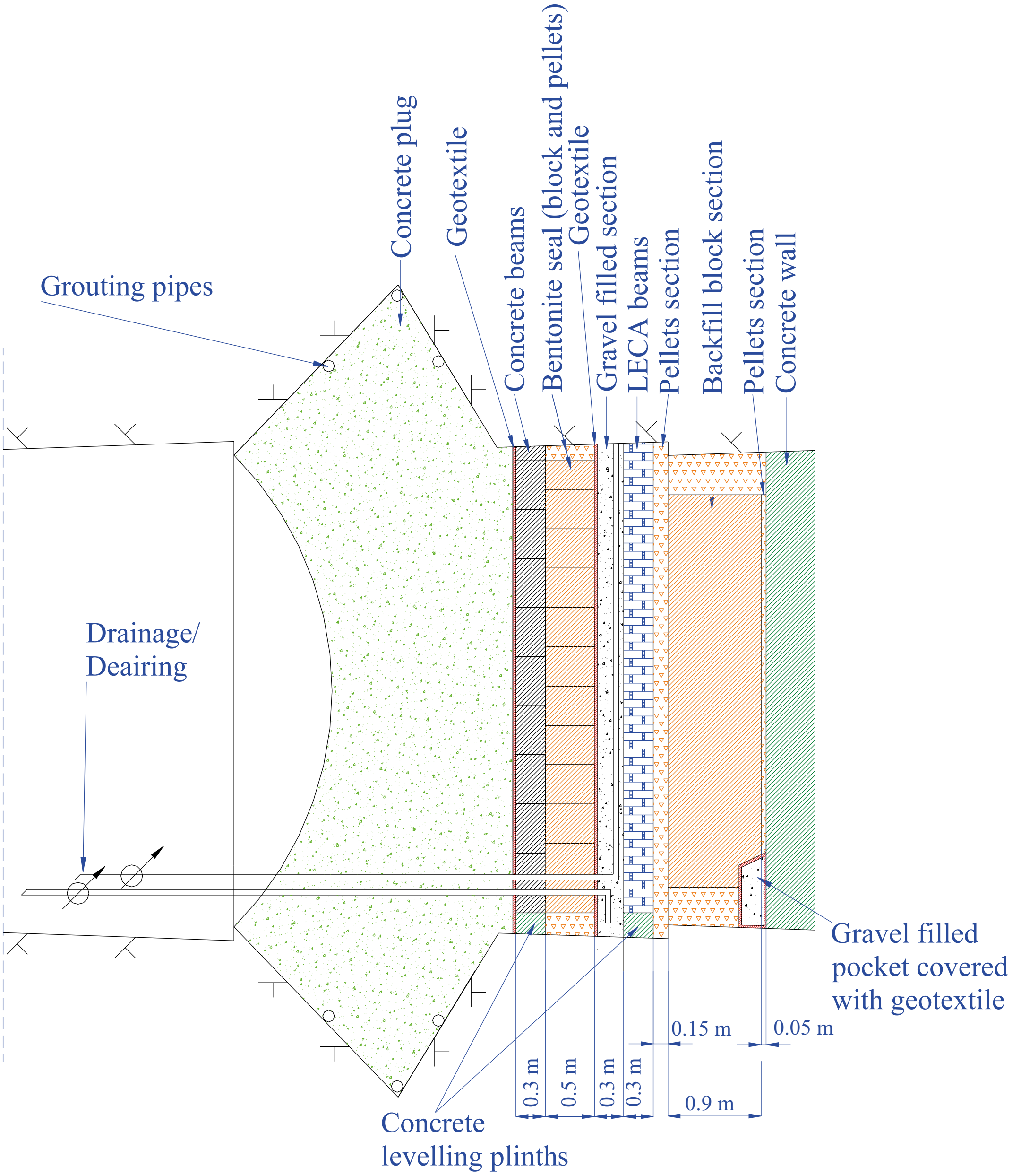


Figure 3-3. *DOMPLU design.*

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 were 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.
- Analyse 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 analysing 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 should be 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 were 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 was breached with a hydraulic hammer. To get started, a 1 × 1 m opening was 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 number of bentonite samples from the sealing- and backfill section were 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

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). Despite serious concerns that it would be difficult to achieve the design pressure, the test was considered very successful.

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 appeared to be the most useful method, the results are too uncertain to be able to establish that the inspection method can be used on this type of object.

One factor of interest to the project was if the NDT had detected the cavity found in the upper part of the slot, as described below and showed in Figure 3-4. 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.

Destructive testing of concrete dome

Approximately 20 cores have been taken from the concrete structure by core drilling. The cores have been analysed at an external laboratory. The visual inspection of the concrete drill cores revealed no obvious defects like cracks, honeycombing or insufficient embedment of cast-in items. Most of the mechanical properties investigated are, on average, comparable with undisturbed samples from earlier tests or from the monolith cast beside the plug. This indicates no dramatic decrease in the mechanical properties of the low-pH concrete due to aging, loading and restrained shrinkage.

During sampling, a cavity was discovered in the upper part of the concrete structure, as seen in Figure 3-4. 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 3-5.

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.

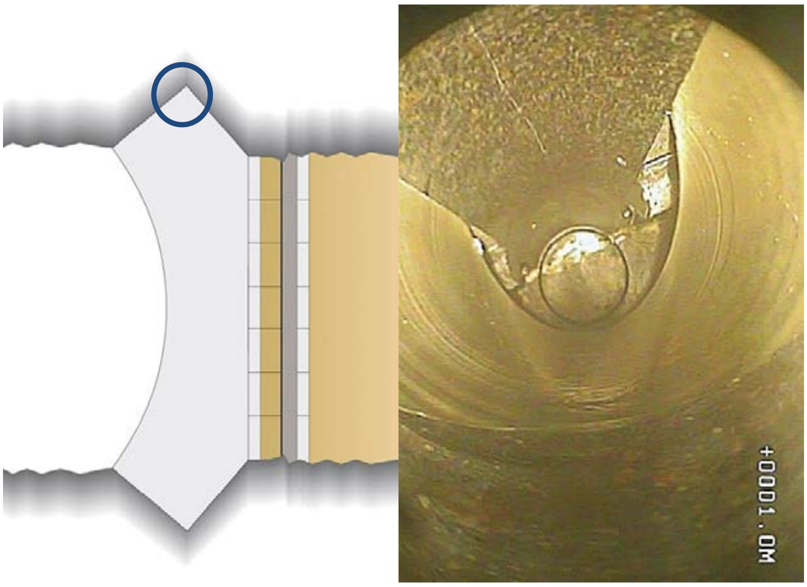


Figure 3-4. *A cavity in the upper part of the concrete was discovered in drill cores in the interface between concrete and rock. The image to the right is taken with a camera inside the bore hole.*

Figure 3-5. *Machine for breaching (left) and result after removal of the concrete dome (right).*

Dismantling and sampling of bentonite and filter components

The sampling of the bentonite seal showed that it was completely saturated. There were, however, remaining large differences in density between the central parts (former block stack) and the periphery (former pellet filling) even if it was obvious that the differences had decreased when comparing with the density of the different components at installation. The homogenization of the bentonite had thus proceeded which also was expected.

During excavation it was observed that the bentonite seal had swelled and compacted the filter section inside (gravel filling) and also moved the LECA wall a few centimeters upstream towards the backfill. A compaction of the filter and movement of the LECA wall will not affect the function of the plug.

The backfill section was also largely saturated but there were some central parts with a lower degree of saturation. The differences in density between the central parts and the pellet filled parts at the periphery were similar to what was determined for the bentonite seal (Åkesson et al. 2019).

3.5 System design of buffer and backfill

Background

For detailed design of the deposition area, the designs of buffer and backfill should be updated to allow for efficient and robust installation. Decisions on new excavation method and new cross sections for deposition tunnels mean that the design of backfill must be adapted to new conditions. A well-balanced and site-adapted design of buffer and backfill is vital both in order to achieve a robust installation and to meet the requirements for ensuring safety after closure. The new design of buffer and backfill will be developed as part of the new project System design of buffer and backfill. As part of this design work, the design of the buffer pellet filling is revisited. As basis for this design, experimental testing is carried out in Äspö's Multi Purpose Facility.

Objectives

SKB has since the installation of the Prototype repository been using a roller compacted pellet type for the buffer. In previous work, the need to optimise the pellets in order to have as robust installation as possible has been identified. The optimisation task includes identifying the desired functions for the pellet filling and testing how different pellet types can fulfill these functions. The objective of the work is to make a recommendation for the choice of a pellet design.

Experimental concept

A number of tests were carried out to be able to determine which bentonite material and which pellet type is best suited to absorb and distribute water in the pellet gap between the buffer and the deposition hole wall and, if possible, see to what extent different water inflows can be limiting for a full-scale installation.

The tests were performed in a laboratory environment where possible water inflows into the buffer's pellet-filled gap were mimicked. The test equipment consisted of a test box fitted with a transparent plexiglass (1 m × 1 m), see Figure 3-6.

The box was filled with a 5 cm thick layer of pressed buffer blocks and a 5 cm thick layer of pellets. The pellets had access to a constant water flow through an inflow point placed in the middle of one plexiglass plate. The reference set-up for the experiments was as follows: a point inflow of 0.01 l/min and compacted Wyoming bentonite (Barakade). The test matrix (see Table 3-1) was then based on variation of water inflow, point and fracture inflow as well as materials and pellet type. In addition to Wyoming bentonite, Bulgarian bentonite (CaBen) was tested for buffer pellets. The blocks in the tests were made from Wyoming bentonite (Barakade). The plexiglass side with pellet filling was photographed continuously to see how the water progressed through the pellet filling. The water ratio and density of the bentonite materials were determined before installation and after dismantling of the tests.

Figure 3-6. Test box.

Table 3-1. Test matrix.

Test #	Material	Pellet type	Water flow (l/min)	Inflow shape
1[*]	Barakade	Roller-compacted	0.01	Point
2[*]	Barakade	Roller-compacted	0.01	Point
3	Barakade	Extruded	0.01	Point
4[**]	CaBen	Roller-compacted	0.01	Point
5[**]	CaBen	Roller-compacted	0.01	Point
6[***]	CaBen	Extruded	0.01	Point
7	Barakade	Roller-compacted	0.001	Point
8	Barakade	Roller-compacted	0.1	Point
9	Barakade	Roller-compacted	0.01	Fracture, vertical
10	Barakade	Roller-compacted	0.01	Fracture, horizontal

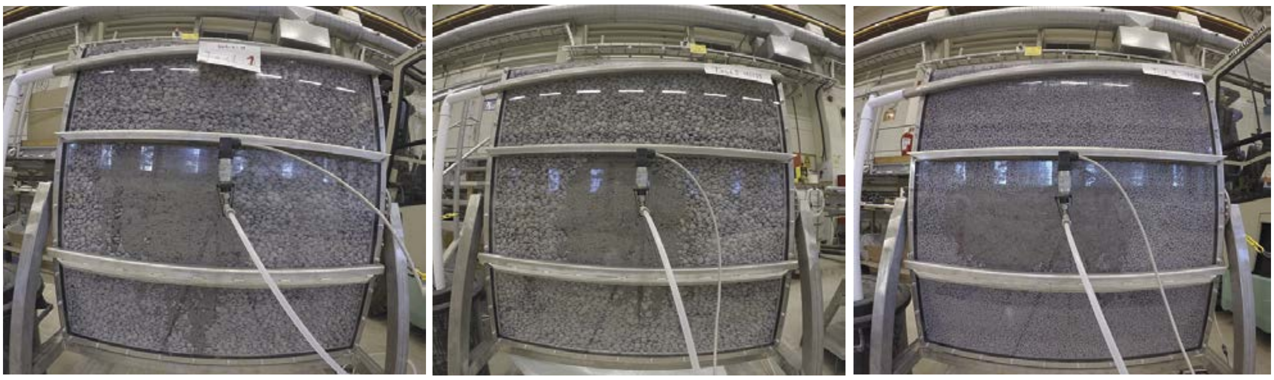
[*] Reference set-up. The test was repeated.
[**] A variation of the reference set-up with a different material. The test was repeated.
[***] For test #6A, the photo documentation was interrupted. The test was repeated under the name 6B.

Results

The results are being evaluated as this report is being written. The evaluation includes the following:

- How water is distributed in the pellet filling. The water ratio for samples from the pellet filling and the centre block is compared for the different tests.
- A visual analysis of the photo documentation at defined times.
- Measurements of water pressure for the inflowing water.

