SKI Report 2007:11

Research

Review of Quality Assurance in SKB´s Repository Research Experiments

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January 2007

ISSN 1104-1374
ISRN SKI-R-07/11-SE

SKI Perspective

Background

SKB is preparing a license application for the construction of a final repository for spent nuclear fuel in Sweden. This application will be supported by the safety assessment SR-Site for the post-closure phase. As a preparation for SR-Site SKB has recently produced the SR-Can safety assessment, which is currently in review. The assessment of long-term safety is based on a broad range of experimental results from laboratory scale, intermediate scale and up to full scale experiments. It is essential that there is a satisfactory level of assurance that experiments have been carried of with sufficient quality, so that results can be considered to be reliable within the context of their use in safety assessment. SKI has initiated a series of reviews of SKB's methods of quality assurance and their implementation. This project in particular addresses SKB's quality assurance of experiments related to the buffer and backfill. These include characterisation of material properties in small scale experiments (Clay Technology AB in Lund Sweden), intermediate scale experiments addressing various aspects of buffer evolution as well as experiments with full-scale canister and buffer components mainly for confirmation and demonstration (Äspö Hard Rock Laboratory).

Purpose of the Project

The purpose of this project is to assess SKB's quality assurance with the view of providing input for the preparation of the SR-Site safety assessment. This has been achieved by examination of a number of SKB experiments using a check list, visits to the relevant facilities, and meetings with contractors and a few members of the SKB staff. As a background for understanding various approaches to handle quality issues, the quality programmes carried out as part of the Drigg (UK), WIPP (USA) and Yucca Mountain (USA) projects are briefly discussed.

Results

The results show that the efforts involving quality assurance are increasing within the SKB programme and in general appear to be satisfactory for ongoing experiments and measurements. Nevertheless, the level of detail in descriptions of QA requirements for experimental work is probably lower than for the other programmes included in this study. In addition, the link between experimental work and its use in safety assessment as well as in the decision-making process is in some cases not entirely clear. It needs to be decided how data from experiments carried out prior to formal QA should be handled in SR-Site.

Future work

Quality aspects will be further analysed as part of the review of SKB's SR-Can safety assessment. Additional scrutiny of this subject will be needed also for the subsequent stages of SKB's programme

Project Information

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Review of Quality Assurance in SKB´s Repository Research Experiments

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January 2007

Executive Summary

SKB is preparing licence applications for a spent nuclear fuel encapsulation plant and repository which will be supported by the SR-Site safety report. A separate safety report, SR-Can, has been produced by SKB in preparation for the SR-Site report.

SKI is in the process of reviewing the SR-Can safety report. In preparation for this review, and with a view to building confidence in SKB's research activities and understanding SKB's handling of data and other information, SKI has examined SKB's application of QA measures in the management and conduct of repository research and development projects that support the SR-Can safety assessment. These preliminary investigations will serve to support the preparation of more detailed quality and technical audits of SKB's repository safety assessment after the submission of a licence application.

SKI's approach to this QA review is based on the consideration of quality-affecting aspects of a selection of SKB's research and development activities. As part of this review, SKI identified the need to examine quality-related aspects of some of the many experiments and investigations that form part of SKB's repository research programme. This report presents the findings of such a review, focusing on experiments concerned with the properties and performance of the engineered barrier system.

First, in order to establish a broad understanding of QA requirements for repository scientific investigations, QA procedures implemented in the management of research and development activities for the low-level radioactive waste repository near Drigg in the UK and the Waste Isolation Pilot Plant and Yucca Mountain repository projects in the US were studied. The QA procedures for experiments and tests undertaken in these projects were compared with those implemented by SKB. Key findings are:

- QA programmes have been implemented for each repository development programme in response to regulatory requirements.

- The need for regular audits of the application, suitability and effectiveness of QA systems has been stressed in regulations and top-level QA requirements documents. In some cases, evidence of such audits has been presented in support of facility safety cases.

- The project QA programmes include requirements for scientific investigations that address the planning and performance of investigations as well as data management. Top-level QA documents for the US repository projects include detailed descriptions of requirements relating to the conduct of scientific investigations. Such detailed QA requirement descriptions have not been identified for SKB's experiments on engineered barrier system components.

The review of SKB's experiments covered the long term test of buffer material (LOT), the large scale gas injection test (LASGIT), the temperature buffer test (TBT), and the Prototype Repository Experiment (PRE), which are being conducted at SKB's Hard Rock Laboratory (HRL) in Äspö, and tests on bentonite swelling pressure, hydraulic conductivity, and resaturation that are being conducted on behalf of SKB at Clay Technology's laboratories in Lund.

To facilitate the reviews, a checklist of quality-affecting issues was devised which proved an effective tool for structuring and recording findings. The checklist covered the framework, design, conduct, analysis and reporting of experiments, and the use of experimental results. Key review findings are:

- The requirements and planning of experiments do not appear to have been coordinated with the planning and requirements of the repository licence application. Some experiments do support relevant function indicator criteria in the SR-Can report and some data may be available for use in the SR-Site safety assessment. However, most of the ongoing experiments have had little impact on the SR-Can safety assessment because the results are not yet available. Furthermore, it is unclear exactly how and when the results of long-term experiments might influence the repository development programme and licence application.

- It is not clear whether or how data acquired before SKB's current QA system was introduced have been formally qualified, or whether the QA system includes procedures for such data qualification.

- SKB's QA programme requires that contractors working on research projects produce their own, or use SKB's, quality plan. Clay Technology appears only recently to have implemented a formal QA system for work in its laboratories.

- Some of the experiments at the HRL involve collaborations of several radioactive waste management organisations. It is unclear how SKB's QA requirements are implemented through all components of the work on these experiments that might be relevant to the SKB repository programme.

- SKB has undertaken pilot studies, over-specified controls and instrumentation, and installed alarmed monitoring systems in order to mitigate risks of experiment failure. These measures are proving invaluable in ensuring the success of the experiments because numerous equipment failures have occurred.

- Work on experiments at the HRL is recorded on logs and field notes. There has been no systematic use of scientific notebooks for the experiments undertaken at the Clay Technology laboratories, although project information and data are stored in spreadsheets.

- SKB maintains lists of documents produced for experiments at the HRL, including information on the review and approval status of each document. Reports of experiments undertaken at the Clay Technology laboratories are published by SKB, but this project was unable to identify any systematic formal document review process.

- Little information has been obtained with regard to the usability of results from ongoing experiments. Generally, there appear to be no firm plans on how to abstract data from such experiments for use in repository safety assessments.

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1 Introduction

1.1 Background

SKB is preparing licence applications for a spent nuclear fuel encapsulation plant and repository which will be supported by the SR-Site safety report. A separate safety report, SR-Can (SKB, 2006), has recently been produced by SKB in preparation for the SR-Site report.

SR-Can is based on a safety assessment for the underground disposal of spent fuel in Sweden according to the KBS-3 repository concept. The assessment involves quantitative analyses aimed at developing an understanding of how the repository system will evolve and the potential risks of spent fuel disposal. Therefore, any demonstration of regulatory compliance must be underpinned by assurances that the development and application of models and estimates of parameter values and uncertainties are of appropriate quality. To this end, the safety assessment must be developed within the framework of a quality assurance (QA) programme.

SKI is in the process of reviewing the SR-Can safety report. In preparation for this review, and with a view to building confidence in SKB’s research activities and understanding SKB’s handling of data and other information, SKI has examined SKB’s application of QA measures in the management of repository research and development projects that support the SR-Can safety assessment. These preliminary investigations will serve to support the preparation of more detailed quality and technical audits of SKB’s repository safety assessment after the submission of a licence application.

SKI’s approach to this QA study is based on the review of quality-affecting aspects of a selection of SKB’s research and development activities. The first stage of this study focused on the numerous computer codes used by SKB in the evaluation of the long-term safety of a repository either as components in the overall risk assessment or in the development of supporting safety arguments, such as in evaluations of engineered barrier system performance. On behalf of SKI, Hicks (2005) provided a review of the quality of the documentation and testing of a selection of these codes. Subsequently, SKI identified the need to review quality-related aspects of some of the many field and experimental investigations instigated by SKB to obtain the data that are used to abstract conceptual understandings of repository evolution and to evaluate the parameters represented in the computer codes. This report provides the results of such a review undertaken by Galson Sciences Ltd on behalf of SKI.

1.2 Approach

In order to establish a comprehensive understanding of QA requirements for repository scientific investigations, the relevant QA procedures adopted in a number of repository programmes were studied. This stage of the project focused on the QA programmes implemented in the management of safety assessments and the supporting research and development activities for the low-level radioactive waste (LLW) repository near Drigg in the UK, and the Waste Isolation Pilot Plant (WIPP) and Yucca Mountain Project (YMP) in the US. The QA procedures undertaken in these projects were compared with those implemented by SKB for the SR-Can safety assessment and for experiments and tests.

The main part of the project aimed to review QA issues for a selection of the experiments that might provide data for use in safety assessments and support an understanding of repository behaviour. The project focused on experiments concerned with gaining an understanding of the properties of repository near-field materials and the evolution of the near field after repository closure because of the significance of these factors to repository performance. Thus, after a preliminary consideration of the range of experiments and tests being undertaken as part of the KBS-3 repository development programme, the following experiments were selected for detailed review: the long term test of buffer material (LOT), the large scale gas injection test (LASGIT), the temperature buffer test (TBT), and the Prototype Repository Experiment (PRE) that are being conducted at SKB's Hard Rock Laboratory (HRL) in Äspö, and tests on bentonite swelling pressure, hydraulic conductivity, and resaturation that are being conducted on behalf of SKB at Clay Technology's laboratories in Lund.

The QA review included meetings with SKB staff and contractors at the Clay Technology Laboratories in Lund on 15th November 2005 and at SKB's HRL at Äspö on 16th November 2005. A further meeting took place at the HRL a year later (17th November 2006). In order to facilitate the discussions at these meetings and the documentation of review findings, a checklist of quality-affecting issues was prepared covering the framework, design, conduct, analysis and reporting of experiments, and the use of experimental results in the KBS-3 repository research programme. The findings of the review were documented on forms based on the above-mentioned checklist. These completed forms are included and discussed in this report.

1.3 Report Structure

Section 2 of the report presents a discussion and comparison of QA programmes from a selection of repository research and development programmes. The review of quality-related aspects of experiments undertaken as part of SKB's repository research programme is presented in Section 3. Conclusions are presented in Section 4. Appendix A comprises the completed QA review forms for each experiment.

2 Approaches to QA in Repository Research Experiments

In order to gain a comprehensive understanding of QA requirements for repository scientific investigations, QA procedures adopted in several national repository programmes have been studied. This part of the project focused on the QA programmes implemented in the management of safety assessments and, in particular, research and development activities for the LLW repository near Drigg in the UK, and the WIPP repository and YMP in the US. Detailed and prescriptive approaches to project quality management have been adopted in these projects. The QA procedures for experiments, tests, and data management undertaken in these projects have been compared with the approach to quality management taken by SKB and its contractors for similar types of activity.

2.1 QA for the Drigg LLW Repository Post-closure Safety Case

The British Nuclear Group (BNG) - a BNFL business group formed in 2005 - currently manages and operates the low-level radioactive waste disposal site near Drigg in the UK. In 2002 - prior to formation of the BNG - BNFL produced a Post-Closure Safety Case (PCSC) for the Drigg site as a regulatory requirement to facilitate a review of the authorisation for waste disposal at the site. The Environment Agency requires that a comprehensive and systematic QA programme is established to cover all activities affecting the safety case, including supporting activities such as research and assessment (Requirement R11 of Environment Agency *et al.*, 1997). This section considers the QA system adopted by BNFL in its preparation of the Drigg PCSC.

BNFL's technical services are carried out as Research and Technology (R&T) projects; the scientific and technical work to develop the 2002 Drigg PCSC was undertaken as an R&T project termed the Drigg Technical Programme (DTP). All R&T projects are subject to QA arrangements according to the R&T Integrated Management System (RIMS), which was developed within the framework of international standards (including ISO 9001-2000), BNFL company policies, and BNFL facility management and capability group systems (BNFL, 2002).

RIMS has numerous procedures and instructions for carrying out work on R&T projects, including an instruction to produce a project plan (R&T_I_012, preparation and control of project/task plans) and an instruction to produce a project-specific QA programme (RIMS instruction R&T_I_014). The DTP project plan specified and periodically updated information on numerous activities for each of eight DTP task areas (inventory studies, site characterisation, coastal erosion, safety case preparation, near-field studies, far-field geochemistry, assessment codes, and post-closure radiological safety assessment). Details of activity schedules, document schedules, resources, and links between activities were included in the DTP project plan.

The DTP QA programme was included in the DTP project manual (BNFL, 2004) and defined the organisational structure, responsibilities, data and document controls, and QA procedures and instructions for the DTP. The DTP organisational structure included a project manager, a quality manager, and a technical auditor, as well as DTP task managers. The quality manager's responsibilities included the co-ordination of audits as a means of checking for the effectiveness of the quality management system. The technical auditor was an external consultant whose responsibilities included ensuring that the work was of an appropriate technical standard. The BNFL QA report (BNFL, 2002) includes reports of several self-audits.

