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Review of SKB's Quality Assurance Programme

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SSM 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. 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. SSM has initiated a series of reviews of SKB's methods of quality assurance and their implementation.

This project includes reviews of the quality assurance (QA) procedures and instructions that have been prepared for the SR-Site assessment as well as reviews of QA implementation at the canister and buffer/backfill laboratories in Oskarshamn, Sweden.

Purpose of the Project

The purpose of this project is to assess SKB's quality assurance with the view of providing a good basis for subsequent quality reviews in the context of future licensing. 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.

Results

Overall, the reviewed set of QA documents and instructions do provide reasonably comprehensive coverage of quality-affecting issues relating to the SR-Site safety assessment and, if implemented correctly, will generate confidence in the reliability of the safety assessment 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.

However, progress in development of the QA documents and instructions has been relatively recent and it may be difficult for these to be fully implemented in the short period remaining before the planned licence application submission. A general concern is that it was often difficult to trace parameter values and other information presented in main safety assessment reports to supporting experiments and analyses. Frequently, information has to be traced back through several documents to locate underpinning experimental data. Also, in some cases the supporting data are old and it is unclear if these data have been qualified for use in the safety assessment.

Future work

Quality aspects will be further analysed as part of SSM´s review of the SR-Site safety assessment.

Project Information

Project manager: Bo Strömberg
Project reference: SSM 2008/351
Project number: 200810224

Content

Executive summery

SKB produced the SR-Can safety assessment for a spent nuclear fuel repository in preparation for the development of the SR-Site assessment that will be part of SKB's application for a final repository. SR-Can provided an opportunity for the Swedish Radiation Safety Authority SSM (then SKI and SSI) to review and comment on SKB's safety assessment approach prior to compilation of the SR-Site safety assessment.

The SR-Can assessment involved quantitative analyses aimed at presenting an understanding of how the repository system will evolve and an evaluation of the potential risks of spent fuel disposal. Such a safety assessment must be underpinned by assurances that the development and application of models and work to estimate parameter values and uncertainties have been undertaken under appropriate quality management systems.

SKB is now in the process of preparing the SR-Site safety assessment and SSM plans to continue to review and provide feedback to SKB on the development of the safety assessment. This report brings together recent work performed by Galson Sciences Ltd on behalf of SSM to review the quality assurance (QA) procedures and instructions that have been prepared for the SR-Site assessment and to perform a quality audit of key experimental data used in the safety assessment.

The first part of this quality audit was to review the Spent Fuel Project QA plan and the associated QA-related documents. The following QA documents were reviewed:

- SDK-001 Quality Plan for the Spent Fuel Project.
- SDK-003 Quality Assurance Plan for the Safety Assessment SR-Site.
- Instruction for Development and Handling of the SKB FEP Database - Version SR-Site.
- Instruction for Developing Process Descriptions in SR-Site and SR-Can.
- Instruction for Model and Data Quality Assurance for the SR-Site Project.
- SR-Site Model Summary Report Instruction.
- Supplying Data for the SR-Site Data Report.
- Qualification of "Old" References.

The aim of the review was to consider whether these documents are sufficiently comprehensive that their application would ensure that the expected requirements of a QA programme would be met.

Several of the QA documents reviewed are preliminary versions and a number of instructions and procedures that are referred to in these documents had not been produced at the time of this review. These documents should be finalised to ensure full implementation of the QA system in the SR-Site Project.

The traceability and reliability of data and analyses that support the safety assessment are key issues that have been of concern throughout this and previous QA reviews of safety assessment documentation. SKB's approach of assigning an individual to track and check the use of data from the Data

Report and its supporting documents through to SR-Site modelling is a positive development that will mitigate concerns over the reliability of supporting information and will generate greater confidence in the results of the SR-Site safety assessment. However, a similar approach is needed to track safety arguments and assumptions, not just data usage, throughout the suite of safety assessment documents to ensure that there are no deviating views or contradictions. Procedures are required that aim to ensure that such discrepancies are identified and resolved.