An example of a photo series is presented in Figure 3-7. The complete evaluation will be published as part of the project documentation.



Barakade test 1
4 h

Barakade test 2
4 h

Barakade test 3
4 h

Figure 3-7. *Examples of the photo documentation for three different tests with Barakade material after 4 h test time.*

3.6 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 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.

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 over-estimated in the numerical models.

The POSKBAR project is SKB's and Posivas 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.

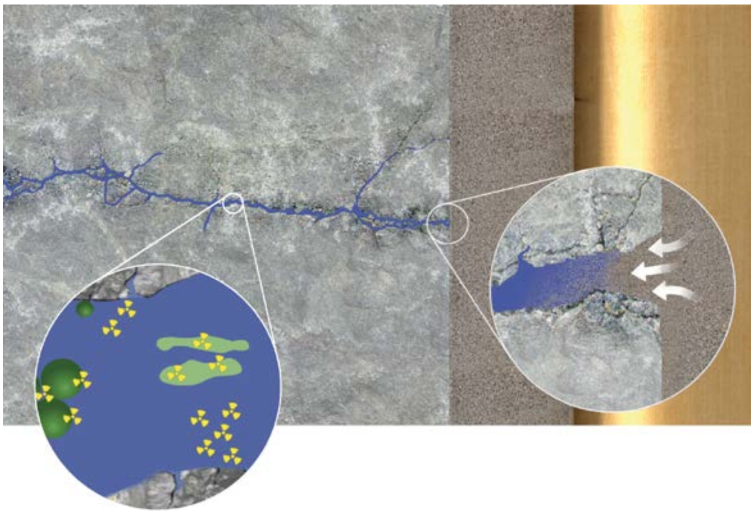


__Figure 3-8.__ Colloid formation and radionuclide transport from a bentonite barrier.

Objectives

The overall project goal was 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.

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.

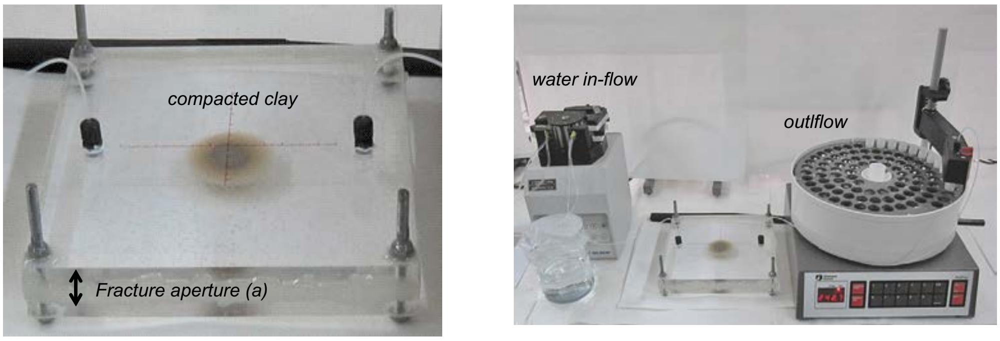
The project thus assesses what type of fractures that may intersect a deposition hole; their geometries (i.e. distribution of width, length, volume, direction, etc) and statistical occurrence.

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 with focus on fractures of 0.1–0.4 mm and mainly with 1 mM NaCl. Sedimentation, expansion as well as erosion by flow has been studied at CIEMAT in Spain, Figure 3-9.

a) Artificial narrow fracture

b) Experimental set-up



c) Erosion tests

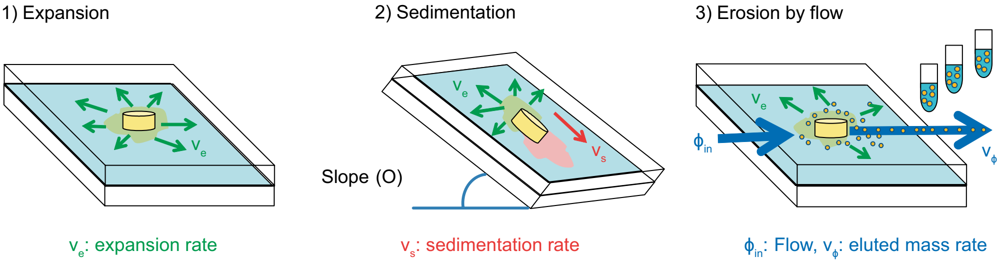


Figure 3-9. *(a) Artificial narrow fracture, (b) Experimental set-up, (c) Scheme of experimental tests: (1) Expansion, (2) Sedimentation and (3) Erosion by flow.*

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 initially dedicated to tackling the same questions in parallel.

A second model development step has been carried out for one of the modelling teams, now supported by POSKBAR experimental data (Alonso et al. 2019).

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) and results from the simulations were that 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 2017–2018 a large set of experiments under different physico-chemical conditions have been carried out at CIEMAT (Alonso et al. 2019), an excerpt from that report is presented below.

The main physical variables analysed were: fracture roughness (smooth or rough), aperture (from 0.1 to 1.7 mm) and slope (horizontal to vertical). The erosion behaviour of Na-rich bentonites (Nanocor® and Wyoming MX-80) was mainly analysed, and compared to that of Na- or Ca-exchanged MX-80. Some experiments were also carried out with a Ca-Mg bentonite (Ibeco) and a Spanish saponite (MCA-C). Most of the experiments were carried out with 1 mM NaCl as initial electrolyte, but higher ionic strengths were analysed as well.

In the experiments, the clay extrusion in the fracture was followed during 30 days, periodical photographs were taken to measure extrusion distances. Eroded masses and physico-chemical evolution were evaluated by post-mortem analyses.

All erosion experiments carried out within narrow fractures with apertures smaller than 1 mm, showed that clay extrusion in the fracture was stopped after some time. Clay expansion was favoured within fractures of wider apertures.

In general, Na-rich bentonites (Nanocor® or Na-exchanged MX-80) exhibited longer extrusion distances than raw MX-80 or Ibeco. Extrusion distances measured for Ca- exchanged bentonites, or other clays as saponite, were clearly shorter, but not null. As suggested by previous studies, which related clay erosion capability to its intrinsic characteristics, the relevance of clay properties is again pointed out.

Each clay established particular chemical conditions, mainly induced by soluble salt dissolution, which generally led to significant increases of water ionic strengths. The water chemistry established at equilibrium plays a major role on erosion.

Particle sedimentation along fracture slope was not detected in smooth fractures with apertures thinner than 0.4 mm, but particle sedimentation streams were observed within smooth fractures of 1 mm aperture and within rough sloped fractures, whose equivalent apertures were wider than 1 mm. Sedimentation behaviour within smooth and rough fractures was dependent on the clay nature: Na-rich bentonites sediment along fracture slope almost from the beginning. In contrast, sedimentation of Ca-rich bentonites was not detected under experimental conditions. In any case, the deposited fraction, under experimental conditions, was always lower than 6 % of the initial mass.

The effect that accessory minerals and soluble salts have on clay erosion processes was analysed in detail by comparing the expansion behaviour of raw MX-80, salt-free MX-80 and mineral-free and salt-free MX-80. Physico-chemical analyses of their corresponding extruded rings within the fracture were conclusive. Coarse mineral fractions can effectively restrict clay extrusion in narrow fractures; however, an enriched region with accessory minerals was not identified in the periphery of the extruded clay. Instead, the smectite particles themselves accumulate and form a filter, which is able to stop further particle expansion.

Erosion by flow was analysed after a previous expansion period of 30 days under stagnant conditions, so that the clay had previously extruded in the fractures. Applying flow velocities in the range of 10^{-7}–10^{-6} $m \cdot s^{-1}$, fresh water is provided and the ionic strength decreased, an additional clay expansion was measured. The mass of eluted particles was lower than 0.02 % of the initial mass, indicating that particle mobilization in the water flow, under studied conditions, was clearly restricted, even though additional expansion was measured.

In all the tests, the major role of water chemistry established at the equilibrium was proved.

Model development

The first modelling step in the POSKBAR project, which included a compilation of experimental data, mainly from BELBaR, but also from other sources followed by verification of the current model (Neretnieks et al. 2017) and a compilation of possible improvements and alternative methods are reported in Neretnieks and Moreno (2018b) and in Laviña et al. (2018).

This work was continued during 2018 where Neretnieks and Moreno (2018a) continues to explore the mechanisms that influence bentonite erosion in a KBS-3 repository. One key question is floc formation.

Flocs, floc-suspensions and the sediments rheological properties influence how fast and how far into the fracture network the montmorillonite can move. The flocs of montmorillonite particles age which makes them stronger. They form gel-like structures that are strong enough to stop continued movement in the fractures. Water movement is also limited in the areas filled with gel. Gel formation can thus have a considerable influence on the expansion of clay and colloid formation. It is shown that for suspensions with more than around 1 volume percent montmorillonite the shear strength has a non-linear dependency on the shear speed.

In some simple, orienting, experiments it is shown that even in very dilute suspensions, the montmorillonite sol will form sediment and gel. These observations and data indicate that even fractures with an aperture in the millimetre scale will block the movement of sediment montmorillonite gel.

Another process which hasn’t been quantitively discussed earlier is what’s happening to the accessory minerals in the bentonite clay. In addition to the main, montmorillonite mineral, the bentonite also includes 10 % or more of larger particles or other minerals. When the clay expands into fine fractures, these accessory minerals get stuck in the narrowest parts of the fractures and start to clog up. Experiments show that filters with pores as large as 0.1 mm quickly fill up and stops additional montmorillonite from passing. Mechanisms and models for this type of clogging is discussed in Neretnieks and Moreno (2018a). Orienting modelling indicates that such clogging can be quantatively simulated based on independent measurements of aperture distribution in natural fractures and by the size distribution of the accessory minerals. The modelling and experimental results thus indicate that the accessory minerals will clog fine fractures and thereby limit the loss of bentonite.

In general the conclusion by Neretnieks and Moreno (2018a) is that the current model (Neretnieks et al. 2017) is still valid. However, the expansion that this model predicts is not in line with available field- and laboratory tests and continued development work is expected.

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 an 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

Geology

The main focus during the past year has been development of investigation methods for application during construction and operation of the planned repository for spent nuclear fuel in Forsmark. The work concerns primarily RoCS, a digital system developed by SKB for geological mapping of undergound openings (tunnels, shafts and niches, etc). The system basis is a photogrammetric mapping record (3D model) upon which the spatial extent of various geological features is digitized. Geological properties of the digitized features are provided by studies of the rock surfaces of the underground openings.

The use of RoCS for regular tunnel mapping during the the Äspö HRL expansion project, as well as subsequent workshops with various experts and end-users, have revealed a demand for additional adaption and development of the system before full application. Aspects of special focus include both functions of the RoCS mapping module and the process for generation of photogrammetric 3D models. To provide support for this work, a series of tests have been completed within the framework of the laboratory. For the photogrammetry, this includes the following components:

- Camera and light setups for photography of deposition holes, deposition tunnels and the repository skip shaft.
- Evaluation of the use of spherical cameras.
- Development of prototypes to camera riggs for the photography of deposition holes (Figure 3-10).
- Change of software for generation of photogrammetric 3D models, from ShapeMetrix 3D to Agisoft Metashape, after market inventory of alternative products.
- Optimization of the workflow in Agisoft Metashape.
- Completion of a draftversion for SKB MD 150.011 *Metodbeskrivning för fotogrammetri som underlag till RoCS.*

The development that covers the mapping method and the functions of the RoCS mapping module, has included the following work:

- Adaption of RoCS to Windows 10 with subsequent acceptance tests.
- Specification of guidelines and principles for geological mapping, based on discussions with various experts and end-users.
- Tests with comparative mapping for evaluation of a remote mapping technique and the impact of work routines and interpretations developed by different geologists.
- An updating of the mapping module, primarily regarding the handling of fracture data, has been initiated and will continue during 2019–2020.

Another issue addressed the past year has been to develop a measurement method that is able to verify that the deposition holes fulfil the geometrical requirements. The main focus in this work has been to rely on laser techniques. Various tests have been completed in deposition hole at Äspö, DO0010G01 (see Figure 3-11), but a final decision on the choice of technique is not yet settled. The most promising approach so far is the use of a high-precision scanner lowered from a rigid tripod, placed immediately above the hole. However, additional tests need to be accomplished, to evaluate the influence of the following aspects on the measurement accuracy:

- Instrumental vibrations.
- Character of the bedrock surface, in terms of mineralogy, roughness and dampness.
- Merging of point clouds from different scan levels.