Contractors were commissioned to perform some of the technical work on the DTP. These contractors were generally selected based on their specialist knowledge and experience. Contractors working on the DTP were required to have an acceptable quality management system or to agree to conform with RIMS and the requirements of the DTP project manual. BNFL audited its contractors to check for compliance with the QA system.

The DTP QA procedures and instructions were applicable to all the task areas and activities specified in the project plan. The DTP project manual lists 28 RIMS procedures and instructions that were of particular relevance to the DTP, including many pertaining to the operation of the Drigg facility and BNFL's Waste Management & Decommissioning (WM&D) Capability Group. In addition, the DTP project manual lists 11 working instructions that were developed specifically for the DTP. Of particular interest to this project are the procedures and instructions that relate directly to the conduct of experiments and field studies, which are listed in Table 2.1, and those relating to data acquisition and data management, which are listed in Table 2.2. However, these procedures and instructions have not been obtained for review under this project.

Table 2.1 Procedures and instructions relating to experiments and field studies in support of the DTP.

Procedure	**Title**
R&T_P_404	Calibration
R&T_WM&D_P_006	Pre-work documentation
R&T_WM&D_P_007	Field investigation
R&T_WM&D_P_009	Experimental design
R&T_WM&D_P_011	Experimental studies
Instruction	**Title**
R&T_I_021	Use of log books
R&T_WM&D_I_034	Technical specification
R&T_WM&D_I_035	Preliminary design of field and experimental studies
R&T_WM&D_I_038	Calibration of analytical equipment

Table 2.2 Procedures and instructions relating to data acquisition and data management in the DTP.

Procedure	**Title**
R&T_P_304	Document and data control
R&T_P_311	Records management
R&T_WM&D_P_004	Database management and design
Instruction	**Title**
DTP/WI/006	DTP central directory

2.2 QA in the WIPP Repository Research Programme

The US Department of Energy's (DOE) Carlsbad Field Office (CBFO) is responsible for operating the WIPP as a repository for the safe disposal of transuranic (TRU) waste. The US Environmental Protection Agency (EPA) requires that the US DOE establishes and implements a QA programme for activities that are important to the containment of TRU waste in the WIPP disposal system. This QA programme must implement the applicable requirements of specific Nuclear Quality Assurance (NQA) standards issued by the American Society of Mechanical Engineers (ASME). The CBFO established these QA requirements in the Quality Assurance Program Document (QAPD), which is the QA plan for the WIPP project (US DOE, 2005). All organisations associated with TRU waste disposal at the WIPP must implement QA programmes that establish and implement the applicable requirements of the QAPD. The areas covered by the QAPD are listed in Table 2.3.

Requirements in each of the areas listed in Table 2.3 are discussed in detail in the QAPD. Of particular interest to this project are the scientific investigation requirements. Broadly, these cover the areas listed in Table 2.4.

The implementation of the QAPD requirements by participants in the WIPP programme is described in the WIPP Compliance Recertification Application (US DOE, 2004a). The CBFO conducts audits to verify the adequacy, implementation, and effectiveness of the QA programmes adopted by the programme participants. The QA programme adopted by Sandia National Laboratories (SNL) is of particular relevance to this QA review project; SNL is responsible for acquiring data from experimental programmes to support WIPP compliance applications and the SNL QA programme has been verified to be compliant with the requirements of the QAPD (US DOE, 2004a). The SNL QA programme is based on a system of nuclear waste management QA procedures (NPs). The NPs that address experiments and data collection are listed in Table 2.5. For instance, procedure NP 20-1 sets out requirements for preparing and implementing test plans for laboratory and field investigations and procedure NP 20-2 provides instructions on the use of scientific notebooks where considered necessary to record information for such investigations.

Table 2.3 Requirements of the QAPD for the WIPP.

Requirement	Description
Management	Organisation, implementation, and management of the QA programme.
Performance	QA in work processes, design processes, service procurement, and in inspection and testing of processes and equipment.
Assessment	Management and independent assessment of the effectiveness of the QA programme.
Sample control	Control of samples of waste and environmental media.
Scientific investigation	Planning and performance of investigations, and documentation, control, and validation of data.
Software	QA of software that is important to compliance application and waste characterisation.

Table 2.4 Scientific investigation requirements in the QAPD for the WIPP.

Requirement	Areas addressed
Planning	Identification and control of variables. Intended use of data. Compatibility of data with models used. Review and approval of technical procedures for conducting investigations. Documentation of new methods or procedures. Coordination with other organisations that provide input to or use the results of the investigation. Acceptance criteria for data quality evaluation (precision, accuracy, representativeness, comparability, and completeness). Identification of known sources of error or uncertainty.
Performance	Use of test plans and procedures. Use of scientific notebooks to record the objectives, details of methods used, the work performed, results, and uncertainties. Periodic independent review to confirm results and check for traceability. Verification and control of methods and equipment. Control of data collection to an extent that allows the process to be repeated. Characterisation and control of test media.
Documentation, control, and validation of data	Identification, traceability, recording, and storage of data using controlled methods and review of data before use. Data validation by independent review of technical adequacy, adequacy of the QA record, and suitability for intended use. Qualification of existing data by consideration of the adequacy of the QA programme under which the data were collected, use of corroborating data, confirmatory testing, and/or peer review.

Table 2.5 SNL procedures that are applicable to experiments and data collection for the WIPP project.

Requirement	Description
NP 9-2	Parameters
NP 12-1	Control of Measuring and Test Equipment
NP 13-1	Control of Samples and Standards
NP 19-1	Software Requirements
NP 20-1	Test Plans
NP 20-2	Scientific Notebooks

2.3 QA in the YMP Repository Research Programme

The US DOE is investigating a site at Yucca Mountain, Nevada, as a potential location for a geological repository for commercial and defence spent nuclear fuel and high-level radioactive waste. The US Nuclear Regulatory Commission (NRC) requires that work on the YMP relating to radiological safety or waste isolation must be performed in accordance with a QA programme that complies with relevant regulatory requirements. The Quality Assurance Requirements and Description (QARD) (US DOE, 2004b) is the principal QA document for the YMP. It establishes the minimum requirements for the YMP QA programme and has been designed to meet regulatory requirements. The requirements set out in the QARD are summarised in Table 2.6. The QARD includes supplements that contain requirements for specialised activities. These supplements are summarised in Table 2.7. Activities required to collect data (such as for siting or design input) are performed in accordance with the scientific investigation supplement, which is summarised in Table 2.8.

Organisations performing work on the YMP are subject to the QARD requirements and must develop implementing documents that translate applicable QARD requirements into work processes. Therefore, the US DOE and its contractors have developed individual procedures that must be followed to implement a project QA programme that addresses the requirements of the QARD (US DOE, 1998). For example, SNL, the newly designated lead agency to coordinate science and technical work for the YMP, has developed quality assurance implementation procedures (QAIPs), Technical Procedures (TPs), and project-level implementing documents such as Administrative Procedures (APs) for its work on the YMP. TPs are generally prepared for scientific investigations involving operations or activities that are repetitive. These QAIPs are listed in Table 2.9.

Table 2.6 Summary of requirements in the QARD for the YMP project.

Requirement	Description
Organisation	Creating and maintaining an organisational structure to implement the YMP QA programme.
Quality assurance programme	Planning, implementing, and maintaining the QA programme.
Design control	Definition, control, and verification of designs.
Procurement document control	Ensuring that service procurement documents contain appropriate technical and QA requirements.
Implementing documents	Ensuring that work is prescribed by, and performed in accordance with, written implementing documents.
Document control	Ensuring that documents are reviewed for adequacy, approved for release, and distributed to and used at the location where the work is being performed.
Control of purchased items and services	Planning and executing procurements to ensure that purchased items and services meet specified requirements.
Identification and control of items	Ensuring that only correct and accepted items are used or installed.
Control of special processes	Control of special processes (such as welding, weld overlay, heat treating, chemical cleaning, and non-destructive examinations).
Inspection	Planning and executing inspections.
Test control	Planning and executing tests that are used to verify conformance of an item to specified requirements, or to demonstrate satisfactory performance for service.
Control of measuring and test equipment	Ensuring measuring and test equipment is properly controlled, calibrated, and maintained.
Handling, storage, and shipping	Handling, storage, cleaning, packaging, shipping, and preservation of items to prevent damage or loss and to minimize deterioration.
Inspection, test, and operating status	Identifying the inspection, test, and operating status of items.
Non-conformances	Control of items that do not conform to requirements in order to prevent inadvertent installation or use of the item.
Corrective action	Ensuring conditions adverse to quality are promptly identified and corrected as soon as practical.
Quality assurance records	Ensuring that QA records are specified, prepared, and maintained.
Audits	Performing internal and external QA audits to verify compliance with, and to determine the effectiveness of, the QA programme.

Table 2.7 Summary of supplements in the QARD for the YMP project.

Supplement	Description
Software	Requirements for the acquisition, development, modification, control, and use of software.
Sample control	Requirements for the control of physical samples.
Scientific investigation	Requirements for scientific investigations, including data identification, data reduction, and model development and use.
Field surveying	Requirements for field surveying that might be undertaken during, for example, site characterization, explorations, and installations.
Control of the electronic management of data	The processes and controls for the management of data that either exist or are used in an electronic format.

Table 2.8 Summary of the scientific investigation supplement in the QARD.

Supplement	Description
Planning	General QA planning requirements. Coordination with organisations that provide input to or use the results of the investigation. Provisions for determining the accuracy, precision, and representativeness of results,
Performance	Use of scientific notebooks to include the objectives, and description of work performed or references to documents that contain such information, methods and computer programs to be used, samples and measuring and test equipment, results, and information on individuals performing the work. Independent review to confirm results and check for traceability.
Data identification	Data should be clearly identified and traceable.
Data review, adequacy, and usage	Data should be independently reproducible. Data directly relied upon to address safety and waste isolation issues should be qualified, involving independent review for technical correctness. Unqualified data should be qualified by one or more of the following: considering adequacy of the controls under which the data were collected, use of corroborating data, confirmatory testing, peer review, and independent technical assessment.
Technical report review	Requirements for document review should be followed.
Model development and use	Requirements for planning, control, and documentation of model development and approaches to validation. Computer software should be qualified. Requirements for models to be validated to levels of confidence appropriate to their importance in repository performance assessment.

Table 2.9 QAIPs implemented by SNL for work on the YMP project.

Procedure	Title
QAIP 1-2	Organization and Quality Assurance Program.
QAIP 5-1	Preparing and Approving Quality Assurance Implementing Procedures.
QAIP 20-01	Technical Procedures.
QAIP 20-03	Sample Control.

2.4 QA in SKB's Repository Research Programme

SKI (2002) and SKI (2004) present regulations and recommendations pertaining to the safe disposal of spent nuclear fuel and radioactive waste in Sweden. SKI (2004) includes the requirement that activities carried out at nuclear facilities are managed, controlled, evaluated and developed with the support of a management system that is designed to ensure that safety requirements are met. Furthermore, the application, suitability and effectiveness of the management system should be systematically and periodically audited. These requirements are applicable to spent fuel and radioactive waste disposal facilities prior to their closure. SKI (2002) requires that measures implemented to comply with quality assurance requirements for pre-closure safety are also adequate for post-closure safety. Furthermore, international experience and best practice calls for SKB's repository research to be developed under a suitable and audited management system that covers all aspects of QA.

SKB has implemented a QA programme that includes a series of procedures for establishing and managing the research and development projects that are undertaken to support the safe management and disposal of spent nuclear fuel and radioactive wastes. No document specifically aimed at presenting SKB's overall approach to and standards for QA has been identified under this QA review project, but SKB's quality system is outlined in, for example, SKB's geoscientific programme for investigation and evaluation of repository sites (SKB, 2000a). The preparation of safety assessments, such as SR-Can, and the experiments undertaken as part of the KBS-3 repository research programme, such as those conducted at the Äspö HRL (see Section 3), are subject to this project management process. The following discussions of SKB's project process and data management system are based on presentations made by SKB staff during the meeting at Äspö in November 2005 (see Section 3).

2.4.1 The Project Process

The framework for initiating, implementing, and completing projects is set out in SKB's procedure for the project process (Procedure SD-002). Each project is initiated on the basis of a project decision, which may require a project feasibility study. Once the requirement for a project has been established, the project is organised and implemented according to a project model, which has planning, reporting, and evaluation phases as indicated in the flowchart in Figure 2.1.