Implementation of the instruction on qualification of old and external references cited in support of the safety assessment is also welcome and should further improve traceability and transparency of data abstractions and decisions about parameter value selection in the safety assessment. However, the methods to be used to qualify old data or analyses that do not meet SKB's current QA requirements should be explained.

Overall, the reviewed set of QA documents and instructions do provide reasonably comprehensive coverage of quality-affecting issues relating to the SR-Site safety assessment and, if implemented correctly, will generate confidence in the reliability of the safety assessment results. Further, the appointment of an assistant project leader with responsibility for QA issues in the SR-Site project provides some confidence that QA requirements will be met. However, progress in development of the QA documents and instructions has been relatively recent and it may be difficult for these to be fully implemented in the short period remaining before the planned licence application submission. Also, there will limited opportunity for any comprehensive QA audits of the SR-Site project in this period.

In the second part of the quality audit, a detailed study was undertaken of the reliability and traceability of parameter abstraction and evaluation for KBS-3 safety assessments. This detailed study followed on from previous QA reviews and initially focused on reports of early experiments carried out and analysed to derive the models of material behaviour that are currently assumed in safety assessments. The review considered the traceability and reliability of data on the following topics:

- Buffer and backfill thermal conductivity.
- Buffer and backfill hydraulic conductivity.
- Buffer swelling pressure.
- Buffer and backfill density and porosity.
- Canister emissivity.
- Canister defect distribution.

A general concern is that it was often difficult to trace parameter values and other information presented in the SR-Can reports to supporting experiments and analyses. Frequently, information has to be traced back through several documents to locate underpinning experimental data. Also, in some cases the supporting data are old and it is unclear if these data have been qualified for use in the safety assessment.

Summary findings from the review are as follows:

- The validity of the interpolation of bentonite thermal conductivity values over the full range of saturations is unclear.

- Measurements of buffer thermal conductivity do not appear to have been made on the full range of bentonites that could be used as a buffer material; it is not clear if values obtained for MX-80 bentonite are directly applicable to other types of bentonite.
- The buffer hydraulic conductivity data appear to derive from experiments in the mid-1990s, but it has not been possible to identify the original source experiments or the process by which the model parameters have been abstracted from experimental results.
- To improve transparency and understanding, an up-to-date statement of the buffer model should be presented with references to the experimental data and analyses that support the model.

Additionally, QA reviews were carried out at SKB's Bentonite Laboratory, at Äspö, and the Canister Laboratory at Oskarshamn. The repository backfill erosion experiment at the Bentonite Laboratory and the friction stir welding (FSW) and non-destructive testing experiments undertaken at the Canister Laboratory were reviewed.

It was evident that each experiment and test had been conducted under an appropriate QA system. For example, in each case, appropriate QA procedures for conducting the experiment or test were in place and the work was undertaken by suitably qualified staff or contractors. Appropriate data management procedures had been used, including data backups and logs, and reporting included suitable document checking and reviewing processes.

It is also clear that SKB has attained a good understanding of the FSW process and NDT techniques for checking welds: SKB considers reliable welds are reproducible and repeatable. Procedures need to be developed for using these techniques under production conditions.

The experimental programme on tunnel backfilling is less mature and SKB indicated that further experiments were being planned to investigate the phenomenon of flow channelling through bentonite pellets.

1. Introduction

SKB produced the SR-Can safety assessment for a spent nuclear fuel repository in preparation for the development of the SR-Site safety assessment that will be part of SKB's application for a final repository. The production of SR-Can provided an opportunity for SKI and SSI (which have since merged to form the Swedish Radiation Safety Authority SSM) to review and comment on SKB's safety assessment approach prior to compilation of the SR-Site safety assessment.

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 presenting an understanding of how the repository system will evolve and an evaluation of the potential risks of spent fuel disposal. Such a safety assessment must be underpinned by assurances that the development and application of models and work to estimate parameter values and uncertainties have been undertaken under appropriate quality management systems.