Figure 3-10. *Tests of setups and riggs for photography of deposition holes. To the left: Adjustable camera cradle with attached lighning. To the right: Rigg with attached lightning used for photography with a spherical iSTAR camera from NCTech.*

Figure 3-11. *Scanning of deposition hole DO0010G01 with a Trimble TX8 Laser mounted on a rigid tripod with a downward extendable centre pole.*

Hydrogeochemistry

During 2018 developed equipment for measurements of hydrochemical and physical parameters in defined borehole sections in tunnels have been tested in Äspö HRL, Figure 3-12. The measuring probe for pH, electric conductivity, Eh and O_2 showed good results in KF0069F01 for pH and electric conductivity. During 2019, the site acceptance test continues in borehole KA3510A.

Development of methods for sampling of dissolved gases in groundwater from tunnel boreholes was carried out in 2017–2018. During these years, SKB produced prototypes of sampling equipment, so called DGSS and GSS. The design of prototypes was the result of ideas and experiences from the use of similar equipment. However it showed that using the new prototypes was not optimal. In order to increase effectivity, improve sample handling and in order to adjust SKB's sampling equipment to a valuable extraction system, a new equipment has been designed as an analoge to ones used in similar underground laboratories (Nagra, ANDRA). The equipment is a sampling line composed of two steel cells where the sampled water is collected and a back-pressure valve which is used to maintain sampling pressure almost identical to that in a sampling borehole. Steel cells are currently being manufactured. The equipment is going to be tested in Äspö HRL in 2019.

Figure 3-12. *Testing the measurement equipment in the Äspö tunnel.*

3.8 Work on concrete barrier

Background

The final repository for 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 waste 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.

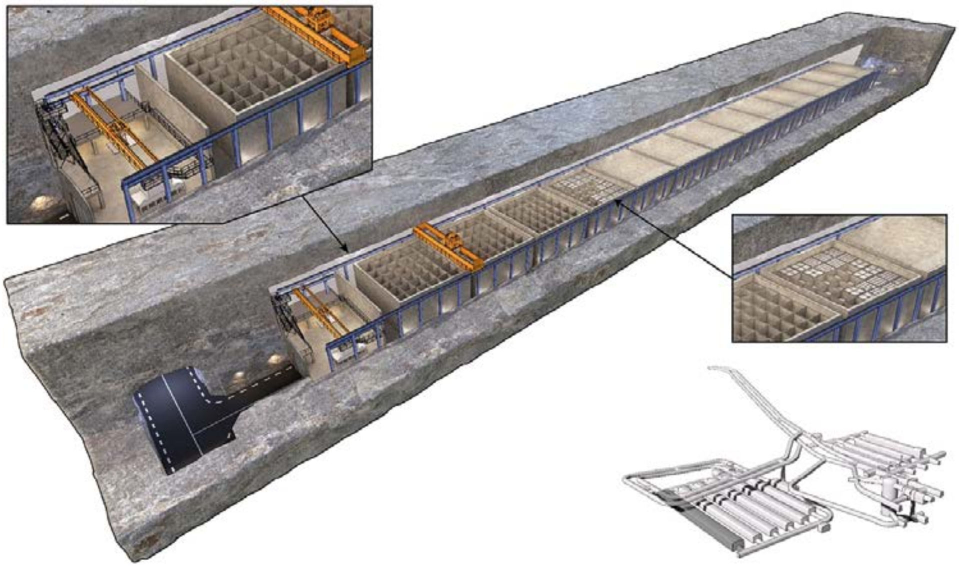


Figure 3-13. *The waste vault for intermediate level radioactive waste.*

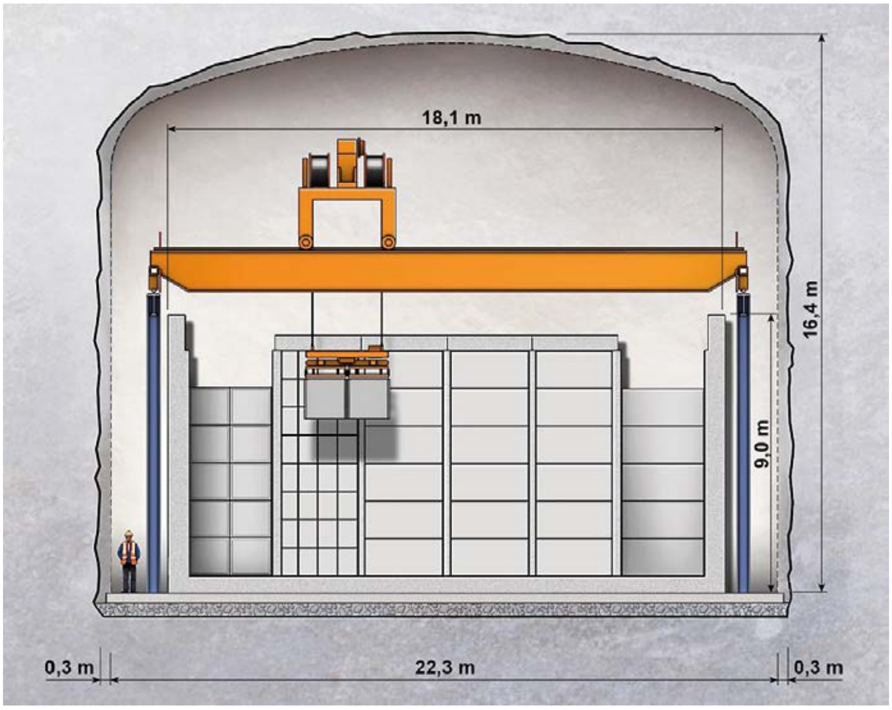


Figure 3-14. *A schematic illustration of a cross section of a concrete caisson for 2BMA.*

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 concrete caisson with all the design elements of the full scale caissons in the future 2BMA 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. Previously 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. Reported in Mårtensson and Vogt (2019).
- 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

A short summary of this work was presented in the 2017 issue of the Äspö annual report and all details are found in Mårtensson and Vogt (2019).

Casting of a down-scaled concrete caisson in TAS08

During 2018 the work on material investigations and development of the construction method for the concrete caissons continued with the construction of a concrete caisson with the dimensions 18 × 9 × 4.5 m in TAS08 in the Äspö laboratory. The thickness of the base slab and the walls were 0.60 and 0.68 m respectively and no reinforcement was used. The main focus of this work was to answer the following questions:

- **Concrete properties** – Verification of the suitability of the concrete also with the new design of the caissons with its thicker walls and base slab compared to the previous reference design. This relates mainly to expected increased temperatures in the concrete due to increased thickness of the walls and base slab.
- **Casting method** – Casting of base slab and walls separately and investigations of the hydraulic properties of the joint between these two parts.
- **Concrete production** – Investigating the influence of producing the concrete in a mobile concrete production plant placed close to the entrance of the Äspö tunnel on logistics during casting.
- **Prevention of crack formation** – Investigation of different methods to prevent the formation of cracks in the base slab and walls during hardening of the concrete.

The work was mainly undertaken during the autumn of 2018 and included the following 4 main activities which are described in more detail below:

- Preparations in TAS08.
- Establishment of a mobile concrete production plant.
- Casting of the base slab of the caisson.
- Casting of the walls of the caisson.

Preparations in TAS08

The first part of the preparations in TAS08 included removing all the rock debris from the excavation of the tunnel. This included the use of heavy machinery in combination with flushing the floor with water in order to create a clean rock surface to serve as a suitable foundation for the base slab, Figure 3-15 left image.

The base slab was produced in 2 subsequent steps. First, a layer of concrete was poured onto the rock floor in order to create a reasonably even surface. After sufficient hardening, the actual foundation slab for the caisson was cast on top of the concrete surface, Figure 3-15 right image. The foundation was left to harden for a few months before casting of the caisson.

Establishment of mobile concrete production plant

The casting undertaken in TAS05 during the previous years showed among others the need for short transports of the concrete in order for accurate control of the concrete properties and fast response to changes in the casting schedule.

For that reason, during this work, a mobile concrete production plant was established in direct vicinity of the entrance to the Äspö tunnel. The concrete plant's main features were 2 mixing trucks, 2 silos and a water tank, Figure 3-16. In addition, a large ramp was constructed to be used when pouring the concrete from the mixing trucks into the concrete transport trucks. Aggregates were stored in large piles within the area.

Figure 3-15. *Preparations in TAS08 prior to casting of the caisson.*

Figure 3-16. *The concrete production plant and the ramp.*

Casting of the base slab of the caisson

The casting of the base slab was done in October 2018, i.e. about 4 months after the completion of the foundation. The formwork was erected using standard methods and a copper joint seal was mounted in the part of the formwork shaping the joint, Figure 3-17 left image. Also, in order to reduce the adhesion and degree of restraint between the foundation and the base slab, a reinforced plastic sheet was placed on the foundation just prior to casting of the base slab, Figure 3-17 right image. In doing so, it was anticipated that the risk for crack formation in the base slab would be reduced.

Casting comprised a total of 100 m^3 of concrete and was accomplished in about 11 hours including post treatment of the surface and cleaning of equipment. In all, the work ran smoothly with concrete production and casting well synchronised, Figure 3-18. Once casting was complete, the base slab was sprinkled with water and covered with a plastic sheet and left to harden, Figure 3-19.

Casting of the walls of the caisson

Just a few days after casting of the base slab, work on erecting the formwork for the walls was initiated. Here the main parts of the formwork for the base slab were left and used as a part of the wall formwork. Only the parts shaping the joint and holding the joint seal were dismantled.

In addition to erecting the formwork, Figure 3-20 left image, preparations before casting of the walls also included heating of the base slab by means of heating mats, Figure 3-20 right image. The purpose of heating the base slab was to reduce the risk of temperature induced cracking of the walls caused by the temperature increase expected from the heat of hydration of the cement reactions in the concrete.

Casting of the walls comprised in total 150 m^3 of concrete and was carried out 5 weeks after casting of the base slab using the same equipment and methods as when casting the base slab. The work was uncomplicated and proceeded at a rate of about 2 trucks per hour, corresponding to 15 m^3 of concrete. Once casting was complete, the top surface was covered with a plastic foil and the concrete was left to harden. About one week after casting the formwork was disassembled, Figure 3-21.

Figure 3-17. *Images showing how the joint seals were fixed in the part of the form work shaping the joint, left image, and the plastic sheet used to reduce adhesion between the foundation and the base slab of the caisson.*

Figure 3-18. *Casting (left image) and post treatment (right image) of the base slab.*

Figure 3-19. Casting complete and the base slab sprinkled with water and covered with a plastic sheet.

Figure 3-20. Wall formwork and heating mats used to heat the base slab prior to casting of the walls.

Figure 3-21. The concrete caisson after dismantling of the formwork.

Follow-up and reporting

At present, the properties of the concrete in the caisson is monitored with focus on temperature, relative humidity, levels of internal strain and external dimensions. Also weekly visual inspections are carried with main focus on the presence of cracks. Data from the monitoring programme will be compiled into a report also including experiences from casting and material properties. The report is expected to be published during 2020.

3.9 Long-term studies of steel corrosion in low-pH concrete

Background

On behalf of SKB, Swerea KIMAB AB and The Swedish Cement and Concrete Research Institute (CBI) have carried out studies that together comprise nine years of corrosion testing in the Äspö HRL's underground environment.

The final phase of the study was carried out in 2018. The work included retrieval and analyses of 12 concrete blocks (six blocks with low-pH concrete and six blocks of construction concrete) with embedded test bars of carbon steel and four approximately four-meter-long rock bolts embedded in low-pH grout in the roof and wall of a tunnel niche in Äspö HRL.

Concrete blocks with embedded steel bars have previously been evaluated after 18 months and five years of exposure. Grouted rock bolts have earlier been retrieved and evaluated after five years of exposure. The five-year results have been separately reported by Aghili et al. (2014).

Objectives

The purpose of this activity is to provide a basis for studies of rock reinforcement with bolts and to provide increased knowledge about the use of low-pH grout. Low-pH grout is different in the material composition compared to conventional grout and has a lower pH. This can lead to deviating properties of low-pH material compared to conventional material. SKB needs to clarify how deviating the properties can be and to what extent the possible deviations affect the properties of the material and the corrosion rate of cast-in steel.