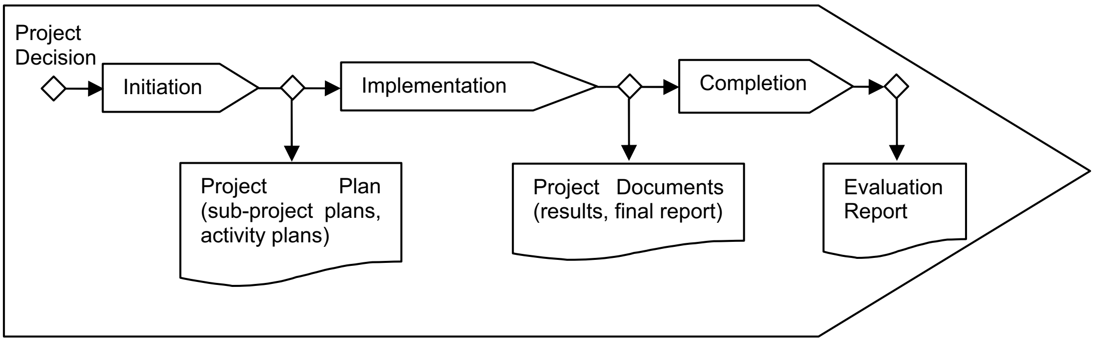

Figure 2.1 **SKB's project model implemented as part of the project process.**

Each phase of the project model is closed by a project document; separate procedures have been established for preparing these documents. Details of all documents produced for each project, including information on responsibility for document preparation and the review and approval process, are recorded on a project document list.

In the first phase of the project model, a project manager establishes the project organisation and prepares a project plan. The project plan defines project objectives, sets out a strategy for meeting these objectives, and addresses quality and environmental control issues. The requirements for quality and environmental management are described separately in Procedure SD-025. A quality plan is required to define responsibilities for quality planning and quality assessment, and to address document control issues, reporting of preventative and corrective actions, and risk analysis. The quality plan may form an integral part of the project plan or may be a separate document referred to by the project plan. Subcontractors working on SKB's projects must produce their own, or use SKB's, quality plan.

Some projects may require more detailed planning and control. Activity plans are prepared for such projects. Each activity plan defines the methods and responsibilities for completing the activity and may include documents such as drawings, manuals, and technical specifications. All projects undertaken at the Äspö HRL require activity plans.

Risk management, including the identification and analysis of technical, economic, environmental, and organisational risks, must be addressed for all stages of the project according to Procedure SD-020. Actions must be taken for reducing or eliminating risks.

In the final phase of the project model, the project manager is required to prepare an evaluation report, which reflects on the implementation and results of the project, evaluates risk management in the project, and considers experiences that may lead to improvements in other projects.

2.4.2 Quality Plans

As noted above, quality plans are required as part of the project process. For example, the SR-Can safety assessment is subject to the project process and SKB has prepared a draft QA plan which represents one of several project steering documents for the SR-Can project (Hedin, 2005). The broad purpose of the draft QA plan for SR-Can is stated as being to aid in assuring that all relevant factors for long-term safety have been included and appropriately handled in the safety assessment. Therefore, the QA plan focuses on quality assurance in the methods for identifying the features, events, and processes (FEPs) that are of potential importance to the safety assessment and in the methods for accounting for those FEPs in the safety assessment. The QA plan addresses the management and documentation of the FEP database, decisions concerning the treatment of the initial state of the repository, and decisions concerning the assessment of repository evolution (scenario analysis).

The draft QA plan was reviewed as part of the present study and SKI provided SKB with review findings during a meeting in May 2005. Of particular relevance to the focus of the present study on QA in repository research experiments, it was suggested that the QA plan should provide more information on: the QA of data from past and ongoing research studies (such as field investigations, experimental studies, and modelling studies); the arrangements made for managing contractors and ensuring QA requirements are met by contractors; and provisions for internal and independent audit.

QA plans are also required for the experimental projects undertaken as part of SKB's repository research programme. Such QA plans have not been reviewed as part of the present study. Instead, an independent checklist of quality-affecting issues has been prepared to facilitate discussions of QA in SKB's experiments as described in Section 3.1.

2.4.3 Data Acquisition and Data Management

Specific SKB procedures for data acquisition and data management have not been identified under this project. However, the data management system implemented by SKB for experiments conducted at the Äspö HRL was described by SKB at the project meeting at Äspö in November 2005.

Measured data from ongoing experiments are recorded continuously and may be viewed internally or remotely via a secure internet connection. Experiments may also be controlled remotely by SKB's contractors. Field work is recorded on daily activity logs and field notes and data are submitted for storage in SKB's SICADA data management system on a daily basis.

The SICADA system was introduced by SKB in 1995 to replace and combine the features of existing databases. SICADA contains data acquired since 1974, which includes data gathered since construction of the Äspö HRL began. Field notes and data (paper or electronic media) are delivered to a SICADA operator, who registers each submission with a unique identifier as well as descriptive data and information relating to the relevant activity plan. Template Microsoft Excel spreadsheets are used to import data into SICADA. The SICADA operator also archives the field notes and data. Traceability is maintained between entries in the SICADA database, associated file and data archives, and activity reports for each activity plan.

SKB and its contractors may access the database using the SICADA/Diary application and data may be delivered to external organisations on request.

2.5 Discussion

The QA systems for the repository programmes considered in this study have been developed in the context of regulatory frameworks and requirements as follows:

- Comprehensive and detailed requirements for ensuring that work carried out in the US WIPP and YMP repository programmes is of an acceptable quality have been set out in top-level programme QA documents (the QAPD for the WIPP project and the QARD for the YMP) that have been developed in response to respective EPA and NRC requirements. All organisations working on these repository programmes have been required to establish their own QA programmes that implement the top-level requirements.

- In the UK, the environment agencies require that any application to dispose of radioactive waste should be supported by a safety case that has been developed under a comprehensive and systematic QA programme. In response, BNFL produced a QA programme for all work performed in support of the Drigg LLW disposal site PCSC.

- SKI's requirements for QA are expressed in terms of a requirement for nuclear activities to be undertaken with the support of a management system. Although this requirement is applicable to spent fuel and radioactive waste disposal facilities, it is limited to pre-closure operations. However, SKI also requires that adequate quality assurance measures are taken with regard to post-closure safety. SKB has in place a process and procedures for establishing and managing projects such as the SR-Can safety assessment and the research and development projects that support such safety assessments.

In all of these repository programmes, the need for regular audits of the application, suitability and effectiveness of QA systems has been stressed in regulations and top-level QA requirements. BNFL presented evidence of several such audits in support of the Drigg PCSC. Checks of the compliance of QA programmes implemented by organisations working on the US WIPP and YMP repository programmes with project QA requirements have been reported in safety assessment documentation. At the meeting at Äspö in November 2006, SKB staff reported that recent checks had found that Clay Technology had adopted and was applying an acceptable QA system in its work for SKB. SKB is undertaking similar audits of its other contractors' QA systems.

Of particular interest to this project are the QA requirements for scientific investigations. Both the QAPD and QARD include similar explicit detailed requirements relating to the conduct of field and laboratory investigations. These requirements address the planning and performance of investigations as well as data management. SNL, a key participant in both the WIPP project and the YMP, has produced procedures for work on experiments and data collection that facilitate the implementation of these requirements. Similarly, BNFL applied written procedures and instructions for field experiments, experimental investigations, and data management under its QA arrangements for the Drigg PCSC. SKB has implemented a project process that addresses experiments and investigations. The project process includes requirements for project planning (including quality plans for activities) and implementation phases. Detailed descriptions of requirements of the type presented in the QARD and QAPD have not been identified for SKB's scientific investigations.

The QAPD and QARD include the requirement that data acquired prior to the implementation of the QA programme are qualified for use in repository safety assessment work. Both documents listed possible data qualification methods. This project has not identified any such requirements or methods for qualifying old data (perhaps generated under previous QA systems) for use in SKB's current repository research and development programme.

3 Review of QA in a Selection of SKB's Experiments

SKI is undertaking preliminary reviews of the QA process in SKB's repository research and development projects in preparation for detailed quality and technical audits of SKB's repository safety assessment after SKB's submission of a licence application for a spent nuclear fuel encapsulation plant and repository. As part of this QA review, SKI has identified the need to review quality-related aspects of some of the many field and experimental investigations instigated by SKB to obtain the data that are used to abstract conceptual understandings of repository evolution and to evaluate the parameters represented in the computer codes.

The main part of this project aimed to review QA issues for a selection of the experiments that might provide data both for use in repository safety assessments and to support an understanding of repository behaviour. The project focused on experiments concerned with gaining an understanding of the properties of repository near-field materials and the evolution of the near field after repository closure because of the significance of these factors to repository performance. After a preliminary consideration of the range of experiments and tests being undertaken as part of the KBS-3 repository development programme, a number of experiments carried out at the Clay Technology laboratories in Lund and at SKB's HRL in Äspö (SKB, 2005a) were selected for review. The QA review was centred on meetings in Lund (15th November 2005) to discuss tests on:

- bentonite swelling pressure;
- hydraulic conductivity; and
- resaturation;

in Äspö (16th November 2005) to discuss the following tests on bentonite buffer performance:

- LOT (long term test of buffer material);
- LASGIT (large scale gas injection test); and
- TBT (temperature buffer test);

and finally in Äspö (17th November 2006) to discuss the following experiment:

- PRE (Prototype Repository Experiment).

The first meeting at Äspö commenced with presentations of SKB's approach to QA in scientific investigations, including document and data management. These presentations form the basis of the discussion of SKB's QA programme for experiments provided in Section 2.4.

The three meetings otherwise followed broadly similar formats. Review of each experiment involved a presentation of the background to, and status of, the experiment by an appropriate member of Clay Technology or SKB staff, followed by a discussion of specific quality-affecting issues. A checklist of questions covering key areas of QA was prepared prior to the meetings to facilitate discussions. This checklist is presented in Section 3.1 and the findings of the QA review of experiments are presented in Section 3.2. The first two meetings concluded with visits to the Clay Technology laboratories and the SKB HRL, respectively, to view the experiments.

3.1 QA Checklist

In order to facilitate the discussions of the QA processes applied to the experiments reviewed in this project, a checklist was prepared comprising a series of questions covering five areas of quality-affecting issues in scientific investigations. The checklist was devised based on consideration of the QA requirements for scientific investigations associated with the repository development programmes discussed in Section 2, as well as a broad understanding of issues relating to traceability and quality control of data. The checklist is as follows:

1. Framework of Experiment
    - 1.1 Purpose and objectives
        - What is being investigated?
        - What experiment is being undertaken?
        - Why is the experiment being undertaken?
        - What is the role of the experiment in the repository programme?
    - 1.2 Resources and schedule
        - Where is the experiment being conducted?
        - Who is conducting the experiment?
        - What is the schedule for the experiment?
        - When will results be available?
        - What constraints do resources such as cost and timing place on experimental planning and design?
    - 1.3 Quality assurance
        - What QA system and standards are used in the planning, design, execution, analysis, and reporting of the experiment?
        - How is the expert team selected/trained for the experiment?

2. Design of Experiment
    - 2.1 Variables
        - What are the dependent variables (i.e. those being observed)?
        - What are the independent variables (i.e. those that are varied to cause change in the dependent variables) and how are their values selected?
        - What are the control variables (i.e. those that are held constant) and how are their values selected?
    - 2.2 Experimental techniques
        - What experimental techniques and instruments are being used?
        - Are they standard techniques?
        - Are acceleration methods used?
        - Have the techniques been validated and documented?
        - Are the techniques being used under normal conditions?
        - Has equipment been calibrated and checked?
    - 2.3 Uncertainty
        - What are the key uncertainties in the experiment?
    - 2.4 Risks to success of experiment
        - What are the risks to the success of the experiment and how are they mitigated?
        - What are the critical decisions in the experiment?
        - Is there duplication in the experiment?
3. Conduct of Experiment

- 3.1 Data collection and quality control
    - How are data collected?
    - How are data stored (e.g. filing, indexing)?
    - How are data checked (e.g. independently)?
    - How are data backed-up?
    - What quality control procedures are used?
- 3.2 Records of experiment
    - Are notebooks being used for the experiments?
    - Are notebooks checked independently?
    - Are planning, execution and analysis correspondences kept (e.g. emails)?
    - Are copies of records kept?
- 3.3 Equipment
    - Is equipment tested, inspected, and maintained?

4. Analysis and Reporting of Experiment
    - 4.1 Data interpretation
        - What data interpretation methods are being used (models, software packages, model simplifications)?
        - How are uncertainties and sensitivities analysed?
    - 4.2 Reporting and review
        - How are data and observations reported?
        - How are interpretations reported?
        - How are limitations on the use of data and results reported?
        - How are reports reviewed (e.g. independently)?
        - How are review results managed/responded to?

5. Usability of Results
    - 5.1 Verification
        - How are experimental outcomes checked against requirements of the experiment?
        - How are experimental results verified?
    - 5.2 Use of results
        - How are results abstracted for use in the repository programme?
        - Are results extrapolated for use on repository length and time scales?
        - What checks are made that data and results are used appropriately and within prescribed limitations?

3.2 Review Findings

The checklist was used as the basis of a form for documenting the results of the QA review. Forms containing reviews of the experiments on bentonite swelling pressure, hydraulic conductivity, and bentonite resaturation undertaken at the Clay Technology laboratories in Lund, and the LOT, LASGIT, TBT, and PRE experiments undertaken at the Äspö HRL, are provided in Appendix A. The following sub-sections summarise key review findings in terms of issues presented on the review checklist.