SKI previously commissioned Galson Sciences Ltd (GSL) to undertake a series of review tasks in order to understand SKB's approach to quality assurance (QA) and the application of QA procedures in SKB's work. Initially, a review of the documentation and testing of a selection of the computer codes used by SKB in its repository research programme was undertaken (Hicks, 2005). Subsequently studies were undertaken to compare SKB's approach to QA with QA programmes used in similar radioactive waste management projects, and to perform a quality review of a selection of experiments on engineered barrier performance undertaken as part of SKB's repository research programme (Hicks, 2007). Most recently, a study was undertaken to build on the findings of the previous studies and review how data and code quality assurance were addressed and reported in the SR-Can safety assessment (Hicks and Baldwin, 2008).

SKB is now in the process of preparing the SR-Site safety assessment, and SSM plans to continue to review and provide feedback to SKB on the development of the safety assessment. This report brings together recent work performed by GSL on behalf of SSM to review the QA procedures and instructions that have been prepared for the SR-Site safety assessment and to perform further quality audits of key tests and experiments that are likely to provide data that support the safety assessment.

1.1 Approach

The project involved review of the QA procedures developed by SKB for preparation of the SR-Site safety assessment and quality audits of specific tests and experiments.

The first task was to review the Spent Fuel Project QA plan and the QA documentation being developed for the SR-Site safety assessment - the SR-Site Project is a sub-project of the Spent Fuel Project. The aim of the review was to consider whether these documents are sufficiently comprehensive that their application would ensure that appropriate levels of quality are achieved throughout the SR-Site safety assessment.

The second part of the project, the data quality audit, involved a detailed study of the reliability and traceability of parameter abstraction for KBS-3

safety assessments, especially in support of safety function indicators. This study, which was an extension of the SR-Can data QA audit (Hicks and Baldwin, 2008), initially focused on the parameter descriptions provided in the SR-Can safety assessment documentation: the SR-Can Data Report (SKB, 2006a), the Buffer and Backfill Process Report (SKB, 2006b), the Initial State Report (SKB, 2006c), the SR-Can Main Report (SKB, 2006d), and the Fuel and Canister Process Report (SKB, 2006e). The review then aimed to check that the derivation of material models could be traced through to appropriate underpinning experiments and analyses.
The data quality audit also included QA reviews of a selection of recent experiments on tunnel backfill materials at SKB's Bentonite Laboratory at Äspö, and of canister welding and testing at SKB's Canister Laboratory at Oskarshamn. The checklist of quality-affecting issues used in the previous audit of experiments (Hicks, 2007) was used to facilitate the present audits.

1.2 Report Structure

Section 2 discusses the findings from the review of SR-Site QA documents. Section 3 discusses the quality audit of key safety assessment parameters. Section 4 presents the review of quality-related aspects of experiments undertaken at the Bentonite and Canister Laboratories as part of SKB's repository research programme. A discussion and conclusions are presented in Section 5. Appendix A comprises the completed QA checklists for each experiment reviewed.

2. SR-Site Quality Assurance Documents

SKB has applied a management system that fulfils the requirements of ISO 9001:2000 (SKB, 2006d, Section 2.8) and the ISO 14001 requirements for an environmental management system (SKB, personal communication, 21 April 2008). SKB's fulfilment of these requirements has been certified by DNV Certification AB, Sweden.

Within this management system, SKB has applied a quality plan for the entire Spent Fuel Project (SKB document SDK-001) and, below this, has defined a QA plan for the SR-Site project (SKB document SDK-003). SKB presented a draft QA plan for the SR-Site safety assessment at a QA meeting held at SKB's offices in Stockholm (21 April 2008), attended by SKB, SKI and SSI staff and consultants. The draft QA plan referred to a series of steering and QA-related documents for the SR-Site safety assessment that were at various stages of development.

The first task in this QA audit was to review the Spent Fuel Project QA plan and the steering and QA-related documents as they became available. During the course of the project, the following QA documents were reviewed:

- SDK-001 Quality Plan for the Spent Fuel Project.
- SDK-003 Quality Assurance Plan for the Safety Assessment SR-Site.
- Instruction for Development and Handling of the SKB FEP Database - Version SR-Site.
- Instruction for Developing Process Descriptions in SR-Site and SR-Can.
- Instruction for Model and Data Quality Assurance for the SR-Site Project.
- SR-Site Model Summary Report Instruction.
- Supplying Data for the SR-Site Data Report.
- Qualification of "Old" References.