The goal of this examination was to:

- Evaluate and compare the corrosion rate of carbon steel in low-pH concrete with the corrosion rate of carbon steel in conventional construction concrete.
- Evaluate whether the bolt-grout (low-pH paste and low-pH grout) has been exposed to leaching.
- Determine if the chlorine initiated corrosion for steel will increase if low-pH-based binders are used in bolting or cast concrete instead of construction cement binders.

Experimental concept

Rock bolts injected with bolt-grout (low-pH paste and low-pH grout)

Originally, 20 rock bolts were installed in the Äspö tunnel (10 pcs horizontally in the rock wall and 10 pcs vertically in the rock roof), see Figure 3-22. The boreholes have a diameter of 46 mm and a depth of about four meters. Before bolting, it was checked that the boreholes were dry. Two different grout formulas have been used. The boreholes were filled from the inside out with either a low-pH paste or a low-pH grout. Subsequently the bolts were pushed into the filled holes. Centering rings were used for centering the bolts in the holes. The quality of the bolting operation was checked using a bolt meter. The bolts grouted with recipe 1 were marked with white color and those grouted with recipe 2 were marked yellow.

In September 2013, three rock bolts were overcored and then removed from the rock for subsequent laboratory analysis. One of the bolts was vertically positioned and two bolts had been placed horizontally. This project-phase was summarised by Aghili et al. (2014).

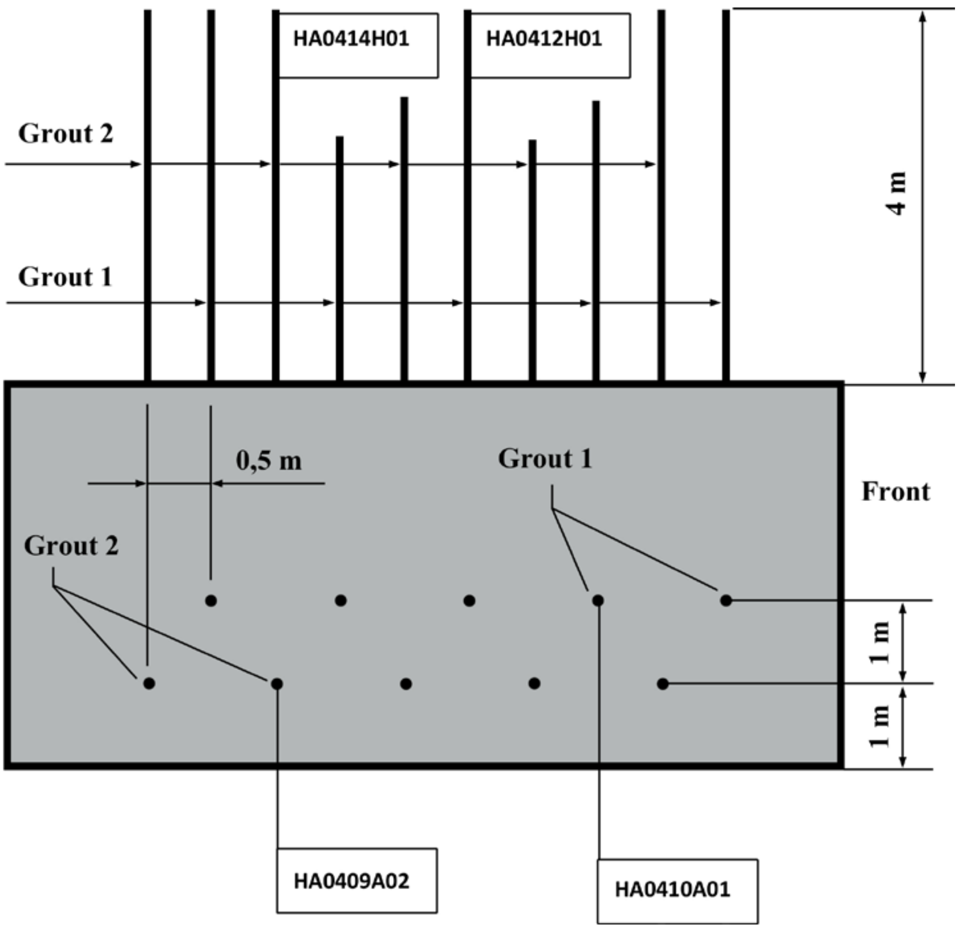


Figure 3-22. The location of rock bolts in the niche NASA0408A.

After nine years of exposure in the rock wall, another four rock bolts were overcored for examination in 2018; Two in vertical position: HA0414H01 (white) and HA0412H01 (yellow), two in horizontal position: HA0409A02 (white) and HA0410A01 (yellow). Since two different grout mixtures had been used, a bolt was taken in each direction from the two different materials. SKB-staff was responsible for the actual removal of the rock bolts with the help of a local drilling company.

The overcoring was made using a special drill with a diameter of 116 mm which allows drilling lengths up to 5 m without interruption. A work platform was built in connection to the drilling machine to facilitate the operator's work on mounting and dismounting drill rods. When a vertically placed bolt is overcored and to be removed, the core drill is secured with a bracket in the ceiling and lifting straps are attached to a loading machine. The bolt is allowed to follow the drill down when the loader lowers. The drill and platform is then moved away and the core drill and bolt is lowered gently down. The horizontally placed bolts are overcored and the core is broken, the bolts are then pulled out using a winch.

Steel test bars embedded in concrete blocks with low-pH concrete and construction concrete

Test bars of carbon steel embedded in concrete blocks, with either a low-pH concrete or a conventional construction concrete, have been exposed for about 9 years in an open container placed in niche NASA2715 in the Äspö tunnel. In order to accelerate the corrosion of the cast-in test bars, chlorides were supplied to the concrete blocks in two different ways, either directly upon casting or after the concrete blocks have been cast and cured for 28 days in 100 % RH. When chlorides were cast in, the chlorides were added together with the mixed water, whereby a total chloride content of 2 % chlorides per binder weight in the concrete was achieved. In the second case, the concrete blocks were submerged in a 10 % sodium chloride solution for three months.

In connection with previously described rock bolt retrieval, the last 12 of the corrosion samples, which were stored in NASA 2715A, were retrieved and sent for analysis to Swerea Kimab.

Results

Sedeholm et al. (2018) reports the following conclusions from the two tests:

Steel test bars embedded in concrete blocks with low-pH concrete and construction concrete

- Steel test bars in the two concrete types without chlorides had negligible corrosion rates and were considered to be in passive state.
- Steel test bars in low pH concrete, pre-exposed in a chloride solution after casting and curing, had negligible corrosion rates (< 1.0 µm/year) due to slow chloride transport and were judged to be in passive state.
- For steel test rods in a construction concrete, pre-exposed in a chloride solution after casting and curing, a corrosion rate of about 6.9 µm/year was measured after nine years in the Äspö tunnel. This shows that the chloride content has been sufficient for corrosion to start.
- On steel test bars in low-pH concrete with embedded chlorides, a corrosion rate of about 43 µm/year was measured. In the construction concrete with embedded chlorides, a corrosion rate of steel bars of about 1.0 µm/year was measured.
- The maximum pit corrosion depth of steel test bars in low-pH concrete with embedded chlorides varied between 1 000 and 1 800 µm and in steel test bars in construction concrete with embedded chlorides the maximum pit corrosion depth varied between 1 000 and 1 500 µm.

Rock bolts injected with bolt-grout (low-pH paste and low-pH grout)

- No corrosion attack could be observed on any of the rock bolts examined, injected with low-pH grout or low-pH paste.
- No shrinkage cracks could be found in any of the injected low-pH grout or paste examined.
- The bond between the rock bolts and the low-pH grout or the low-pH paste was good.
- The pH value of both injected bolt-grouts varied between 10.5 and 11.5.
- Examination of the CaO/SiO2 ratio in the bolt-grouts showed that no leaching occurred during nine years of exposure, in either of the two low-pH grout formulas.

3.10 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 previous reference method for sealing these investigation boreholes (SKB 2010) was 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 were to be filled with quartz-based concrete plugs that prevents erosion of the clay. The drawback with this method is that it is very expensive and labour intense. A new technology development project was therefore initated in 2015 with the goal to optimize the sealing of SKB's investigation boreholes in Forsmark.

A new modular design for sealing of deep boreholes has been developed based on the updated design requirements. This method, referred to as "The Sandwich concept" (Figure 3-23), 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 boreholes not penetrating the rock will only use the top most part of the concept; the Bentonite pellets.

- Regular boreholes without a hydraulic connection to any of the repositories will be sealed using either the sandfilling or quartz conrete filling combined with the upper end seal and bentonite pellets.
- Boreholes with a hydraulic connection to any of the repositories will be sealed with the complete Sandwich concept including at least one bentonite seal.

The Sandwich concept implies that the main part of the borehole is filled with sand. 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.

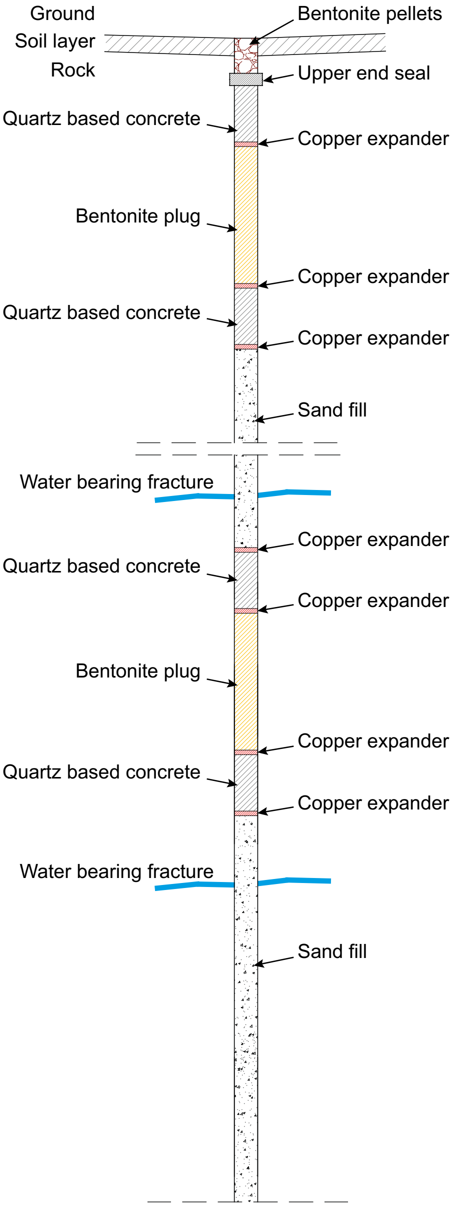


Figure 3-23. *Schematic drawing of the suggested principle for sealing of deep investigation boreholes, the "Sandwich concept". The design includes dense bentonite plugs positioned in sections with good rock. Permeable sand is filling up the main part of the borehole. Quartz-based concrete is positioned in the transition zones between bentonite and sand. Copper expanders are positioned at all transitions between different materials.*

Objectives

The main objectives with the project were:

1. To investigate the properties of the different sealing components included in the Sandwich concept by performing small scale laboratory tests.
2. To develop and demonstrate the installation technique for different sealing components. Pre-tests were performed in both laboratory and in field.
3. To perform a sealing of a full-scale borehole using the Sandwich concept. The main objectives with this test were to demonstrate the installation technique of different sealing components in full scale and to test the suggested quality control system regarding e.g. achieved density and position of the different components in the borehole.

Except for the objectives mentioned above, it has also been a goal to perform an inventory of all boreholes together with a classification. This work is, however, still ongoing.

Experimental concept

Laboratory tests were performed to test and demonstrate the installation of the different sealing components but also to measure and demonstrate the swelling pressure built up and the sealing effect of dense bentonite. Installation tests in large scale were performed in the Multi Purpose Facilities at Äspö. The tests included installation of both bentonite pellets and sand in an artificial borehole with a length of ten meters. The tests were made at both dry and wet (water filled simulated borehole) conditions. Furthermore, tests were made to install concrete in a simulated borehole with the use of standard drill tubes.

After finalizing the preparatory tests, a full-scale installation test demonstrating the Sandwich concept, was performed in the field.

Results

The different components included in the sandwich concept, the sand, bentonite, concrete and the copper expander have been tested at the Multi Purpose Facility 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 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 3-24, were installed and retrieved during 2017. This test was preceded by laboratory tests 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 measurements of the achieved final density of the installed bentonite after the dismantling of the test. The result of the mock-up test is reported in Sandén et al. (2018).

An inventory of a suitable borehole 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. 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 was done in June 2018 and it was performed as a pure installation test.