3.2.1 Framework of Experiment

It was straightforward to ascertain the objectives of each experiment reviewed during the meetings. The aims were generally to improve or confirm understanding of the properties and behaviour of the bentonite buffer material under potential repository conditions. However, the role of the experiments in the decision-making process for the repository design or safety assessment was, in some cases, found to be less clear. The laboratory experiments on bentonite swelling pressure and hydraulic conductivity are complete and the results have been used to support relevant function indicator criteria[1] in the SR-Can report. However, the recent laboratory experiments on bentonite resaturation appear to have no clearly-defined role in the repository programme, although results may be used in the future in model verification studies.

Initial findings on copper corrosion from the LOT experiment at Äspö and data from the PRE project on buffer density have been used in the SR-Can assessment. However, the ongoing experiments have generally had little impact on the SR-Can safety assessment because the results were not available in time. Furthermore, it is unclear exactly how and when the results of these long-term experiments might influence the repository development programme and licence application, although further data from the LOT, LASGIT, TBT, and PRE projects may be available for use in the SR-Site safety assessment.

SKB has implemented a comprehensive QA system for projects conducted at the HRL and requires that contractors working on such research projects produce their own, or use SKB's, QA system. It emerged that some experiments (e.g. the pilot tests for the LOT project) were undertaken before SKB's current QA system was introduced. It is not clear whether old data and results have been formally qualified for use under the present QA system. Similarly, although some written procedures have been used for the experiments carried out at Clay Technology's laboratories, it is apparent that a formal QA system has only recently been implemented. As a result, there is uncertainty about the quality of old data. The qualification of old data should be addressed to an extent that depends on the significance of the data to the repository safety assessment.

Some of the experiments at the HRL involve collaborations of several radioactive waste management organisations. For example, the LASGIT project involves SKB, Posiva (Finland), BGR and GRS (Germany), and Andra (France). Project working groups make key decisions in these experiments. It is unclear how SKB's QA requirements are implemented through all components of the work on these experiments that might be relevant to the SKB repository programme. However, during discussions on the PRE project, which also involves international collaboration, SKB provided assurances that all work was being conducted under appropriate QA systems.

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[1] Function indicators describe buffer properties and processes and these are required to meet associated criteria (SKB, 2004).

3.2.2 Design of Experiment

The design of each experiment was presented clearly during the meetings. In general, standard components have been used in the experiments, although in non-standard equipment and in novel situations. Therefore, the risks of equipment failure, and measures to mitigate such risks, require consideration in the design phase of the experiment. Such risk management is a requirement of SKB's project QA process (see Section 2.4.1).

Pilot studies have been undertaken as part of the design process for novel experiments such as the LOT project, which has enabled problems to be identified and addressed in the design of the full experiments. Risks of equipment failure during the experiments have been mitigated by over-specifying controls and instrumentation in most tests. Also, alarms have been installed in monitoring systems for long-term tests at the HRL to ensure rapid response to failures in key systems such as temperature controls in the LOT project. However, there has been no systematic duplication of experiments as a means of risk mitigation.

3.2.3 Conduct of Experiment

All work on the experiments at the HRL is recorded on logs and field notes, and data are stored on the SICADA database (see Section 2.4.2). In some cases, the HRL experiments are managed remotely by SKB's contractors under SKB's QA system (BGS manages the LASGIT project and Clay Technology manages the LOT, TBT, and PRE projects). The contractors are responsible for submitting data for inclusion in the SICADA system.

A more informal approach to recording project activities appears to be followed for the experiments undertaken at the Clay Technology laboratories. Although there is no formal use of scientific notebooks, project information and data are stored in well-structured Excel spreadsheets.

3.2.4 Analysis and Reporting of Experiment

SKB maintains lists of all documents produced for each experiment at the HRL. These lists include information on the review and approval status of each document. A less formal document management process is adopted for the experiments undertaken at the Clay Technology laboratories. Reports of the experiments are published by SKB, but no formal document review process was identified during this project.

3.2.5 Usability of Results

As noted above, the laboratory experiments on bentonite swelling pressure and hydraulic conductivity have been used to support relevant function indicator criteria in the SR-Can report. However, other experiments that were reviewed in this project are ongoing and there appear to be no firm plans to abstract data from such experiments for use in repository safety assessments.

4 Conclusions

In order to establish a broad understanding of QA requirements for repository scientific investigations, QA procedures implemented in the management of research and development activities for the LLW disposal facility near Drigg in the UK, and the WIPP and YMP repository programmes in the US have been studied. The QA procedures for experiments and tests undertaken in these projects were compared with those implemented by SKB. Key findings are:

- QA programmes have been implemented for each repository development programme in response to regulatory requirements.

- In each case, the need for regular audits of the application, suitability and effectiveness of QA systems has been stressed in regulations and top-level QA requirements documents. In the US and UK, evidence of such audits has been presented in support of facility safety cases. It is understood that SKB has recently undertaken, and is continuing to carry out, audits of the QA systems used by contractors involved in the repository research programme.

- The project QA programmes in each case include requirements for scientific investigations that address the planning and performance of investigations as well as data management. The top-level QA documents for the US repository projects include detailed descriptions of requirements relating to the conduct of scientific investigations. Such detailed QA requirement descriptions have not been identified for SKB's experiments on engineered barrier system components.

QA aspects of several field and experimental investigations undertaken by SKB as part of the repository research programme have been reviewed. The review is intended to support SKI's preparations for more detailed quality and technical audits of SKB's repository safety assessment after the submission of a licence application.

The review focused on experiments to investigate the properties and behaviour of repository near-field materials carried out at SKB's Äspö HRL and the Clay Technology Laboratories in Lund. A checklist of quality-affecting issues was devised which proved an effective tool for structuring meeting discussions and recording review findings. Key findings are:

- The requirements and planning of experiments do not appear to have been coordinated with the planning and requirements of the repository licence application. Some experiments do support relevant function indicator criteria in the SR-Can report and some data may be available for use in the SR-Site safety assessment. However, most of the ongoing experiments have had little impact on the SR-Can safety assessment because the results are not yet available. Furthermore, it is unclear exactly how and when the results of long-term experiments might influence the repository development programme and licence application. For example, although some data from the PRE project have been used in the SR-Can safety assessment, it appears that much data from this project will not be available until after applications for both repository construction and operation have been made.

- Some experiments were undertaken before SKB's current QA system was introduced. It is not clear whether old data and results have been formally qualified for use under the present QA system, or whether the QA system includes procedures for such data qualification.

- SKB's current QA programme requires that contractors working on research projects produce their own, or use SKB's, quality plan. Some written procedures have been used for the experiments carried out at Clay Technology's laboratories and a formal QA system is being implemented.

- Some of the experiments at the HRL involve collaborations of several radioactive waste management organisations. It is unclear how SKB's QA requirements are implemented through all components of the work on these experiments that might be relevant to the SKB repository programme.

- Equipment failure presents a significant risk in the HRL experiments, many of which involve novel designs and methods. Measures to mitigate such risks have included pilot studies, over-specification of controls and instrumentation, and alarmed monitoring systems. These measures are proving invaluable in ensuring the success of the experiments because numerous failures have occurred.

- All work on the experiments at the HRL is recorded on logs and field notes, and data are stored on the SICADA database. There has been no systematic use of scientific notebooks for the experiments undertaken at the Clay Technology laboratories, although project information and data are stored in well-structured Excel spreadsheets.

- SKB maintains lists of documents produced for experiments at the HRL, including information on the review and approval status of each document. Reports of experiments undertaken at the Clay Technology laboratories are published by SKB, but this project was unable to identify a systematic formal document review process. In general, there appears to be no consistently used formal document review process for the reports published in SKB's report series.

- Little information has been obtained with regard to the usability of results from ongoing experiments. Generally, there appear to be no firm plans on how to abstract data from such experiments for use in repository safety assessments.

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Appendix A

QA Reviews of SKB's Experiments

QA reviews of a selection of SKB's experiments on repository near-field materials have been carried out. The reviews were based on meetings at the Clay Technology laboratories in Lund on 15th November 2005 and at SKB's HRL in Äspö on 16th November 2005 and 17th November 2006. Information was also extracted from SKB's reports on the experiments.

The QA review of Clay Technology's experiments on bentonite swelling pressure and hydraulic conductivity is summarised in Table A.1 and the review of laboratory experiments on bentonite resaturation is presented in Table A.2. Tables A.3, A.4, A.5, and A.6 present the QA reviews of the LOT, LASGIT, TBT, and PRE experiments undertaken at the Äspö HRL.

Table A.1 Laboratory tests on bentonite swelling pressure and hydraulic conductivity.

1. Framework of Experiment	
1.1 Purpose and objectives	
What is being investigated?	The effects of groundwater salinity and bentonite density on bentonite swelling pressure and hydraulic conductivity.
What experiment is being undertaken?	Swelling pressure oedometers in multiple concentration tests on a range of bentonite samples.
Why is the experiment being undertaken?	Bentonite swelling pressure represents a safety assessment function indicator, with the requirement that the swelling pressure must be greater than 1 MPa. Swelling pressure is known to decrease as salinity increases. The SR-97 assessment adopted a conservative approximation to the effects of salinity on bentonite swelling pressure at different dry densities. The experiments have aimed to gain a better understanding of this relationship in support of the assessment approximation. In particular, the experiments have been undertaken to increase understanding of the potential effects on swelling pressure of: - salt deposition during buffer resaturation, - draw-up of saline groundwater while the repository is open, - saline groundwater intrusion during glaciation. The experiments have also aimed to gain a better understanding of the effects of density and salinity on hydraulic conductivity. Bentonite hydraulic conductivity is a safety assessment function indicator and it is known to be strongly dependent on material density.
What is the role of the experiment in the repository programme?	The findings have been used to support assumptions about buffer performance in the SR-Can safety assessment. In particular, the results have been used to show that the function indicator criteria can be met for swelling pressure and hydraulic conductivity.
1.2 Resources and schedule	
Where is the experiment being conducted?	Clay Technology's geotechnical laboratory in Lund.
Who is conducting the experiment?	Ola Karnland of Clay Technology led the experiments on behalf of SKB and Posiva.
What is the schedule for the experiment?	The experiments have been completed and analysed.
When will results be available?	The results will be published as an SKB report in the near future.
What constraints do resources such as cost and timing place on experimental planning and design?	The experiments were done well in advance of SR-Can safety assessment preparation. No specific constraints were identified. Small sample sizes were used in the experiments in order to achieve equilibrium on an acceptable timescale.

1.3 Quality assurance	
What QA system and standards are used in the planning, design, execution, analysis, and reporting of the experiment?	Experimental procedures with written instructions were used. No specific standards or QA system have been used.
How is the expert team selected/trained for the experiment?	Individuals were chosen who have expertise specific to the type of experiment conducted and these individuals were involved throughout the course of the experiment.
2. Design of Experiment	
2.1 Variables	
What are the dependent variables (i.e. those being observed)?	Swelling pressure and flow rate. The latter variable was used to derive the hydraulic conductivity. The meeting presentation focused on determination of swelling pressure.
What are the independent variables (i.e. those that are varied to cause change in the dependent variables) and how are their values selected?	Salinity, bentonite dry density, and material type. Salinity varied over a broad range: pure water and 0.1, 0.3, 1.0, and 3.0 M NaCl. Seawater has a salinity of around 0.6 M NaCl. The salinity of 3.0 M NaCl is extreme. Bentonite dry density ranged from 350 to 2000 kg/m^3. The dry density of the bentonite buffer is expected to be around 1590 kg/m^3. The dry density of the bentonite in the backfill is expected to be lower. Lower densities may also result from bentonite erosion. Material type: Experiments have been undertaken with MX-80 (a Na-bentonite), Deponit CA-N (a Ca-bentonite), and Friedland ton (clay). These represent possible buffer and backfill materials. Natural materials and materials converted to pure sodium and pure calcium states (by removal of accessory minerals and ion exchange) have been used. The meeting presentation focused on experiments with MX-80 that had been purified to the Na$^+$ state.
What are the control variables (i.e. those that are held constant) and how are their values selected?	Temperature was fixed (room temperature). The hydraulic gradient across the samples was fixed at a value greater than expected in a repository (see comment below on acceleration methods).
2.2 Experimental techniques	
What experimental techniques and instruments are being used?	Material preparation included removal of soluble accessory minerals by washing in order to obtain montmorillonite with small amounts of insoluble accessory minerals (quartz). The experimental equipment (swelling pressure oedometer) was manufactured at Clay Technology's laboratory. Commercial pumps and pressure gauges were used.
Are they standard techniques?	Established theory, techniques, and measuring methods were used. Standard components were used but the equipment was otherwise non-standard.
Are acceleration methods used?	The hydraulic gradient across the samples was increased relative to expected conditions. Hydraulic conductivities are generally not expected to be dependent on the hydraulic gradient, except possibly when the hydraulic conductivity is very small.

Have the techniques been validated and documented?	Published techniques were used. Any new techniques are always documented. The methods have been checked against basic theory.
Are the techniques being used under normal conditions?	Techniques were used under normal conditions.
Has equipment been calibrated and checked?	Equipment is factory calibrated. Equipment is then calibrated before each test and the equipment is checked after the experiment.
2.3 Uncertainty	
What are the key uncertainties in the experiment?	Mineral content represents one area of uncertainty. Different parts of the mine have different montmorillonite content and the material cost increases as the required precision in montmorillonite content increases. Clay Technology addresses this uncertainty by checking the mineral content. There is also some uncertainty in material density. Measurement accuracy would be improved if the height of the sample were increased. However, it would take longer to conduct the experiment to determine hydraulic conductivity if a larger sample were used. Experiments with high-density samples take about two weeks for present sample size.
2.4 Risks to success of experiment	
What are the risks to the success of the experiment and how are they mitigated?	There is a risk of material erosion in the purification process.
What are the critical decisions in the experiment?	Setting the pressure gradient is important. Piping may occur if the pressure gradient and swelling pressure are high. The experiment may take too long if the pressure gradient is too low for high-density samples. Measurements must be made when equilibrium conditions have been achieved. Therefore, determining when equilibrium has been reached is important.
Is there duplication in the experiment?	Some duplicate experiments are run, but not systematically.
3. Conduct of Experiment	
3.1 Data collection and quality control	
How are data collected?	Water flow rates and volumes are recorded manually. Pressure is recorded automatically.
How are data stored (e.g. filing, indexing)?	Data (e.g. swelling pressure, grain density) are stored in an Excel spreadsheet.
How are data checked (e.g. independently)?	There is no formal independent checking of the data, although quality checks are made (see comment below on quality control).
How are data backed-up?	The data are stored on two computers.
What quality control procedures are used?	Quality checks on data are always carried out. Reproducibility of data has been checked successfully by running continuous tests from fresh water to saline water and back to fresh water.

3.2 Records of experiment	
Are notebooks being used for the experiments?	No.
Are notebooks checked independently?	No.
Are planning, execution and analysis correspondences kept (e.g. emails)?	Informal group discussions are held and recorded. Correspondence with external organisations, such as labs, is recorded.
Are copies of records kept?	Yes.
3.3 Equipment	
Is equipment tested, inspected, and maintained?	Yes. Equipment is checked before use and is checked for leaks during the experiments.
4. Analysis and Reporting of Experiment	
4.1 Data interpretation	
What data interpretation methods are being used (models, software packages, model simplifications)?	Hydraulic conductivity values were derived from the applied pressure gradients and recorded flow rates assuming Darcy's Law. Calculations were performed using an Excel spreadsheet. The swelling pressure measurements were compared with a thermodynamic approach that includes the Donnan model (ion equilibrium, electrical neutrality) for estimating the drop in swelling pressure as a function of salinity. Application of the thermodynamic approach/Donnan model required: - analysis of the pore water in clay samples (centrifuge, ultra-filtration, ion chromatography) to determine the molarity of chloride ions introduced to the clay, from which the molarity of introduced sodium ions could be evaluated by the assumption of electrical neutrality, - measurement of the water activity in the clay (i.e the amount of water available for hydration, which effects suction).
How are uncertainties and sensitivities analysed?	Uncertainties associated with scaling the results are addressed through conduct of large-scale experiments. Results are most sensitive to material density. Uncertainties in density measurements have not been quantified, but are not thought to be significant. There is some uncertainty regarding the applicability of the hydraulic conductivities that were derived for flow rates much greater than would be expected under repository conditions. However, the approach is considered to be conservative.
4.2 Reporting and review	
How are data and observations reported?	To be published as an SKB report. Results were presented and discussed at a workshop on long-term stability of buffer and backfill organised by SKI and held in Lund in November 2004 (SKI, 2005).

How are interpretations reported?	Journal publications and an SKB report.
How are limitations on the use of data and results reported?	Limitations are reported in the publications.
How are reports reviewed (e.g. independently)?	There are no formal reviews of the material presented in the SKB report. The report presents the authors' interpretations of the experiments. There is some internal review by Clay Technology. The results are subject to external review as part of the SR-Can assessment review.
How are review results managed/responded to?	There has been no external review as yet.
5. Usability of Results	
5.1 Verification	
How are experimental outcomes checked against requirements of the experiment?	The requirement to improve understanding of the effects of groundwater salinity and bentonite density on bentonite swelling pressure and hydraulic conductivity have evidently been met.
How are experimental results verified?	Some results have been checked against published data.
5.2 Use of results	
How are results abstracted for use in the repository programme?	The results have been used directly in the SR-Can safety assessment to demonstrate that the function indicator criteria can be met for swelling pressure and hydraulic conductivity.
Are results extrapolated for use on repository length and time scales?	Results are considered independent of length and time scales.
What checks are made that data and results are used appropriately and within prescribed limitations?	The experiments cover all possible ranges of materials (i.e. reference, purified in Na, and purified in Ca) and conditions expected in the repository. However, there may be concerns over use of data for backfill (e.g. hydraulic conductivity). Properties will depend on mixtures and mixing techniques.

Table A.2 Laboratory tests on bentonite resaturation.

1. Framework of Experiment	
1.1 Purpose and objectives	
What is being investigated?	Bentonite resaturation processes.
What experiment is being undertaken?	Three types of laboratory experiment are being carried out: Experiment 1. The use of oedometers to study the effects of suction and compression on water content and swelling of bentonite samples. Experiment 2. Measurement of the rate of suction- and vapour-driven water transport in bentonite samples. Experiment 3. Measurement of water retention in bentonite samples (glass jar method).
Why is the experiment being undertaken?	The experiments are aimed at developing a better understanding of the resaturation of MX80 bentonite. Analysis of redistribution of water and bentonite will provide information on the final saturated density distribution of bentonite in a deposition hole. The experiments will support the development of more accurate representations of thermoelastoplastic processes in CODE_BRIGHT as an alternative to previous analysis of bentonite resaturation using the ABAQUS code.
What is the role of the experiment in the repository programme?	The experimental results have not had a direct role in the SR-Can assessment: representation of mechanical processes in the resaturation phase is not included in the assessment. Furthermore, there are no function indicators for the unsaturated phase; uncertainty in the path to resaturation is expected to have little impact on the final saturation state (SKB, 2004). However, the experimental results might be used by the Äspö Task Force in its analysis of buffer behaviour.
1.2 Resources and schedule	
Where is the experiment being conducted?	Clay Technology's geotechnical laboratory in Lund.
Who is conducting the experiment?	Mattias Åkesson, Herald Hökmark, and Ann Dueck of Clay Technology are running the experiments on behalf of SKB.
What is the schedule for the experiment?	The experiments are ongoing.
When will results be available?	Dueck (2004) has published results and analysis of Experiment 3.
What constraints do resources such as cost and timing place on experimental planning and design?	The experimental results have not been used in the SR-Can assessment and, as such, are not constrained by the assessment schedule. The results will be used in the longer term, for example in model verification. Small sample sizes are used in the experiments in order to achieve equilibrium on an acceptable timescale.

1.3 Quality assurance	
What QA system and standards are used in the planning, design, execution, analysis, and reporting of the experiment?	Experimental procedures with written instructions are used. No specific standards or QA system have been used.
How is the expert team selected/trained for the experiment?	Individuals were chosen who have expertise specific to the type of experiment conducted and these individuals were involved throughout the course of the experiments.
2. Design of Experiment	
2.1 Variables	
What are the dependent variables (i.e. those being observed)?	Experiment 1. Vertical strain and radial stress. Void and water ratios at equilibrium. Experiment 2. Relative humidity, void ratio, and water ratio at a specific time and at specific locations in a sample. Experiment 3. Water ratio (at equilibrium).
What are the independent variables (i.e. those that are varied to cause change in the dependent variables) and how are their values selected?	Experiment 1. Axial stress and relative humidity are varied independently during the experiment. Relative humidity has been varied from 43% to 100%. Axial stress has been varied by applying loads from 0 to 30 MPa. Experimental conditions are considered to encompass expected repository conditions. Experiment 2. None. Experiment 3. Relative humidity is set a different value for each sample.
What are the control variables (i.e. those that are held constant) and how are their values selected?	Experiment 1. The initial void ratio (about 0.6), initial water ratio (about 10%), and temperature (room temperature) of the sample are fixed. Experiment 2. The initial void and water ratios are set. Relative humidity at the upper surface of the sample is fixed. Experiment 3. Initial water ratio is set. Temperature is fixed. Temperature would be an independent variable if varied between samples.
2.2 Experimental techniques	
What experimental techniques and instruments are being used?	Experiment 1. Stress-path tests with four suction-control oedometers. Suction depends on relative humidity, which is generated by a saturated salt solution. Axial stress and relative humidity are varied. Experiment 2. Three 40-mm-high cells containing samples. Relative humidity is set at the upper surface of the sample. A single set of measurements at three locations in the sample is made at a specific time after the start of the experiment to give a snapshot of water transport through the sample. Experiment 3. Samples are conditioned over salt solutions in glass jars. Moisture is measured by weighing the sample during the test. The sorption isotherm (water uptake) is determined. The equipment used in the experiments includes relative humidity sensors and transducers. Water content is measured by drying.

Are they standard techniques?	Experiment 1. Yes. Experiment 2. Yes. Experiment 3. Yes, although the application of the jar method is unique.
Are acceleration methods used?	No.
Have the techniques been validated and documented?	The experimental techniques are described in the PhD thesis Dueck (2004).
Are the techniques being used under normal conditions?	Techniques were used under normal conditions.
Has equipment been calibrated and checked?	Relative humidity sensors and other equipment are checked carefully. Manufacturers supply standard calibration procedures. Equipment to measure water content by drying is checked before and after use.
2.3 Uncertainty	
What are the key uncertainties in the experiment?	Experiment 1. There is some uncertainty over the accuracy of the radial stress measurements for unsaturated material. The material is stiff, especially if relative humidity is low. The experiment aimed to identify any hysteresis.
2.4 Risks to success of experiment	
What are the risks to the success of the experiment and how are they mitigated?	Dueck (2004) discussed and analysed potential problems associated with conducting the experiments, such as the impact of equipment on test results, and considered methods for evaluating uncertainties.
What are the critical decisions in the experiment?	In Experiments 1 and 3, it is important to determine when equilibrium conditions have been reached and measurements can be made. For Experiment 2, it is important to decide when to stop the experiment to take measurements.
Is there duplication in the experiment?	There is no duplication of experiments.
3. Conduct of Experiment	
3.1 Data collection and quality control	
How are data collected?	Variables are recorded either automatically or manually.
How are data stored (e.g. filing, indexing)?	Data are stored in an Excel spreadsheet.
How are data checked (e.g. independently)?	Not done independently.
How are data backed-up?	The data are stored on two computers.
What quality control procedures are used?	Quality checks on data are always carried out.
3.2 Records of experiment	
Are notebooks being used for the experiments?	No.

Are notebooks checked independently?	No.
Are planning, execution and analysis correspondences kept (e.g. emails)?	Informal group discussions are held and recorded. Correspondence with external organisations is recorded.
Are copies of records kept?	Yes.
3.3 Equipment	
Is equipment tested, inspected, and maintained?	Yes. It is important to maintain constant temperature and this is checked during the experiments.
4. Analysis and Reporting of Experiment	
4.1 Data interpretation	
What data interpretation methods are being used (models, software packages, model simplifications)?	The experimental results are being used to support the development of a bentonite material model in CODE_BRIGHT. An elastic strain model is being quantified using the compression tests (Experiment 1). A Mathcad application has also been developed for sensitivity analyses
How are uncertainties and sensitivities analysed?	Not done as yet.
4.2 Reporting and review	
How are data and observations reported?	Dueck (2004) presented data from the jar experiments (Experiment 3). It is expected that all the data will be presented in an SKB report.
How are interpretations reported?	Dueck (2004) presented analysis of the jar experiments (Experiment 3) and information on experimental techniques. It is expected that interpretations (e.g. CODE_BRIGHT analysis) will be presented in an SKB report.
How are limitations on the use of data and results reported?	Experimental conditions are considered to encompass expected repository conditions.
How are reports reviewed (e.g. independently)?	The experiments have been presented to the Äspö Task Force. The results would be reviewed in the event that the Task Force planned to use them.
How are review results managed/responded to?	There has been no external review as yet.
5. Usability of Results	
5.1 Verification	
How are experimental outcomes checked against requirements of the experiment?	Experiments are ongoing.
How are experimental results verified?	Experiments are ongoing. Verification was not discussed.

5.2 Use of results	
How are results abstracted for use in the repository programme?	The experimental results have no direct role in the SR-Can assessment, but are being used to support the development of a bentonite material model for the unsaturated phase in CODE_BRIGHT.
Are results extrapolated for use on repository length and time scales?	Results are expected to be applicable at repository scales, but large-scale tests are also being undertaken.
What checks are made that data and results are used appropriately and within prescribed limitations?	This issue was not discussed because the experiments are ongoing.

Table A.3 Long term test of buffer material (LOT project) at the Äspö Hard Rock Laboratory.