The installation included several different components: a special developed concrete with a very low cement content, a standard concrete, sand, highly compacted bentonite and copper expanders (bridge plugs), see Figure 3-24. The sand was installed by gravity (controlled installation rate) while the installation of the other components required access to the drill rig. The installation was made according to the plans and the techniques developed and tested in laboratory also worked in the full scale. The total installation time was approximately two weeks.

To ensure the quality of the performed work it was necessary to have a detailed quality plan including organization, available borehole data, preparatory work, drilling rig, material data and a controlled installation procedure. The quality of the borehole sealing was assessed to be successful regarding e.g. achieved density of the bentonite section and the two sections filled with sand. Regarding the concrete sections, there was a difference between injected volume and filled borehole volume for two of the five sections. The difference was believed to depend on problems to fill the injection tubes properly i.e. there may be trapped air in the concrete which means that the injected volume was overrated. The installation test is reported in Sandén et al. (2018).

The KAS13 borehole crosses the tunnel ramp close to the elevator shaft at the −220-meter level. This means that it will be possible to have access to the lower part of the borehole. It is planned to over-core the lowest five meters of the borehole from the bottom to be able to take out samples and study the quality of the installed components i.e. two types of concrete and one copper expander. This activity will be done during 2019.

Depth (m)	Material	Remark
0–102	na	na
102–102.5	Plug d = 76/96 mm, concrete	SKB-type
102.5–102.6	Copper expander	
102.6–170	sand	< 2mm
170–170.1	Copper expander	
170.1–175.1	Concrete	SKB-type
175.1–175.2	Copper expander	
175.2–185.2	Bentonite	MX-80
185.2–185.3	Copper expander	
185.3–190.3	Concrete	SKB-type
190.3–190.4	Copper expander	
190.4–232.3	sand	< 2mm
232.3–232.4	Copper expander	
232.4–252.4	Concrete	Standard
252.4–252.5	Copper expander	
252.5–253.5	Concrete	SKB-type
253.5–254	Plug d = 76/96 mm, concrete	SKB-type
254–255–	Concrete	SKB-type
255–	Mechanical packer	Bottom of the borehole

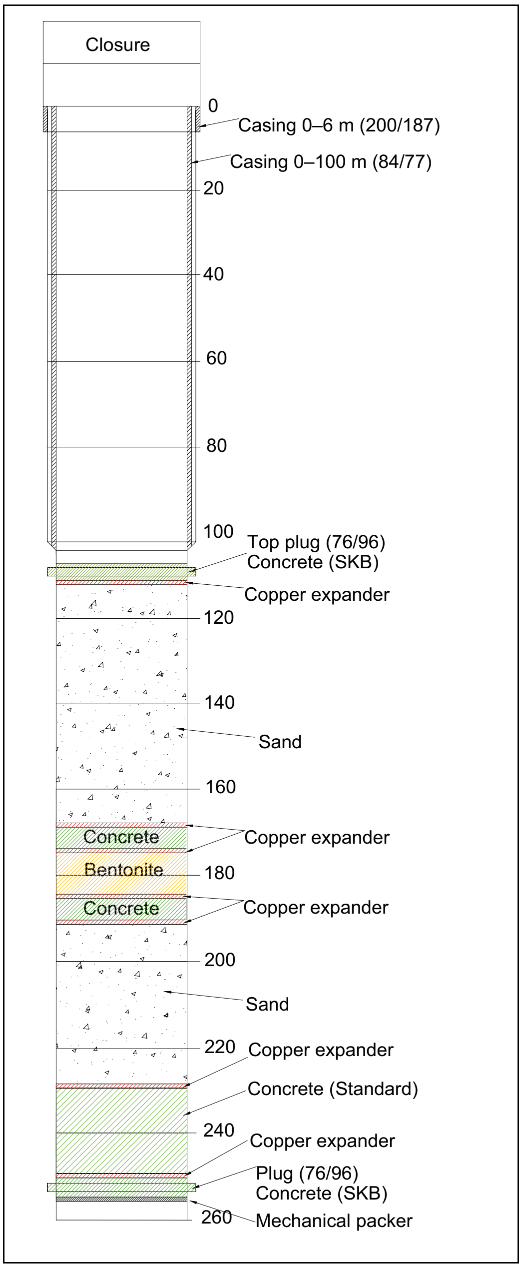


Figure 3-24. *Schematic drawing showing the planned position of the different sealing components for boreh hole KAS13 at Äspö.*

3.11 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 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 2017a).

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.

During 2019, a method for controlling bentonite pellet quality has also been added to the laboratory.

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.

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 6 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 (SKB 2019b).

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.

Assessing the variability, i.e. the heterogeneity of the material in larger purchases will be a key question for future industrial applications, when thousands of tons of materials are purchased. The current sampling strategy for a full scale test production, material purchase (20 tons), is presented in Figure 3-25. 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 composite 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 2017–2018 the methods have been updated and analyses of the 6 selected materials; Milos clay, a Moroccan clay, Bulgarian clay, Turkish clay, Wyoming clay and Indian clay have been carried out. The data has been compiled and assessments have been initiated.

Most work has been updates of established (at Äspö) methods. However, one new method has been established during 2018, namely thermal conductivity.

There is a requirement that the system shall not be hotter than 100°C. The temperature is dependent on the canister temperature and the thermal conductivity of the buffer as well as the design of the repository and therefore there is no direct requirement on the thermal conductivity of the bentonite clay. However, in order to evaluate different designs of the clay components, the thermal properties of the bentonite clay need to be known.

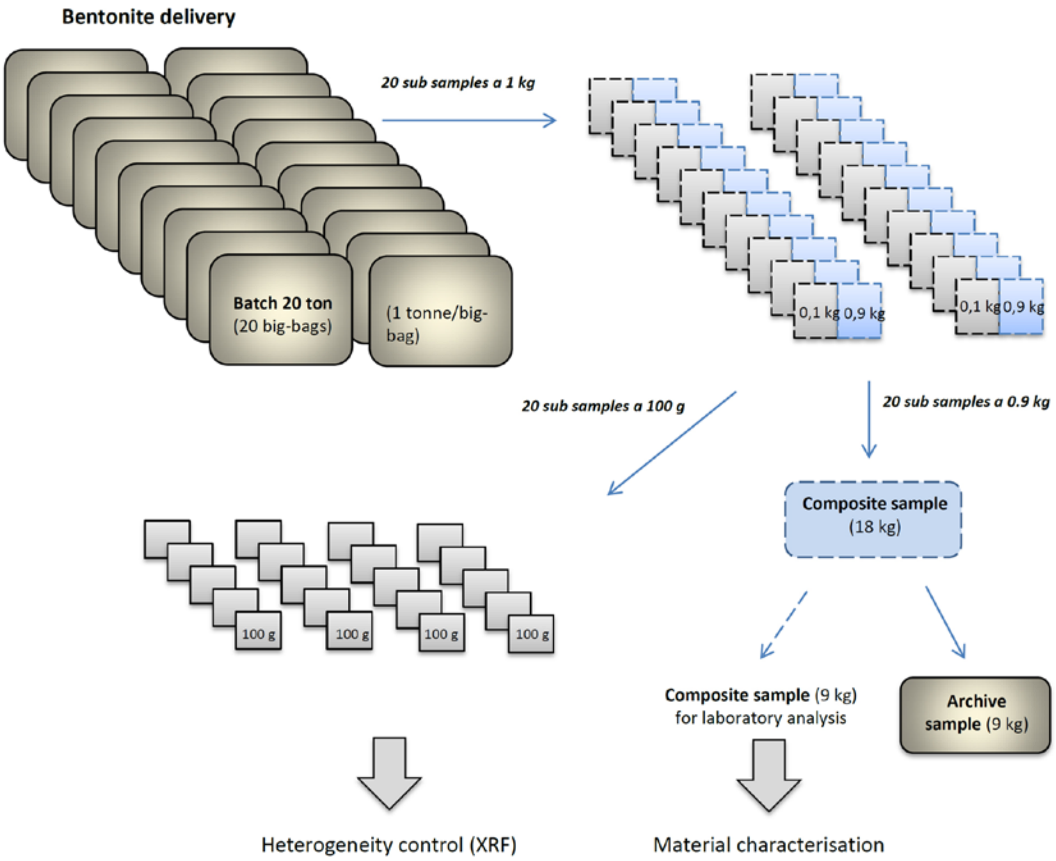


***Figure 3-25.** Sampling strategy for a 20 ton material purchase.*

The TPS (Transient plans sensor) method has been chosen for determine the thermal properties of the bentonite clay. With this type of sensor the thermal conductivity is evaluated by applying thermal energy to the sample and then measure how the temperature dissipates in the sample.

Some results of the measurements are shown in Figure 3-26. The figure shows that the specific heat is clearly dependent on the water content of the bentonite. All tested bentonites (those in the project and some extra materials) have similar values on the specific heat although there are some smaller differences. Although there is some scatter in the results it seems that some of the bentonite types have slightly higher values on specific heat compared to the other.

For the case of modelling this has a small effect as the specific heat only affects the heat transport calculations in short timespans. However, as the specific heat also is used for calculating the anisotropy of the thermal conductivity, this might be a source of uncertainty.

The focus during 2018 has been on investigating candidates for buffer materials. All of the materials except two fulfilled the requirements. For the two materials that did not work, one had too low bulk density for the currently available mould. However, if it is purchased with less fine material, it would probably work as well. The other bentonite that did not work was a material which was purchased for testing a quality with lower montmorillonite content than the rest of the materials.

Full scale buffer production of three promising materials is planned for 2019. If it works out as expected, it will be the first time buffer blocks are made of other materials than MX80, which would be an important step forward for the adaptive design methodology.

The current plan is to publicly report both the material studies and adaptive design, including buffer production, during 2019.

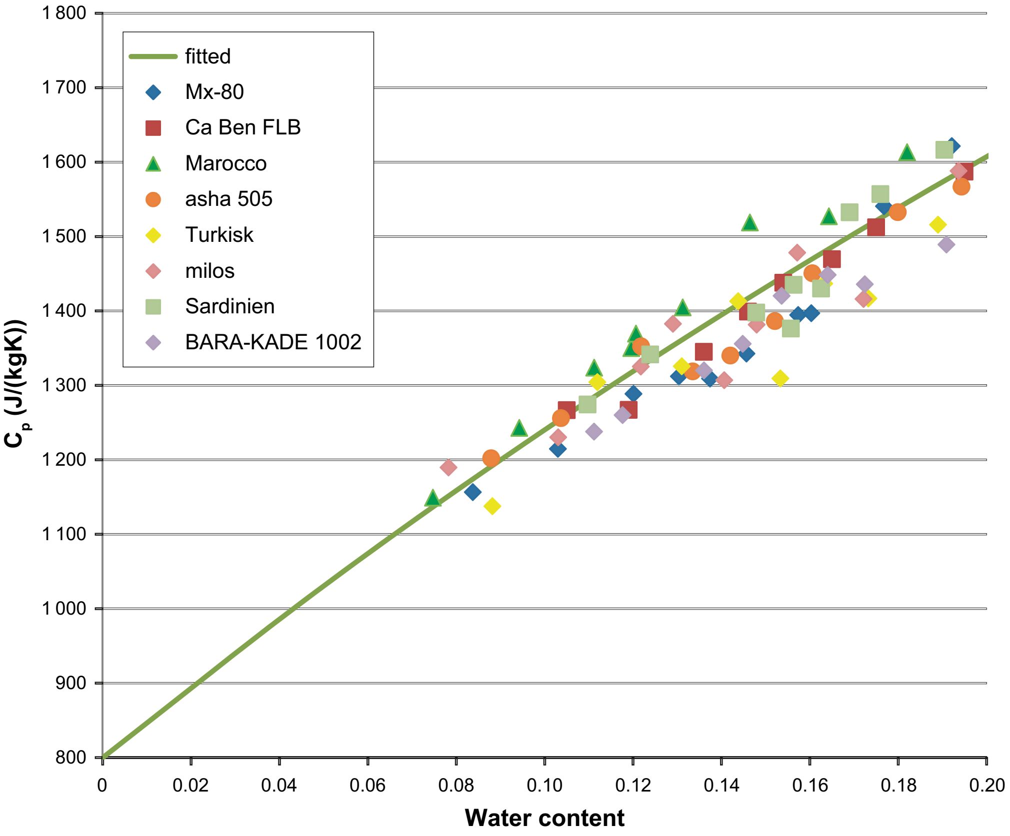


***Figure 3-26.** Specific heat data (preliminary).*

3.12 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 one project – Concrete & Clay – has had retrieval of experiments during 2018.