1. Framework of Experiment	
1.1 Purpose and objectives	
What is being investigated?	The main LOT tests are investigating bentonite buffer properties and mineral stability in a repository-like environment. Other LOT tests are studying copper corrosion, cation diffusion, and bacterial behaviour.
What experiment is being undertaken?	Experiments are being undertaken in which copper tubes containing heater elements and surrounded by bentonite (parcels) are placed in boreholes at Äspö. There are two types of bentonite parcel: - standard or S-parcels (S1, S2, and S3) in which the bentonite is exposed to expected repository conditions, - adverse or A-parcels (A0, A1, A2, and A3) in which the bentonite is exposed to adverse repository conditions. Various laboratory tests are performed on the bentonite after extraction of the parcels at the end of each experiment.
Why is the experiment being undertaken?	To test models and understanding of bentonite buffer performance after saturation and bentonite degradation processes, and to serve as pilot tests for the canister retrieval test and prototype repository project.
What is the role of the experiment in the repository programme?	Available findings from the one-year tests (S1, A0, and A1) will be used, in conjunction with data from laboratory experiments, to verify models of buffer performance (mainly chemical evolution) used in the SR-Can safety assessment. Data from the longer-term tests were not available for the SR-Can safety assessment. However, data from the five-year tests (A2 and S2) will probably be available by 2007, when they could be used for the SR-Site assessment.
1.2 Resources and schedule	
Where is the experiment being conducted?	SKB's Hard Rock Laboratory on Äspö near Oskarshamn.
Who is conducting the experiment?	Ola Karnland of Clay Technology is leading the experiment on behalf of SKB and Posiva in collaboration with four other research groups. Clay Technology is leading the work on bentonite mineralogy and physical properties, VTT Finland is responsible for work on pore water chemistry, the University of Gothenburg is working on bacterial behaviour, KTH is working on cation diffusion, and Studsvik Material is working on copper corrosion.
What is the schedule for the experiment?	Two one-year pilot tests (A1 and S1) were conducted in 1997 and 1998. Work on five more tests (S2, S3, A0, A2, and A3) was started in 1999 and parcel A0 was retrieved after one year in 2001. Parcels S2 and A2 are planned to be in place for five years and will be retrieved in 2006. Parcels S3 and A3 will be in place for in excess of five years.
When will results be available?	The results of the two pilot tests (A1 and S1) were reported in SKB (2000b). The results of analysis of Parcel A2 were due to be reported in late 2006, and the results of analysis of Parcel S2 will be reported in September 2007.

What constraints do resources such as cost and timing place on experimental planning and design?	The time for resaturation constrains the scale of the test. Full saturation would not occur in one year in a full-scale test. The smaller parcel size also facilitates extraction of the parcels in one piece.
1.3 Quality assurance	
What QA system and standards are used in the planning, design, execution, analysis, and reporting of the experiment?	The early experiments were not performed under the present QA process.
How is the expert team selected/trained for the experiment?	SKB proposed the five research groups to work on the experiments and asked Ola Karnland to design the experiments. Selection was based on experience of the research groups.
2. Design of Experiment	
2.1 Variables	
What are the dependent variables (i.e. those being observed)?	During experiment monitor: - water content, water pressure, total pressure, and temperature distributions in bentonite. After parcel extraction a range of tests are conducted to determine bentonite properties: - physical (water ratio, density, swelling pressure, hydraulic conductivity, and tensile and shear strength), - mineralogical (enrichment from groundwater, dissolution/precipitation, surface reaction, and alteration). After parcel extraction also analyse: - tracer distributions to determine diffusion rates, bacteria behaviour, and copper corrosion.
What are the independent variables (i.e. those that are varied to cause change in the dependent variables) and how are their values selected?	Heat sources maintain copper temperature at about 90°C (S-parcels) and about 130°C (A-parcels) and generate a temperature gradient across the bentonite. Groundwater pressure in the rock and rate of inflow to the bentonite, which vary depending on conditions local to each test hole. Chemical conditions are varied in A-parcels by exposing bentonite to high potassium concentration, high pH from cement, and accessory minerals. Cation and microbe sources are also placed in the bentonite.
What are the control variables (i.e. those that are held constant) and how are their values selected?	No specific controls. Bentonite is exposed to a range of different conditions to see what happens.

2.2 Experimental techniques	
What experimental techniques and instruments are being used?	Experimental procedure: - copper surrounded by bentonite blocks lowered into 4-m long, 30-cm diameter boreholes. The copper tubes contain heater elements (600 W for A-parcels or 850 W for S-parcels) over the lower 2-m length of the borehole, - copper plates and cement, tracers (^{134}Cs and ^{60}Co), bacteria, and additives placed in some bentonite blocks (A-parcels), - about 40 sensors (relative humidity, water pressure, total pressure, and temperature sensors) placed at different locations in the bentonite blocks in each parcel to allow continuous monitoring. Parcel extraction and analyses: - extract by core drilling, - analyse bentonite physical properties (triaxial, beam and oedometer tests, drying, and weighing), - analyse bentonite mineralogical properties (XRD, CEC, ICP/AES and SEM/EDX analyses), - other tests (water analyses, copper corrosion analyses, tracer analyses, and microbial analyses).
Are they standard techniques?	A lot of the equipment is newly constructed. Heaters were specially designed. Generally, standard components and sensors are used, although titanium was used instead of the usual steel in some sensors to avoid corrosion. The laboratory analyses methods are standard, although the oedometers were specially designed.
Are acceleration methods used?	Parcel diameter is smaller than in a canister deposition hole to shorten the resaturation time. High temperatures and temperature gradients are imposed coupled with high concentrations of accessory minerals and cements to accelerate alteration processes (e.g. illitisation).
Have the techniques been validated and documented?	Results of the two pilot tests (A1 and S1) guided the design of the later tests. Descriptions, results and analyses of the pilot tests are provided in SKB (2000b).
Are the techniques being used under normal conditions?	Equipment such as sensors is used under normal conditions and is expected to be reliable. However, some sensors have failed (including relative humidity sensors).
Has equipment been calibrated and checked?	Copper tubes were checked for leaks when sealed. Equipment is calibrated before use and checked after use.
2.3 Uncertainty	
What are the key uncertainties in the experiment?	The timescale to achieve the resaturated conditions needed to verify the chemistry model.

2.4 Risks to success of experiment	
What are the risks to the success of the experiment and how are they mitigated?	Lack of control of resaturation. Rapid resaturation is preferred and water can be injected if saturation is too slow. Saturated conditions are essential for verification of the chemistry model. Risk of equipment failure (e.g. temperature control, sensor). Alarms are used in the monitoring system with associated response actions. The following sensor issues were noted: - electrical interference between pressure sensors and malfunction of sensors, but sufficient sensors are in place to obtain data, - anomalous relative humidity values explained by early water flow in gaps between blocks, - some relative humidity sensors failed but data are not critical. Interactions. Try to avoid interactions beyond the block scale (A-parcels). High groundwater flow rates into the borehole resulting in washout of bentonite slurry. Avoid high flows. Loss of bentonite during drilling and extraction of the parcel. Extraction method has been modified and improved after problems with a pilot parcel. Careful and rapid handling of samples to avoid disturbances to final conditions after parcel extraction (e.g. oxygen, CO_2, atmospheric pressure). Staff turn-over is a potential risk, but experiments are well documented to mitigate against this risk.
What are the critical decisions in the experiment?	Decision on when to terminate tests.
Is there duplication in the experiment?	There is duplication in blocks and between blocks. Experiments are always over-specified.
3. Conduct of Experiment	
3.1 Data collection and quality control	
How are data collected?	Hourly and event-triggered data collection (Orchestrator data acquisition software).
How are data stored (e.g. filing, indexing)?	Data are collected using the Orchestrator software and stored on a local project computer, with monthly transmission to Clay Technology. Clay Technology processes the data using Microsoft Excel, stores the data on CD-Rom, and submits it to SICADA database (see Section 2.4.2). An indexing system is used for identifying tests, sensors, bentonite blocks, and bentonite test sample locations.
How are data checked (e.g. independently)?	Data are checked using a monitoring system with alarm functions.
How are data backed-up?	Regular backup on separate hard disk.
What quality control procedures are used?	Non-conformance reports are prepared when deviations occur. Quality checks are made on data entered into the SICADA database.

3.2 Records of experiment	
Are notebooks being used for the experiments?	Field notes, daily logs, database entries.
Are notebooks checked independently?	No.
Are planning, execution and analysis correspondences kept (e.g. emails)?	Important correspondence is kept and stored by Clay Technology or at Äspö. Activity plans are used.
Are copies of records kept?	No.
3.3 Equipment	
Is equipment tested, inspected, and maintained?	Yes.
4. Analysis and Reporting of Experiment	
4.1 Data interpretation	
What data interpretation methods are being used (models, software packages, model simplifications)?	There has been little interpretation of the field data. Standard theories and methods are used to evaluate water ratio, density, hydraulic conductivity (Darcy's Law), swelling pressure, tensile strength, and shear stress from measured quantities. Calculations are performed using Excel spreadsheets. Details of the analytical methods used to determine bentonite mineralogical properties (XRD, CEC, ICP/AES and SEM/EDX) are provided in SKB (2000b). A solution to the diffusion equation (one-dimensional spherical diffusion) has been used to evaluate apparent diffusivities for cations.
How are uncertainties and sensitivities analysed?	In general and as expected, changes in the mineralogical and physical properties of the bentonite are small. It has not been possible to quantify any uncertainties.
4.2 Reporting and review	
How are data and observations reported?	Many documents have been produced and are listed in a project document chart. Results have been published in scientific journals and in two PhD theses. SKB (2000b) contains observations from the pilot tests.
How are interpretations reported?	As above. SKB (2000b) contains interpretations from the pilot tests.
How are limitations on the use of data and results reported?	Such issues have not yet been addressed.
How are reports reviewed (e.g. independently)?	Reviewed and approved by SKB.
How are review results managed/responded to?	It is unclear how the review process is carried out.

5. Usability of Results	
5.1 Verification	
How are experimental outcomes checked against requirements of the experiment?	SKB performs such checks and decides on whether further studies are required.
How are experimental results verified?	Observations are compared with expected results, such as from laboratory experiments.
5.2 Use of results	
How are results abstracted for use in the repository programme?	The experiments are being analysed or are ongoing. The possible abstraction of data for use in the repository programme was not discussed.
Are results extrapolated for use on repository length and time scales?	The results are assumed to apply to repository time and length scales.
What checks are made that data and results are used appropriately and within prescribed limitations?	The results are used to verify and validate an existing model. The model must be used appropriately.

Table A.4 Large Scale Gas Injection Test (LASGIT) at the Äspö Hard Rock Laboratory.

1. Framework of Experiment	
1.1 Purpose and objectives	
What is being investigated?	The LASGIT project is a full-scale test aimed at studying gas transfer through the bentonite buffer.
What experiment is being undertaken?	A copper canister and bentonite buffer are placed in a deposition hole. The hole is sealed and the bentonite is fully water saturated, after which the canister is pressurised with helium. The pressure at which the gas starts to move through the bentonite is measured.
Why is the experiment being undertaken?	To examine potential problems associated with hydrogen generation resulting from the corrosion of the nodular iron insert in a canister (fracture formation in the bentonite, bentonite de-saturation, and mechanical damage at high pressure).
What is the role of the experiment in the repository programme?	The experiment will enable evaluation of uncertainties in up-scaling gas migration findings from laboratory experiments, improve understanding of gas transport, and allow testing and validation of gas transfer models. A demonstration that gas generation will not have a detrimental effect on repository performance is being sought. Any findings that differ from expectations would be accounted for in revised modelling and analyses. Data were not available for the SR-Can safety assessment, but results should be available for the SR-Site assessment.
1.2 Resources and schedule	
Where is the experiment being conducted?	SKB's Hard Rock Laboratory on Äspö near Oskarshamn.
Who is conducting the experiment?	The project is a collaborative experiment involving SKB, Posiva (Finland), BGR and GRS (Germany), and Andra (France). Lead contractors are BGS (UK) and Clay Technology.
What is the schedule for the experiment?	The experiment began in 2003 and installation was completed in 2004. Water saturation of the bentonite had been ongoing for 290 days by mid-November 2005, with artificial saturation commencing in May 2005. The timescale for the experiment depends on the time to achieve full water saturation, which could be in excess of three years.
When will results be available?	Results should be available in 2007.
What constraints do resources such as cost and timing place on experimental planning and design?	The time for resaturation (uncertain) constrains the time scale of the test. Full canister pressurisation is not planned for most of the tests because of the operational risks of working with high gas pressures. However, it is possible that the canister will be fully pressurised as a final test once a risk analysis has been undertaken.
1.3 Quality assurance	
What QA system and standards are used in the planning, design, execution, analysis, and reporting of the experiment?	The lead contractor BGS uses SKB's QA system (see Section 2.4).