3.12.1 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 4-1. 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.

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.

3.12.2 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.

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.
- Interface reactions 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.

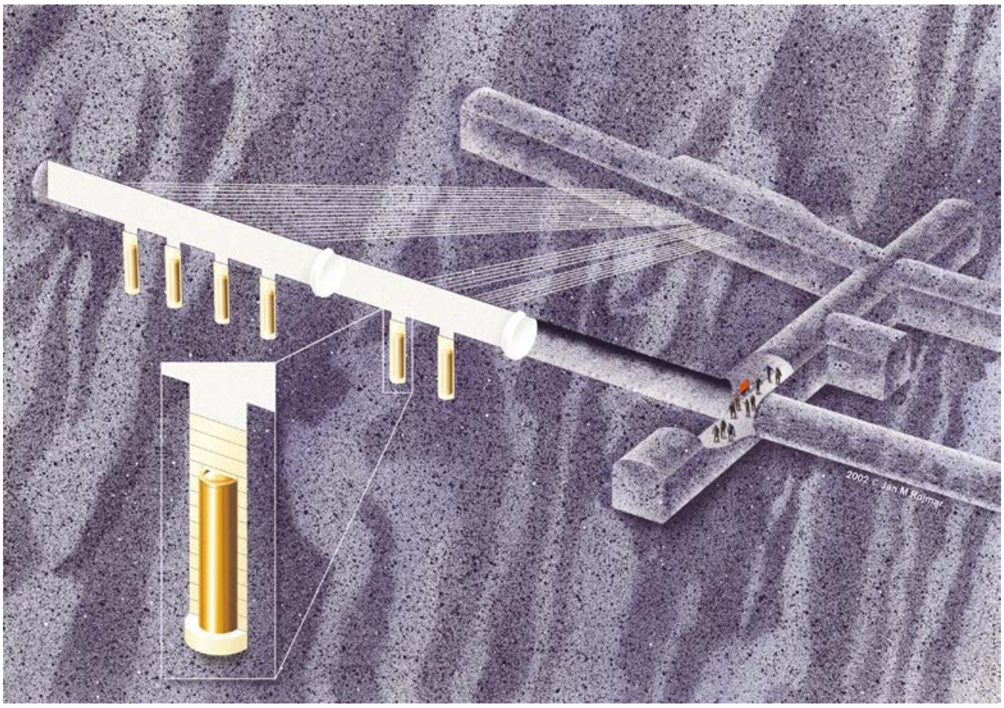


Figure 3-27. *Schematic view of the layout of the Prototype Repository (not to scale).*

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 materials representative of low- and intermediate-level waste 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.

The experimental concept is further described in Mårtensson (2015).

Results

Retrieval and analysis of experiment #20

During 2017 experiment #20 was over cored and retrieved and samples prepared for analysis as briefly described in SKB (2019b). The specimens comprised blocks of bentonite in which small cement cylinders containing a powder of a metal or a metal chloride representative of metals in low- and intermediate-level waste had been emplaced as described in Mårtensson (2015).

During 2018, he samples have been analysed with main focus on diffusion of trace elements from the cement cylinders into the bentonite as well as cement bentonite interactions including both standard cement paste and low-pH cement paste.

The results from the analysis are currently being compiled and a full report covering retrieval and analysis is planned for 2019.

Retrieval and analysis of concrete cylinders containing organic material

During 2018, 2 concrete cylinders containing organic material representative of low- and intermediate-level radioactive waste were retrieved from their deposition hole in NASA0507A, Figure 3-28 and segmented.

After segmenting, cores were extracted from the concrete cylinders Figure 3-29, left image. The cores were then segmented and care was taken to ensure that the central segment contained some piece of organic material, Figure 3-29, left image.

Figure 3-28. *Retrieval and segmenting of the concrete cylinders.*

Figure 3-29. *Cores from the segments of the concrete cylinders and a segment of the core containing a piece of organic material.*

The final step in the sample preparation before analysis of the specimens was crushing the individual segments into a powder in order to facilitate liquid extraction of any organic compounds from the individual specimens. Analysis with focus on identifying any types of organic compounds in the concrete were initiated early 2018. A report from the laboratory is expected during 2019. The results will be compiled in a report including also other similar experiments but the time for this is yet not decided.

3.12.3 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 MX-80 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 includes 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. 2016; 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 3-30), detailed analysis of the blocks are to be performed in the coming years.

Figure 3-30. *Highly fractured bentonite blocks from the very high temperature experiment ABM5 excavated in 2017.*

3.12.4 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 3-31.

In 2001 SKB published a RD&D programme (SKB 2001) for the KBS-3H variant with four phases. The most recept joint (SKB/Posiva) project phase, KBS-3H System Design, was initiated in 2011 and was concluded end 2016. All development steps have been made in close cooperation between SKB and Posiva. The recent project phase covers all areas of the KBS-3 method but the focus was on the KBS-3H specific issues (Posiva SKB 2017b).

Objectives

The final goal of the KBS-3H System Design phase was 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 was 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 has been 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 was based on earlier safety assessment work and made use of Posiva's safety case "TURVA-2012" for KBS-3V (produced by SAFCA) for Olkiluoto and SR-Site for Forsmark (Posiva SKB 2017b).

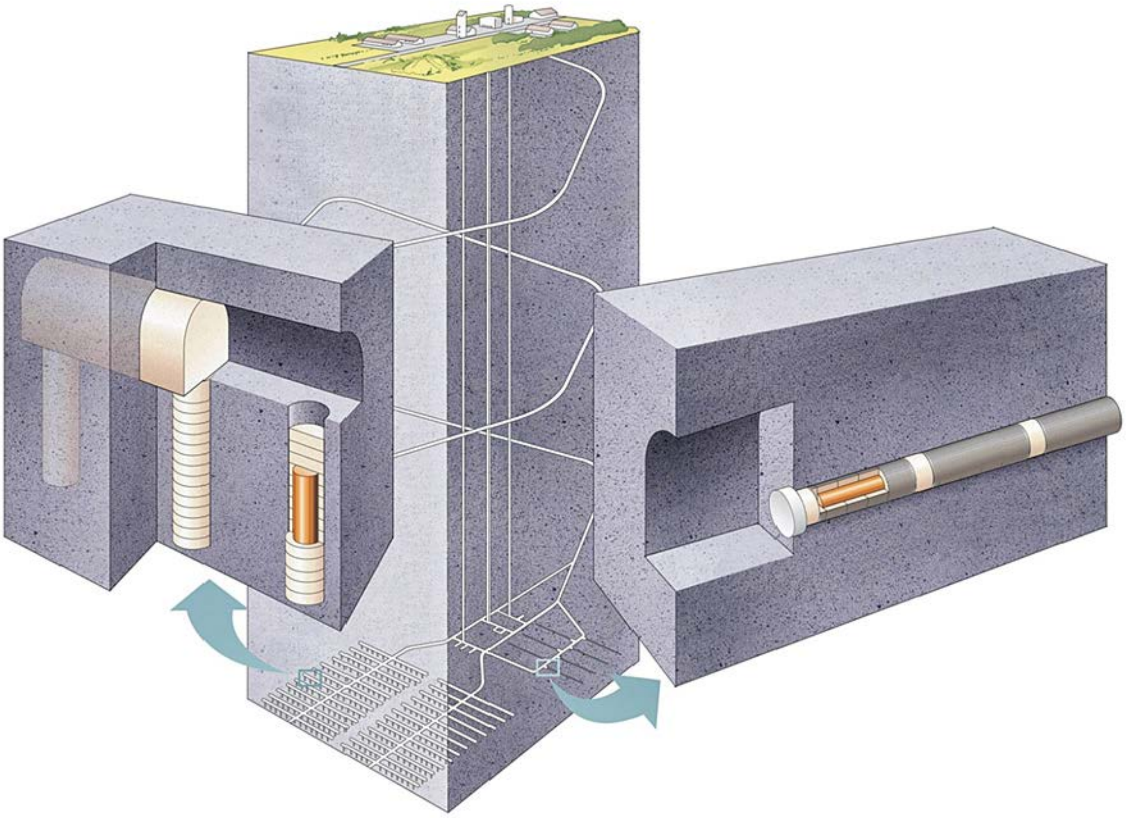


Figure 3-31. *Schematic drawing of the KBS-3V reference design (left) and KBS-3H (right).*

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 3-32. 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.

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.

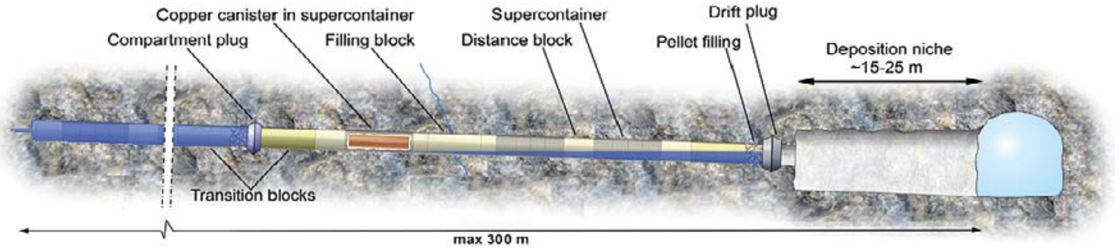


***Figure 3-32.** KBS-3H reference design DAWE with its main components; the plugs with their transition zones, the Supercontainers, and the distance and filling blocks. The illustration shows an ongoing artificial water filling procedure of the second compartment.*

Multi Purpose Test (MPT)

The MPT is basically a down-scaled (length-wise and temporal) non-heated installation of the KBS-3H reference design, DAWE, and includes the main KBS-3H components in full scale. It is installed at the −220 m level which implies that the hydraulic boundary conditions differ from those foreseen at a typical repository depth.

The test itself was installed by the end of 2013 according to the DAWE reference design in a 20 m long drift section in the innermost part of the 95 m long full face drift DA1619A02 (d = 1.85 m).

The MPT has been set up with two main objectives:

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

Verification is the overarching objective and the test has provided important experiences from working in full-scale at ambient in situ conditions, although not fully representative of typical repository depth.

The MPT has also been a part of the EU-project LucoeX and it has been granted funding from the European Atomic Energy Community's (Euratom) Seventh Framework Programme. The LucoeX project was concluded at the end of August in 2015.The deliverables of the MPT are accessible on the website www.lucoex/deliverables.eu under Work Package 4.

The MPT test has been instrumented with 227 sensors and the monitoring phase has been ongoing since Dec. 7, 2013. The monitoring phase will continue until the dismantling of the MPT which will begin at the earliest in 2020.

3.12.5 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.

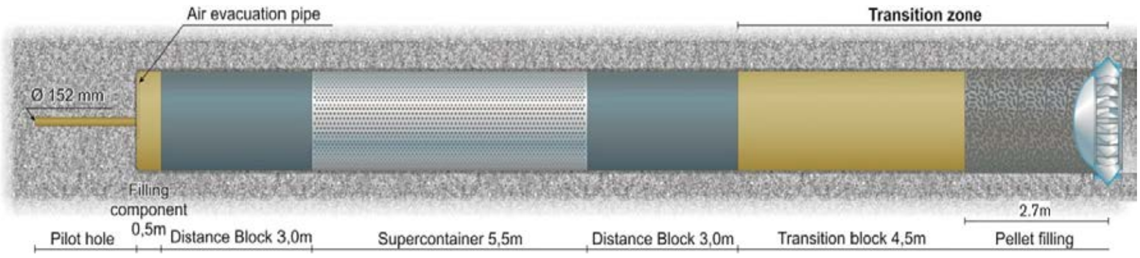


Figure 3-33. *Schematic illustration of the MPT layout.*

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 3-34). 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.

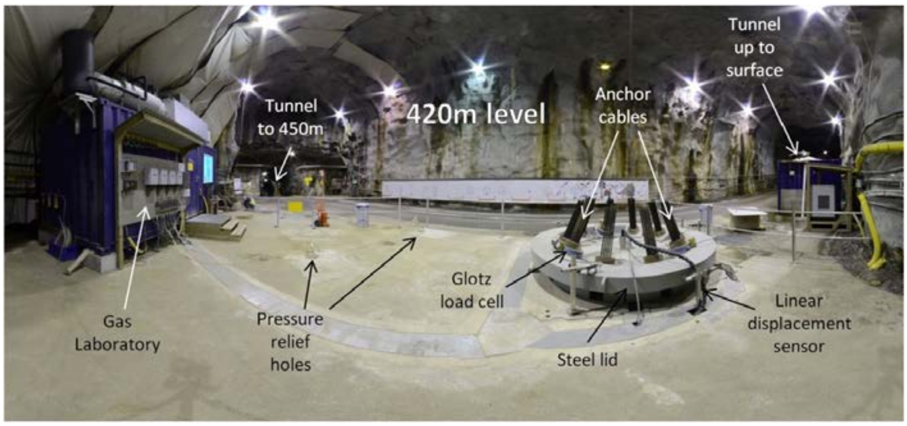


Figure 3-34. *The Large scale gas injection test at the −420 m level in Äspö HRL.*

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.

3.12.6 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 3-35), 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).

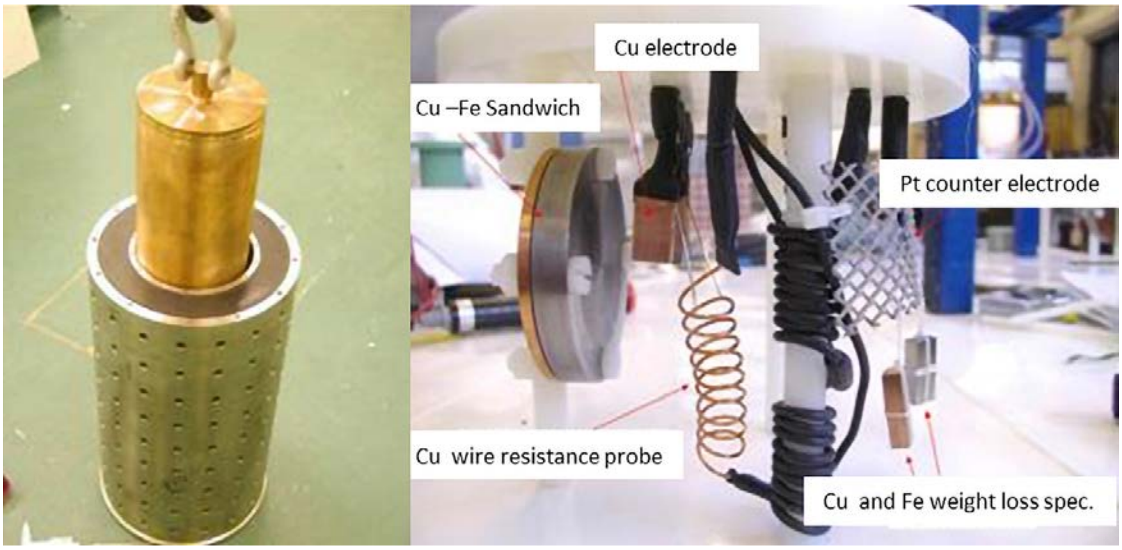


***Figure 3-35.** Model canister being lowered into support cage containing bentonite pellets in annulus (left). Test electrodes inside support cage around model canister experiments (right).*

3.12.7 Long term tests of buffer material

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 3-2.

Table 3-2. 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 2018, two projects within mechanical- and system engineering have been active at Äspö:

- Equipment for milling of buffer blocks.
- Backfill 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 concept 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.

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.

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 4-1.

The milling of bentonite with the motor spindle was tested with good results, see Figure 4-2. Tests of the drive of the linear movement were also successfully carried out, showing that the integration of software and hardware is functional and that the linear parts of the equipment work as expected.

In 2018, the prototype was finalized and the remaining work on testing the circulation drive and making integration tests between the separate shafts was carried out, see Figure 4-3.

After the final test showed approved results, the final implementation of the sample milling of a bentonite block was performed. The bentonite block was placed on the ground with a slope corresponding to a height of 17 mm from one edge to the other, see Figure 4-4. The prototype was placed on the bentonite block and then leveled to a horizontal position. Then the entire surface intended for the canister was milled, see Figure 4-4, Figure 4-5 and Figure 4-6. The socket for the canister flange was last processed, see Figure 4-7.

The testing of the concept of milling of buffert blocks shows that it meets the set requirements and functional principles.

Figure 4-1. *Test rig for the linear motor and the motor spindle.*

Figure 4-2. *Milled track in bentonite with the linear motor.*

***Figure 4-3.** The prototype fully assembled and ready for milling test.*

***Figure 4-4.** The picture shows the slope of the buffert block.*

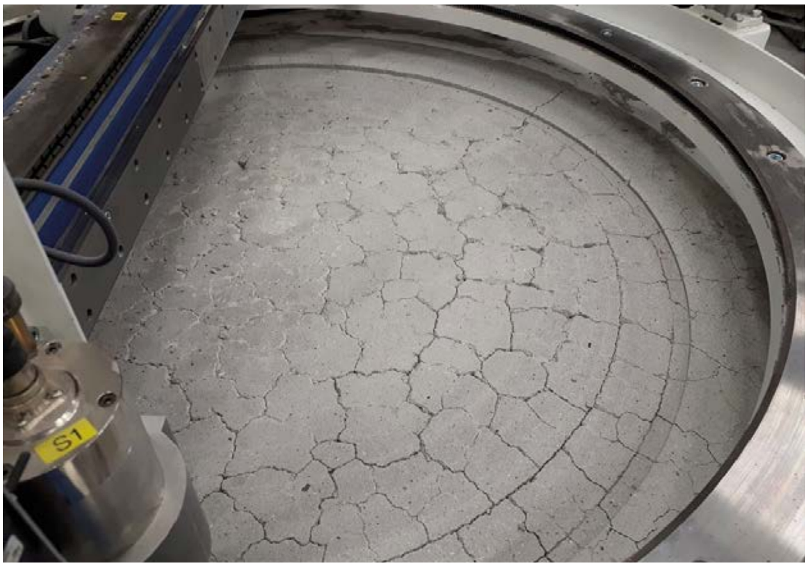


***Figure 4-5.** Milling the surface levelled on which the canister stands.*

Figure 4-6. The picture shows that the milled surface for the canister is horizontal.

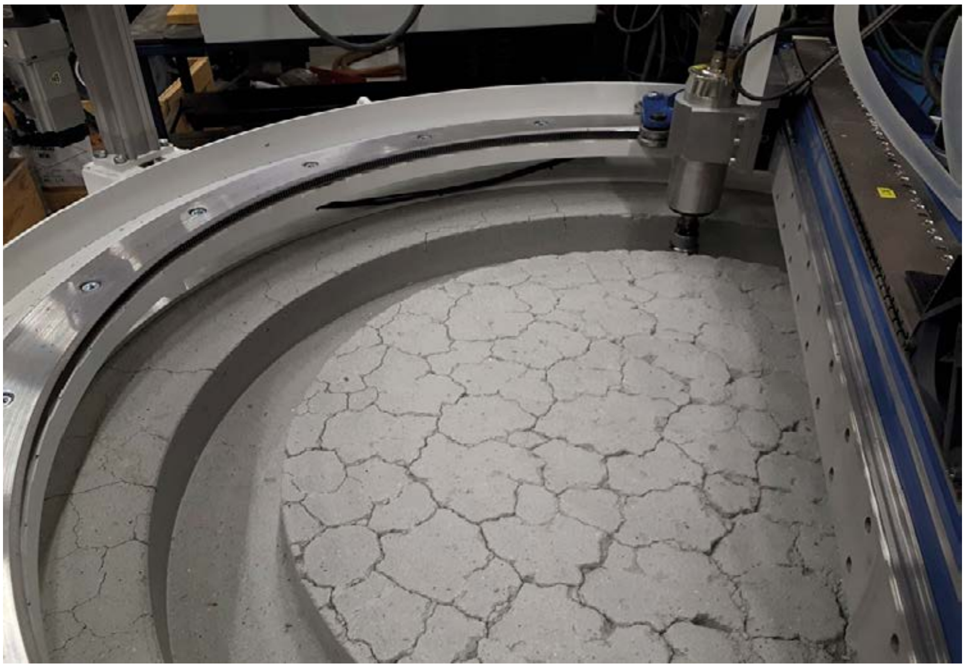


Figure 4-7. Milling of the socket for the canister flange.

4.3 Backfill installation equipment

Background

Canisters of copper with spent nuclear fuel will be deposited in deposition holes drilled vertically in the sole of tunnels, surrounded by a buffer of bentonite clay, in accordance with the KBS-3V method. The deposition tunnel is planned to be backfilled with blocks and pellets of bentonite clay. A well-executed installation ensures, together with the properties of the material, that a similar swelling pressure and a reduced hydroconductivity around the tunnel cross section can be achieved and thereby prevent water-conducting cracks from being short-circuited. The tasks can be performed by mainly standard equipment but some modifications have to be made.

Earlier development of the modular chassis concept was done in the project Transport System for Buffer and Backfill, and the concept of the universal chassis was developed further in the later project Universal Chassis. That project was conducted as a part of a joint effort together with a heavy transporter manufacturer. The choice of manufacturer Cometto Industries depended on the design parameters of the universal chassis, they already had a transporter called EMT (Electrical Modular Transporter) which fitted the design profile, Figure 4-8. It has a payload of approximately 20 tonnes. The issue with only having a battery powered platform was addressed and the conclusion was made that it is possible with minor modifications to fit a combustion engine into the EMT to make it more versatile for use in a final repository.

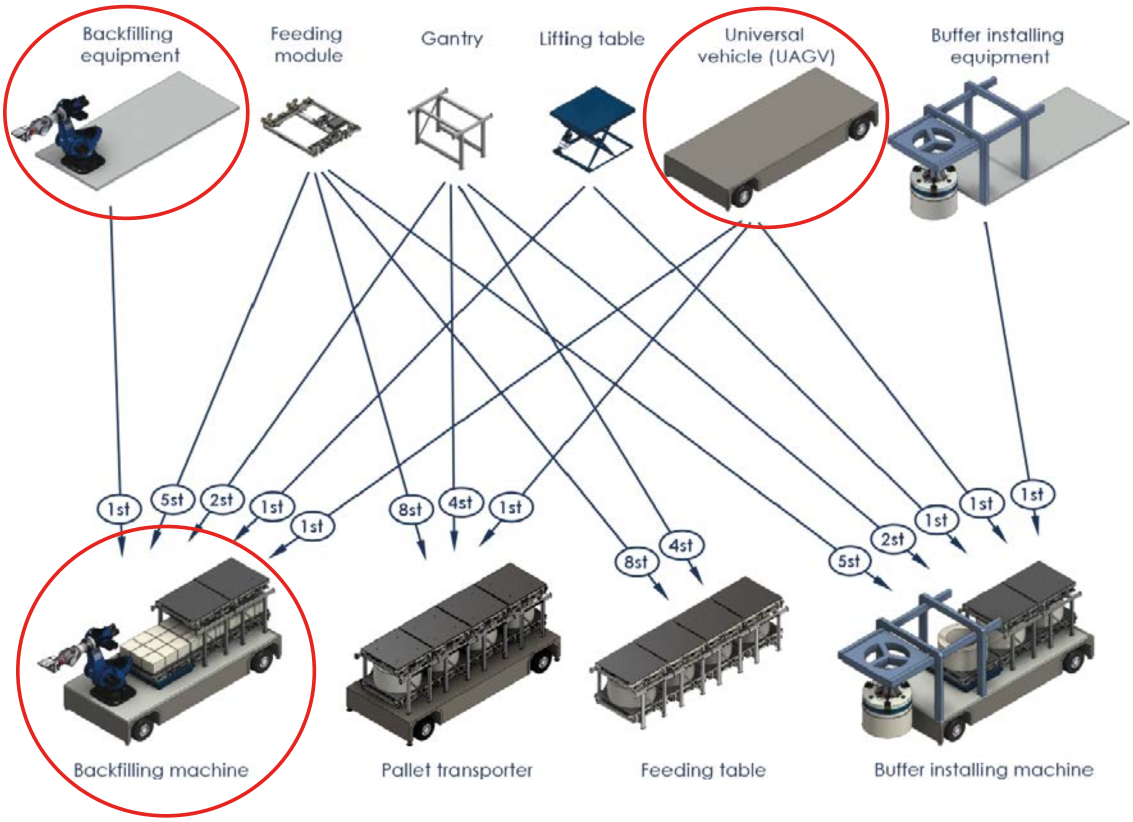


Figure 4-8. *Modular chassis concept, with parts used for installation of backfill circled.*

The concept of using a robot for the installation of the backfill was tested at a large-scale test in 2014 with promising but not satisfactory results, see Figure 4-9.