How is the expert team selected/trained for the experiment?	Selection of the lead contractor BGS was based on expertise of key BGS staff in this field (John Harrington).
2. Design of Experiment	
2.1 Variables	
What are the dependent variables (i.e. those being observed)?	During hydration: - total stress, strain, pore water pressure. During gas injection: - total stress, strain, pore water pressure, and gas pressure.
What are the independent variables (i.e. those that are varied to cause change in the dependent variables) and how are their values selected?	During hydration: - water inflow rate and location. During gas injection: - either gas flow rate or gas pressure (more likely), - location of gas injection and size of gas injection filter.
What are the control variables (i.e. those that are held constant) and how are their values selected?	Temperature (seasonal variations considered insignificant) and chemical conditions. Also require saturation and equilibrium stress conditions to be achieved before gas injection.
2.2 Experimental techniques	
What experimental techniques and instruments are being used?	The copper canister and bentonite buffer have been placed in an existing deposition hole. The bentonite blocks were almost fully saturated (about 96%) prior to placement and the slots around the blocks were filled with pellets and water. The hole was sealed (to simulate effects of overlying backfill) and the bentonite is being fully water saturated, after which the canister will be pressurised with helium (which is used to simulate hydrogen). Hydration mats are included to facilitate artificial hydration. Syringe pumps will be used to inject the gas through one or more of thirteen gas injection filters incorporated at different locations in the canister walls. Instrumentation on the rock wall and above the bentonite collects pore pressure and stress values. Lid deformations are monitored.
Are they standard techniques?	The pumps are similar to those used in laboratory experiments and have corrosion resistant pump houses. The sensors are similar to those used in other large-scale experiments. Lid design to simulate the effects of backfill is novel and achieving the appropriate deformation response is difficult. It has not been possible to design a lid rated to the gas pressures measured in laboratory experiments (as high as 22 MPa). The lid is rated to 20 MPa.

Are acceleration methods used?	Almost fully saturated bentonite blocks were used in order to reduce the time to full saturation prior to gas injection. Artificial hydration, using all 13 gas injection filters, was started after a period of natural hydration in order to speed up the saturation process, but it still may take in excess of three years to achieve full saturation. Gas injection rates will be higher than gas generation rates expected under repository conditions and therefore the increase in pressure will be much more rapid than expected. A slow increase in pressure is difficult to simulate. If gas breakthrough is slow then consolidation of the clay may be considered.
Have the techniques been validated and documented?	A full document list is available, which includes design and testing reports.
Are the techniques being used under normal conditions?	Equipment, such as sensors and pumps, is being used under normal conditions and is expected to be reliable.
Has equipment been calibrated and checked?	Yes. Extensive leak testing has been carried out involving checking of all filters by certified technicians.
2.3 Uncertainty	
What are the key uncertainties in the experiment?	Bentonite properties if affected by loss of material during piping. However, swelling pressure is thought to be high enough to avoid further piping and the effects of earlier piping are expected to be insignificant.
2.4 Risks to success of experiment	
What are the risks to the success of the experiment and how are they mitigated?	Leakages represent a key risk but thorough leak testing has been carried out. Thirteen gas injection filters have been included to mitigate leakage risks. Lack of control of the saturation process. Pore pressure has been stabilised by drilling drainage holes. Artificial hydration has been introduced to exert more control over and speed up the hydration process. Channels (piping) through the bentonite have occurred during hydration, but these are expected to self-seal. Artificial gas pathways (voids, sinks) have been avoided by excluding instrumentation from the bentonite. A risk assessment will be carried out before a decision is made to undertake a final test involving full pressurisation of the canister.
What are the critical decisions in the experiment?	When to begin gas injection and which gas injection filters to use. A gas injection testing programme could be adopted. This part of the experiment is being designed as the experiment progresses and monitoring and testing information is acquired.
Is there duplication in the experiment?	Any of 13 gas injection filters, of different sizes and at different locations, can be used. At least two will be used.
3. Conduct of Experiment	
3.1 Data collection and quality control	
How are data collected?	Instrumentation on rock wall and above bentonite collects pore pressure and stress values continuously.

How are data stored (e.g. filing, indexing)?	Data are stored on local project computer, with transmission to BGS. BGS processes the data and sends them to the SICADA database (see Section 2.4.2).
How are data checked (e.g. independently)?	BGS checks the data.
How are data backed-up?	As described in Section 2.4.2.
What quality control procedures are used?	Issue not discussed.
3.2 Records of experiment	
Are notebooks being used for the experiments?	All work on the experiment is recorded/logged.
Are notebooks checked independently?	No.
Are planning, execution and analysis correspondences kept (e.g. emails)?	Dialogue between project participants and modelling teams is recorded and copied to SKB at Äspö. Activity plans are used.
Are copies of records kept?	Yes.
3.3 Equipment	
Is equipment tested, inspected, and maintained?	Yes.
4. Analysis and Reporting of Experiment	
4.1 Data interpretation	
What data interpretation methods are being used (models, software packages, model simplifications)?	Hydration and material modelling is being undertaken. Gas migration modelling has already been carried out using the TOUGH2 code. Decisions are yet to be made on interpretation and modelling methods. The EBS Task Force will lead this decision making. A solution to the diffusion equation (one-dimensional spherical diffusion) has been used to evaluate apparent diffusivities for cations.
How are uncertainties and sensitivities analysed?	Experiment is ongoing. To be addressed.
4.2 Reporting and review	
How are data and observations reported?	Documents are listed in a Project document chart.
How are interpretations reported?	As above for reporting observations.
How are limitations on the use of data and results reported?	Such issues have not yet been addressed.
How are reports reviewed (e.g. independently)?	Reviewed and approved by SKB.
How are review results managed/responded to?	It is unclear how the review process is carried out.

5. Usability of Results	
5.1 Verification	
How are experimental outcomes checked against requirements of the experiment?	SKB performs such checks and decides on whether further studies are required.
How are experimental results verified?	Observations are compared with expected results (laboratory experiments).
5.2 Use of results	
How are results abstracted for use in the repository programme?	Data on piping is likely to be used to provide an understanding of the potential magnitude of water and bentonite expulsion from deposition holes in a repository.
Are results extrapolated for use on repository length and time scales?	The experiment is full scale. Acceleration methods are used and interpretation for expected timescales is required.
What checks are made that data and results are used appropriately and within prescribed limitations?	Such issues have not yet been addressed.

Table A.5 Temperature Buffer Test (TBT) at the Äspö Hard Rock Laboratory.

1. Framework of Experiment	
1.1 Purpose and objectives	
What is being investigated?	The TBT project is a large-scale test aimed at determining how MX-80 bentonite is affected by high temperature.
What experiment is being undertaken?	Two canisters (French design) are placed in a single deposition hole and surrounded by bentonite, which is subjected to high temperatures.
Why is the experiment being undertaken?	To determine how bentonite behaves at, and is affected by, temperatures above 100°C. The experiment is intended, partially, to meet Andra's requirements to understand bentonite behaviour at such temperatures. Canister surface temperatures in excess of 100°C are expected in the French design but not in the Swedish design.
What is the role of the experiment in the repository programme?	The experiment is not intended to result in changes in the temperature function indicator (requiring temperatures in the bentonite to remain less than 100°C), but is aimed at understanding the significance of the temperature criterion. The test will support modelling and understanding of THM processes in bentonite at high temperatures. Data on thermal conductivities at different degrees of saturation would be used in THM analyses. Tests to obtain information on water distribution and chemical and mineralogical properties of the bentonite at the end of the test may also be undertaken.
1.2 Resources and schedule	
Where is the experiment being conducted?	SKB's Hard Rock Laboratory on Äspö near Oskarshamn.
Who is conducting the experiment?	The project is being led by Andra (France), and involves SKB and its contractor Clay Technology (principally Mattias Åkesson). Clay Technology is responsible for conducting the experiment, but the TBT modelling group makes key decisions. Enresa (Spain) supplied heaters and DBE (Germany) supplied total pressure sensors.
What is the schedule for the experiment?	The experiment began in 2002 and is intended to be completed in 2006 (when saturation is expected to be complete). It has been running for about 1,000 days and the system is close to saturation, except close to canisters.
When will results be available?	See above comment on schedule. The results should be available for use in the SR-Site assessment.
What constraints do resources such as cost and timing place on experimental planning and design?	The time for bentonite saturation (uncertain) constrains the time scale of the test.
1.3 Quality assurance	
What QA system and standards are used in the planning, design, execution, analysis, and reporting of the experiment?	The QA system applied to this project is discussed in Section 2.4.

How is the expert team selected/trained for the experiment?	Team selected by partners based on known expertise in relevant area.
2. Design of Experiment	
2.1 Variables	
What are the dependent variables (i.e. those being observed)?	Temperature, water content, total pressure, and pore pressure, and strain. Values of other variables may be determined at the end of the experiment if relevant tests are undertaken on the bentonite (water distribution, hydraulic conductivity, and chemical and mineralogical properties).
What are the independent variables (i.e. those that are varied to cause change in the dependent variables) and how are their values selected?	None.
What are the control variables (i.e. those that are held constant) and how are their values selected?	Canister temperature (controlled by constant heat load). Temperatures at the surface of each canister are around 140°C. Uniform water pressure at saturated boundary, although the value of the water pressure is not controlled.
2.2 Experimental techniques	
What experimental techniques and instruments are being used?	Two carbon steel canisters (French design representing vitrified waste) are placed in a deposition hole (8 m). The canisters contain heating elements (1500 Watt). The gap between the deposition hole wall and the bentonite is filled with sand to facilitate control of the hydraulic boundary condition by allowing the bentonite to have full access to water. Water is injected via titanium tubes. The space between the top canister and the bentonite is also filled with sand. The top steel/concrete plug is anchored in the surrounding rock. The canister includes thermocouples for continuous temperature measurement. Instrumentation in the bentonite measures temperature, relative humidity, total pressure, and pore pressure. Cable forces and lid deformations are also measured. Test to obtain information on physical, chemical, and mineralogical properties of the bentonite at the end of the test may also be undertaken.
Are they standard techniques?	Yes.
Are acceleration methods used?	No.
Have the techniques been validated and documented?	A full document list is available, which includes design and testing reports. THM modelling was undertaken as part of the experimental design.
Are the techniques being used under normal conditions?	The experiment is unique in terms of the high temperatures involved (above 100°C). Although the heaters and sensors are expected to operate under such conditions, several failures have occurred (SKB, 2005b).
Has equipment been calibrated and checked?	Yes.

2.3 Uncertainty	
What are the key uncertainties in the experiment?	Concerns over the reliability, heaters, hydraulic controls, and sensors may introduce some uncertainty when interpreting the experiment. For example, SKB (2005b) reported that some temperature measurements showed deviations from expected values.
2.4 Risks to success of experiment	
What are the risks to the success of the experiment and how are they mitigated?	There have been problems with clogging of water injection points. Durability of sensors is a potential problem. When fully saturated the relative humidity sensors are intended to break, although some have stopped functioning earlier. Several transducers used for pressure and displacement measurements have failed (SKB, 2005b). It is possible that water maybe escaping from the system, which leads to uncertainty in the hydraulic conditions. If the heaters were to break the experiment would end. Several interruptions to the heater power supply have occurred (SKB, 2005b).
What are the critical decisions in the experiment?	Setting up the monitoring system. Determining when to dismantle the experiment.
Is there duplication in the experiment?	There is only one TBT experiment. However, many sensors have been used in the experiment, which has ensured continued data collection.
3. Conduct of Experiment	
3.1 Data collection and quality control	
How are data collected?	Measured data are recorded continuously (see Section 2.4.2).
How are data stored (e.g. filing, indexing)?	Data are transmitted to Clay Technology on a monthly basis. Clay Technology processes the data using Microsoft Excel, stores the data on CD-Rom, and submits it to SICADA database (Section 2.4.2). An indexing system is used for identifying instrumentation in the bentonite (SKB, 2005b).
How are data checked (e.g. independently)?	Data are checked using a monitoring system with alarm functions.
How are data backed-up?	Regular backup on separate hard disk.
What quality control procedures are used?	Non-conformance reports are prepared when deviations occur. Quality checks are made on data entered into the SICADA database.
3.2 Records of experiment	
Are notebooks being used for the experiments?	All work on the experiment is recorded/logged.
Are notebooks checked independently?	No.
Are planning, execution and analysis correspondences kept (e.g. emails)?	Yes. Activity plans are used.
Are copies of records kept?	Yes.
3.3 Equipment	

Is equipment tested, inspected, and maintained?	Yes.
4. Analysis and Reporting of Experiment	
4.1 Data interpretation	
What data interpretation methods are being used (models, software packages, model simplifications)?	Thermal conductivities and suction in the bentonite are calculated. Some modelling has been undertaken to try to understand the THM behaviour using Code_Bright and Code Aster. Evaluation modelling will include prediction of THM behaviour in a mock-up laboratory test.
How are uncertainties and sensitivities analysed?	Experiment is ongoing. To be addressed.
4.2 Reporting and review	
How are data and observations reported?	Documents are listed in a Project document chart. There are six sensor data reports with some conclusions and some conference contributions.
How are interpretations reported?	As above on observation reports.
How are limitations on the use of data and results reported?	Such issues have not yet been addressed.
How are reports reviewed (e.g. independently)?	Reviewed and approved by SKB.
How are review results managed/responded to?	It is unclear how the review process is carried out.
5. Usability of Results	
5.1 Verification	
How are experimental outcomes checked against requirements of the experiment?	Experiment is ongoing. To be addressed.
How are experimental results verified?	Experiment is ongoing. To be addressed.
5.2 Use of results	
How are results abstracted for use in the repository programme?	The experiments are being analysed or are ongoing. The possible abstraction of data for use in the repository programme was not discussed.
Are results extrapolated for use on repository length and time scales?	The results apply directly to repository length scales.
What checks are made that data and results are used appropriately and within prescribed limitations?	Experiment is ongoing. To be addressed.

Table A.6 Prototype Repository Experiment (PRE) at the Äspö Hard Rock Laboratory.