Objectives

The ongoing project Concept for Installation of Backfill intends to conduct comprehensive tests with components of the system for installation of backfill that are identical or similar to those used in a final repository for spent nuclear fuel. The result should be considered as a validation of the subsystem Backfill.

A prototype for a universal chassis is being purchased, as well as an industrial robot of smaller size than the one used in earlier tests. Software developed in earlier projects and tests will be adapted and further developed. This system consists of:

- A supervisory system to control the route and driving of the equipment.
- Laser sensors which are used to scan the operating environment.
- Navigation system which enables the equipment to validate its route.
- An automated machine control system which in this case emulates the commands done by an operator using a remote control.

Results

When the concept was tested last time in 2012–2014 the results were promising but not satisfactory, the concept needed some more development, and since then the tunnel area of the reference design has changed.

Preparations, planning and purchasing work was performed during 2018.

Figure 4-9. *Robot stacking blocks in a full scale test in the Multi-purpose test facility. Tests were also performed in the underground laboratory.*

5 Äspö facility

5.1 General

The Äspö facility comprises the Äspö Hard Rock Laboratory and the above ground Research Village. The facility has been introduced in Section 1.1 where the historic background, goals for the laboratory together with its organizational structure were presented.

Layouts of the facility can be found in Figure 1-1 and 1-2.

In this section, enlightenment is given on the multi-purpose test facilities, research laboratory, chemistry laboratory and the facility operations. Updated information is also provided on communication activities and future strategies for the underground laboratory.

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 2018 experiments have been performed in the Multi-purpose test facilities within projects such as KBP1013 – Borehole sealing and KBP1018 – Design of buffer and backfill, including mixing of bentonite materials and pressing of bentonite pellets.

Bentonite materials have also been prepared for the projects KBP1015 – Material studies project, KBP1017 – Techniques for manufacturing blocks and pellets and KBP1018 – Design of buffer and backfill, totalling approximately 75 tonnes.

During 2018 the Multi-purpose test facilities were expanded to increase the capability for storage of materials within the building. The new space is approximately 15 × 12 metres, providing 180 m^2 of added space.

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 Post-closure Safety 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 research laboratory is continuously evolving.

The laboratory is used in a number of projects and activities including technological development in (i) the material science projects, 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 2018 highest activity was from atmosphere tests (Figure 5-1), erosion tests (Figure 5-2), and material characterisation (e.g. Figure 5-3).

Figure 5-1. *Deposition hole atmosphere test. Bentonite blocks, pellets and a copper heater are placed in a confined volume while oxygen, hydrogen and hydrogensulfide gases are monitored with time.*

Figure 5-2. *Experimental cell for measuring of chemical erosion of swelling clays. In this case the clay used is dialysed Nanocore at very low ionic strength in a 0.2 mm vertical fracture. The vertical placement show the impact from gravity on the sedimentation.*

***Figure 5-3.** Naturally present smectite at −1 100 m level in the Kiruna mine. These swelling clay minerals are very similar to bentonite and this location is very promising for a natural analogue study.*

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).

5.4 Water Chemistry Laboratory

5.4.1 History

The Chemistry Laboratory at Äspö HRL 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. 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.

The laboratory includes an on-site laboratory in Forsmark intended to aid the construction of the repository with sampling and water chemistry analysis for the site descriptive modelling. The information below concerns the work performed at Äspö.

The laboratory is certified in accordance with ISO/IEC 17025 Testing and calibration laboratories, and the certification was renewed by Swedac in October of 2018.

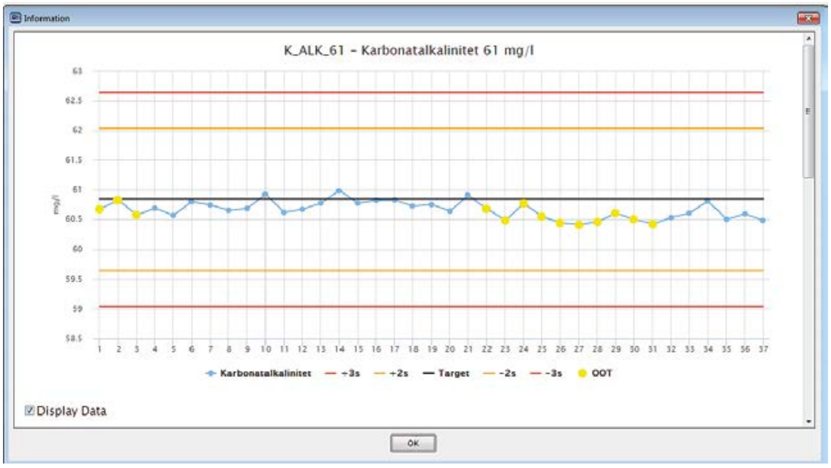
5.4.2 Analyses and equipment

For the moment the Chemistry Laboratory can perform 14 different analyses for water samples. Several of these analyses are accredited – pH, electrical conductivity, alkalinity, total organic carbon (TOC) and dissolved organic carbon (DOC), potentiometric measurements for chloride and fluoride, ion chromatography (IC) for anions such as chloride, bromide, fluoride and sulphate and UV/VIS spectroscopy for nitrogen such as ammonia, sulphide and iron (Fe^{2+} and Fe^{tot}). The newest instrument is the Liquid Water Isotope Analyser (LWIA) for determination of ^{18}O and ^{2}H. External laboratories are used for analysing cations (ex. sodium, calcium and sulphur), lanthanides and other trace elements, nutrient salts and isotopes such as ^{3}H, ^{34}S, ^{87}Sr and ^{37}Cl.

5.4.3 Performed activities

Once a year the Chemistry Laboratory performs a monitoring programme in the tunnel. At that time approximately 25 sections of different boreholes are collected and analysed at the laboratory. This programme has been ongoing since the tunnel was built in the 1990s and the data is used for modelling the groundwater in the HRL and understanding the area.

Quality control and quality assurance are performed every time an instrument is to be used.
The results for both control samples and regular water samples are stored in a laboratory database (LabWare LIMS), see Figure 5-4. The chemistry laboratory has a useful and well described quality system for all the work that is done.



☑ Display Data

Figure 5-4. Example of control chart for the registration of control samples.

5.5 Facility Operation

Background and objectives

The main goal for the operation of the rock laboratory is to provide a high service capability, exceeding 95 % accessibility for the projects and external customers. This target was well fulfilled 2018 despite of major rock maintenance work.

The laboratories must also be safe for everybody working or visiting, and for the environment. This includes preventative and remedial maintenance in order to ensure that all systems such as drainage, electrical power and lighting, ventilation, fire alarm system, personell monitoring system and communication systems are available in the underground laboratory at all times.

Results

The facility has had a stable operation during 2018.

The independent rock inspectation, which was carried out in late 2016, has led to some focus activities in different areas of the underground laboratory:

- Inventory of rock bolts based on historic choice of material (obsolete bolts).
- A plan for exchange of obsolete rock bolts has been developed.
- Enhanced rock maintenance near and in the elevator shaft.
- Reinforcement and clothing of the roof and walls in the rescue chamber.

The rock maintenance work in the tunnel system has progressed very well during 2018. Extensive work was carried out at all three of the elevator's floor plans. Furthermore, the grand rescue chamber, holding a safe place for up to 60 persons in case of an emergency, has been fully refurbished.

A new heat pump has been installed and trimmed in for a more efficient heating of the office buildning.

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

5.6 Communication Oskarshamn

5.6.1 General

The main goal for the Communication unit in Oskarshamn is to create public acceptance for SKB. This is achieved by presenting information and showing SKB's facilities and the RD&D work e.g. at Äspö HRL. The unit is also responsible for visitor services at Clab and the Canister Laboratory as well.

In addition to the main goal, the unit organises visits for international guests every year. The international visits are mostly of technical nature, but increasing interest is shown regarding public acceptance of a geological disposal programme for high level radioactive waste.

The unit has a booking team which books and administrates all visits to SKB's facilities. The booking team also works for Oskarshamn NPP's service according to agreement.

External and internal communication activities carried out by the unit also range from local media relations, web and editorial work, school information and much more.

During 2018 the Communication Oskarshamn unit consisted of eight persons.

5.6.2 Special events and activities

During 2018, 3 091 persons visited the Äspö HRL and with the visitors at Clab and the Canister Laboratory included, it resulted in a total of 4 411 persons. The total number of visitors to SKB's facilities in both Oskarshamn and Forsmark/Östhammar was 6 561 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 268.

The special summer arrangement "Upptäck underjorden" (Discover the underground) was arranged during six weeks and 860 persons visited the underground laboratory. Tours for the general public also took place some Saturdays during the year.

During 2018, 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 programmed lego robots and visited the Äspö HRL. Students in the 3rd grade of high school were offered a visit to Clab.

To celebrate the national event "Geologins Dag" (The Geological Day), the unit arranged a geological and historical excursion in Stadsparken in the center of Oskarshamn on September 8, for the interested public.

On November 11, about 75 competitors participated in "the Äspö Tunnel Race", a race where you run from the −450 meter level to surface. The winner was Hugo Lillieström. He reached the surface after 20.15 minutes.

On November 21, "Äspö Miljöforskningsstiftelse" handed out awards to two persons/organziations/companies that have contributed to increase the public knowledge and awareness about the environment. Winners 2018 were Huvududdens Samfällighetsförening and the researcher Elias Broman.

As a part of external information efforts, the unit arranges lectures on different themes related to SKB's work. The lectures during 2018 focused on the Canister Laboratory since it celebrated 20 years during the year.

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

5.7 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.

5.7.1 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 most of 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 until now 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 the existing above ground laboratory resources and infrastructure past 2023.

5.7.2 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 early 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.

5.7.3 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 2018 work has been carried out within the following development activities which have been initiated.

National Geosphere Laboratories (NGL)

SKB and the Municipality of Oskarshamn decided in 2011 to investigate the potential of Äspö HRL as a national infrastructure for research and innovation. This was the first and early proactive initiative to meet the foreseen phase-out of SKB's own R&D activities in the laboratory. Discussions were initiated with the Royal Institute of Technology (KTH) which resulted in the recommendation to qualify the laboratory 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 Municipality of 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”. A preparation for a new application was initiated and was submitted to the Swedish Research Council (VR) in October of 2017. In May 2018 VR decided to not evaluate the application. This unexpected outcome will be analysed by all involved stakeholders. VR's coming calls is expected in the autumn 2019 and 2021.

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.

The BSUIN network consists of 14 organisations. Six of them are 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 5.7.4 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 response and the study was 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.

5.7.4 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 BSUIN conference at Äspö HRL was conducted successfully 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 INF3 classification allowing transports of the highest class of radioactive cargo.

SKB International's main areas of operation are:

- Consulting services.
- Laboratory services.
- Training programmes.
- 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 Multipurpose 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 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 develop their methodology of 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 Chemistry and Material Science laboratories, Multi-purpose test facility 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 2018

Äspö International partnership

For the Äspö International partners SKB International arranged different events during 2018.

A **topical workshop for regional scale and tunnel scale modelling based on Äspö data** was organised.

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.
- Tunnel and deposition hole production.

- Detailed investigation methods.
- Casting of Caissons.
- Design of buffer and backfill.
- Material bentonite study.
- Glacial effects on bentonite.
- Technique for block and pellets production.
- Dismantling of the dome plug (DOMPLU).
- Sealing of investigation boreholes.

At the annually **International Joint Committee meeting** SKB presented planned activities at Äspö during 2019 and for the coming years. Additional presentations were held, e.g. SKB's overall status and plans and also how SKB has developed and handled our requirements

Training course

During October 2018 SKB International and SKB organised a scientific training course covering important issues governing a national nuclear waste disposal programme. Based on the experiences gained by SKB during the past 40 years the course presented the planning and execution of a successful programme. The starting point being a strategic and graded approach with an early safety prediction via detailed understanding of processes, research achievements and gains in correctly defined targets and how this leads to a communicative safety case based on a solid and well defined safety assessment. 30 participants from organisations world-wide attented the course.

In 2018 several customized training course were accomplished, e.g. Tunnel and shaft excavation, experiences from site investigations, etc.

Experiment accomplished by other organisation

In autumn 2018 RWM from UK accomplished own test in a percussion drilled borehole at the Simpevarp peninsula close to Äspö. With an own developed concept different kinds of bentonite successfully were installed down to a depth of 200 m.

Figure 6-1. *Left: installation equipment. Right: Simon Norris, senior research manager at RWM, speaking to a local newspaper.*

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

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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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