1. Framework of Experiment	
1.1 Purpose and objectives	
What is being investigated?	The sequence of actions required to emplace and backfill canisters in deposition holes and the evolution of the deposition holes and backfill over several years (SKB, 2005a), which may be broken down as follows: 1. Drilling of tunnels and deposition holes 2. Manufacturing and installation of buffer and backfill 3. Construction and casting of concrete plugs 4. THM processes in the buffer and backfill including water uptake 5. Hydraulic regime in the rock 6. Hydraulic conductivity of the rock and its time and pressure dependence 7. Rock stresses around the deposition holes and their time and temperature dependence 8. Chemical and bacterial changes in the buffer and backfill 9. Function of the concrete plug
What experiment is being undertaken?	A full-scale experiment in which canisters have been placed in six deposition holes in a tunnel section, four in an inner section and two in an outer section, and surrounded by bentonite buffer. The canisters contain heaters to enable simulation of the heat output from waste. The deposition tunnel is backfilled with bentonite and crushed rock. Concrete plugs separate the inner and outer deposition tunnel sections and the test area from the open tunnel system.
Why is the experiment being undertaken?	To demonstrate and test the functions of the repository components under realistic (but not radioactive) conditions at full scale. Although most of the processes are studied in other experiments at Äspö and elsewhere, the PRE uniquely tests almost all components of the KBS3-concept.
What is the role of the experiment in the repository programme?	The PRE has provided substantial information about the buffer and backfill installation phase. Further, the experiment is intended to demonstrate that the behaviour of the engineered barriers and host rock over the initial timeframe (20 years) is sufficiently understood (performance confirmation). The results will be compared with the assumptions and models used in safety assessments. However, the PRE is not a critical experiment because it does not aim to derive data that are critical to the safety assessment; other experiments are more detailed. The experiment aims to test the quality assurance system planned for use in the real repository.
1.2 Resources and schedule	
Where is the experiment being conducted?	SKB’s Hard Rock Laboratory at Äspö near Oskarshamn. The final part of the TBM tunnel at a depth of 450 m was allocated to the PRE.

Who is conducting the experiment?	Between 2000 and 2004, the project was co-funded by the EU and involved SKB, three Swedish expert groups, Andra (France), GRS and BGR (Germany), Enresa, Aitemin and Cimne (Spain), JNC (Japan), Cardiff University (UK), and Posiva and VTT (Finland). The current participants are: 1. Project manager: Lars-Erik Johannesson (Clay Technology AB) 2. Administration personal: (SKB) 3. Geohydraulic measurements: Ingvar Rhen (SWECO VIAK AB) 4. Chemical measurements: Ignasi Puigdomenech (SKB) 5. Bacterial measurements: Karsten Pedersen (Microbial Analytics Sweden AB) 6. Rock stresses/strains: Martin Ederman (BBK) 7. Water uptake in buffer and backfill: Lars-Erik Johannesson, Reza Goudarzi (Clay Technology AB) 8. Resistivity measurements in buffer and backfill: (GRS) 9. Canister displacements: Ignasi Barcena (AITEMIN) 10. Acoustic measurements in the rock: (ASC) 11. THM modelling of the buffer and backfill: Ola Kristensson (Clay Technology AB) SKB (through its contractor Clay Technology) has the lead responsibility in project planning and decision-making.
What is the schedule for the experiment?	The project commenced in 1988 and the tunnel and deposition holes were excavated between 1992 and 1994. The inner tunnel section was backfilled and sealed in 2001. The outer section was completed in 2003 after a delay because of heater problems. The two outer deposition holes will be excavated after about five years (in 2009), but the inner section experiment may be run for up to 20 years.
When will results be available?	Measurements in the buffer, backfill, and rock are reported continuously. Many results won't, however, be available until after dismantling of the experiment, which will be after the repository site licence application.
What constraints do resources such as cost and timing place on experimental planning and design?	Costs constrained the number of measurement points. The timescale of buffer and backfill saturation constrains when the test should be dismantled. There will be a long time between excavation and any conclusive statements based on evaluation of the data.
1.3 Quality assurance	
What QA system and standards are used in the planning, design, execution, analysis, and reporting of the experiment?	SKB's QA system is used for work performed at Äspö. Contractor's QA systems are used for work performed outside Äspö and these QA systems have been or are being checked. Many of the activities carried out in the project are described in Activity Plans (which incorporate Quality Plans) under SKB's QA system.
How is the expert team selected/trained for the experiment?	Most selected on the basis that they had performed similar work at Äspö before their involvement in the PRE.

2. Design of Experiment	
2.1 Variables	
What are the dependent variables (i.e. those being observed)?	Buffer and backfill: temperature, pressure, water pressure, water content, chemical changes, gas composition, and bacterial growth and migration. Rock: temperature, water pressure, stresses, strains, chemical changes, and hydraulic conductivity changes. Canister: temperature, displacement.
What are the independent variables (i.e. those that are varied to cause change in the dependent variables) and how are their values selected?	Canister temperature based on typical heat output of waste. An initial heater power of 1,800 W was applied in each canister. The power has been decreased progressively to simulate the effects of radioactive decay. There is some control over the buffer and backfill saturation process by the controls on the tunnel drainage system.
What are the control variables (i.e. those that are held constant) and how are their values selected?	The dimensions of the deposition holes and tunnel, and the type of buffer and backfill and their initial density and water ratio are realistic. The stress, water content, water pressure, water chemistry, and temperature conditions in the rock represent possible conditions during repository operations.
2.2 Experimental techniques	
What experimental techniques and instruments are being used?	The use of plastic sheets to prevent unwanted water inflow during buffer installation is being developed. The concrete plug at the end of the deposition tunnel is intended to withstand water and swelling pressure. Tunnel drainage is controlled, which affects the saturation process. Electric heaters provide the thermal load in canisters. More than 1,000 transducers measure temperature, pressure, stress, strains, and canister displacements. Relative humidity sensors monitor water saturation. Resistivity measurements provide water ratios. Water pressure is measured in packed-off sections of boreholes near the tunnel. The boreholes are also used for hydraulic conductivity measurements. Equipment has been installed for taking gas and water samples from the buffer and backfill.
Are they standard techniques?	Most of the sensors are standard. However, in many cases the equipment had to be modified to withstand high pressures and temperatures.
Are acceleration methods used?	No.
Have the techniques been validated and documented?	The techniques for manufacturing and installing the buffer have been tested in the Canister Retrieval Test, TBT, and LASGIT projects at Äspö. The techniques for manufacturing and installing the backfill have been tested in the Backfill and Plug Test at Äspö.
Are the techniques being used under normal conditions?	No.

Has equipment been calibrated and checked?	Most of the equipment has been calibrated in the laboratory. Some sensors have only been calibrated by the supplier. Some sensors are calibrated annually (water pressure in rock).
2.3 Uncertainty	
What are the key uncertainties in the experiment?	Whether the sensors are measuring the right parameters. How the different parts of the KBS3 concept will interact.
2.4 Risks to success of experiment	
What are the risks to the success of the experiment and how are they mitigated?	Failure of the regulation system or heaters: Only 6 heaters are required to apply full power to the canisters. In each canister 36 heaters were installed and they were connected to the regulation system with 3 separate cables. Closure of the tunnel drainage system in late 2004 resulted in rapid increases in pore pressure and stress in the backfill (SKB, 2005a). Subsequently, in early 2005, the heater in one of the canisters failed because of cable failure. The drainage system was then re-opened resulting in an immediate drop in pore pressure and stress in the backfill. The drainage system has remained open with power supplied to the heaters in the remaining five canisters since that time. This implies that the backfill and buffer saturation rates in the experiment may be lower than in a real repository where there is no drainage. More recently, a heater in another canister has been experiencing problems (SKB, 2005c). Failure of instrumentation: Several transducers and one canister movement sensor have failed. However, sufficient devices have been installed to ensure continued data collection to date. Also, different types of sensors measuring the same parameter are used. Unplanned buffer and backfill evolution: The buffer and backfill may not saturate and evolve as expected because of the need to continue drainage. The value of data from dry deposition holes is unclear. Drainage means that oxygen consumption analysis (e.g. by bacteria) is of little value. A borehole packer failed recently leading to additional flow into the backfill. Where flows are high, piping and erosion of the buffer may have occurred. Temperature evolution in the deposition holes depends on the degree of saturation. The range of saturation over different boreholes provides the range of expected behaviour. Around a dry deposition hole the rock is a key barrier, whereas the buffer is the key barrier in a saturated deposition hole. Dismantling: It will be important to perform excavations quickly to avoid cooling of the materials prior to analysis.
What are the critical decisions in the experiment?	When to stop the experiment and dismantle the two sections. The dismantling of the outer section will provide information to support the decision on when to dismantle the inner section. Whether to stop tunnel drainage and to allow the buffer and backfill to saturate such that more realistic conditions are reflected before dismantling. Whether a similar experiment will be needed subsequently based on the PRE experience and findings.
Is there duplication in the experiment?	There are six deposition holes, four with sensors installed. SKB has aimed to use two different measuring systems for each parameter in the buffer and backfill. Data collection has been continuous despite a number of instrument failures.
3. Conduct of Experiment	

3.1 Data collection and quality control	
How are data collected?	Hourly data collection (Orchestrator data acquisition software).
How are data stored (e.g. filing, indexing)?	Data are collected using the Orchestrator software and stored on two project computers on site, with monthly transmission to Clay Technology. Clay Technology processes the data using Microsoft Excel, stores the data on CD-Rom, and submits it to the SICADA database (on a monthly basis). An indexing system is used for identifying the sensors.
How are data checked (e.g. independently)?	The monitoring system is used for checking the sensors. An alarm system is connected to the power regulation system for the heaters.
How are data backed-up?	A backup of the stored data is made every day. The backup is made on a separate hard disk.
What quality control procedures are used?	A quality check on the stored data is made before they are entered into the SICADA database.
3.2 Records of experiment	
Are notebooks being used for the experiments?	Daily logs, non-conformance reports, and activity lists are used.
Are notebooks checked independently?	Yes.
Are planning, execution and analysis correspondences kept (e.g. emails)?	Activity plans are used. Important correspondence is kept and stored by Clay Technology or at Äspö.
Are copies of records kept?	Yes.
3.3 Equipment	
Is equipment tested, inspected, and maintained?	Generally, it is not possible to maintain equipment used in the experiment.

4. Analysis and Reporting of Experiment	
4.1 Data interpretation	
What data interpretation methods are being used (models, software packages, model simplifications)?	The PRE involves the following tests and their interpretation: - Acoustic emission and ultrasonic measurements. - Tracer tests. - Interference tests. - Pump tests. - Resistivity measurements. FEM-analysis for simulating the water uptake in the buffer and backfill, the swelling of buffer and backfill and the temperature in buffer and backfill are being undertaken. The experiment has allowed the significance of the gaps between components in the deposition holes on heat transfer to be evaluated. Also, saturated bentonite densities have been evaluated. Code Bright and Thames are being used for THM analysis. Compass, Rockflow and ABAQUS have also been used. A new three-phase model of resaturation is being developed for interpretation of the resistivity measurements (SKB, 2005a). Governing equations of various chemical phenomena are being developed. Geochemical modelling of pore waters and changes in solid phases is being undertaken.
How are uncertainties and sensitivities analysed?	In the THM concepts and modelling.
4.2 Reporting and review	
How are data and observations reported?	The data from the measurements in the buffer, backfill, and rock are reported in Data Reports (two per year). When the work described in an Activity Plan is finished it is reported in an International Progress Report (IPR).
How are interpretations reported?	In IPRs.
How are limitations on the use of data and results reported?	Those using the data must understand the PRE and make their own judgments.
How are reports reviewed (e.g. independently)?	The IPRs are checked by the project manager or another person in the project organisation. The IPRs are approved by SKB.
How are review results managed/responded to?	Any comments made are responded to. Comment forms may be introduced.
5. Usability of Results	
5.1 Verification	
How are experimental outcomes checked against requirements of the experiment?	There is a process for such checks in the QA system.

How are experimental results verified?	Independent measurements are compared (e.g. temperature, pressure, water pressure). Many of the experiments are repeated. The final verification of the status of the buffer and backfill (water ratio, density, etc) will be made when the test is dismantled. If possible the sensors will be calibrated after the dismantling (sensor drift and accuracy is a potential problem).
5.2 Use of results	
How are results abstracted for use in the repository programme?	The PRE is full scale and has provided experience on drilling, construction, and deposition processes. For example, the use of plastic sheets to facilitate buffer installation will support decisions on whether and how to use the method in a real repository. The PRE has also provided information that will help decision-making on the timing of tunnel backfilling after buffer emplacement.
Are results extrapolated for use on repository length and time scales?	The experiment is full scale, with the appropriate power applied to the canisters. Results can be used directly in the repository programme, at least for the saturation phase. Geochemical conditions at Äspö are similar to those at the potential repository sites at Forsmark and Laxemar, but rock thermal conductivity is significantly different at Forsmark. Some validation of THM models will be possible.
What checks are made that data and results are used appropriately and within prescribed limitations?	Interactions between modellers and experimentalists provide such checks.

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