The aim of the review was to consider whether these documents are sufficiently comprehensive that their application would ensure that the expected requirements of a QA programme would be met. For example, consideration was given to whether appropriate application of these documents would ensure that transparency and traceability of information would be sufficient to enable judgments to be made regarding the reliability and validity of the safety assessment.

In conducting this review, consideration has been given to Sandia National Laboratories' Quality Assurance Program Description (QAPD) for the Yucca Mountain Project (QA-PRG-001, Revision 1, 10 January 2007) and its implementing procedures, which have provided useful background information for making judgments on the scope of the QA documentation for the SR-Site Safety Assessment.

Initial comments on the SKB QA documents were given to SKB. SKB supplied responses prior to an SR-Site QA meeting held at SKB's offices in Stockholm (28 November 2008), which was attended by SKB and SSM staff and consultants. In addition, SKB provided a revised draft of the QA document "Supplying Data for the SR-Site Data Report", dated 20 October 2008, and a preliminary draft of the document "Qualification of 'Old' References". Comments on the QA documents and SKB's responses were discussed at the meeting and are summarised in the following sub-sections.

2.1 SDK-001 Quality Plan for the Spent Fuel Project

The version of the quality plan reviewed here (Version 1.0, approved on 30 June 2008, document ID 1174832) is an uncontrolled English translation of the original Swedish document.

The quality plan indicates that participants in the Spent Fuel Project receive information about the plan from project leaders (*Section 1.4*[1]), but it is unclear if any training is provided on how to apply the procedures in project work. SKB explained that all new participants in the Spent Fuel Project receive individual instruction in the quality management system, focusing on issues relevant for the task assigned to the person within the project. The instruction of new staff in QA procedures is recorded in the minutes of monthly QA co-ordinator meetings.

The Spent Fuel Project is divided into sub-projects and operations within sub-projects may be conducted as activities according to activity plans (*Section 2.1.1*). One such sub-project is 'Site-Project Oskarshamn' and the review queried whether investigations carried out at the Äspö Hard Rock Laboratory (HRL), the Bentonite Laboratory, and the Canister Laboratory are included in this sub-project, or whether they are separate sub-projects within the Spent Fuel Project. Further, the quality plan does not specify if the requirements on the realisation and analysis of raw data (*Section 2.1.2*), or controls on measuring devices (*Section 3.5*), apply to investigations at the HRL, the Bentonite Laboratory, the Canister Laboratory and other laboratories involved in experiments in support of the repository development programme.

SKB stated that the HRL, the Bentonite Laboratory and the Canister Laboratory are not part of the Spent Fuel Project but that they do follow the SKB quality management system and there are specific procedures for their activities. SKB's data handling procedure requires that, before a data set is given QA clearance for use in the SR-Site safety assessment, checks are made on the data controls carried out by a contractor when data are delivered and a further check is made when data are entered into the SICADA database. Depending on the nature of the data, tools linked to the database can be used to review the data.

The discussion of document review procedures (*Section 4.4*) indicates the types of review required for safety analysis reports. However, it is not clear if there are specific review procedures and criteria for SKB's TR-, R-, P- and IPR-series reports in addition to those for safety analysis reports. In particular, it is not clear if there are review requirements for reports that support, but are not part of, a licence application. For example, the review requirements for reports that document the application of models for detailed assessments of particular processes or which may involve the abstraction of parameter values for the safety assessment are not discussed. In addition,

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[1] References to sections within the SKB QA documents under review are presented in italics.

the QA plan does not mention if there is a process for addressing review comments.

In response, SKB stated that reviews and/or referrals are made on all SKB reports. SKB explained that reports that are included in the licence application, and supporting references within those documents, are reviewed according to special procedures in the quality management system. The review process includes a factual review, a quality review and an integrated review with other documents. For documents included in the preliminary safety report, a primary safety review and an independent safety review are made according to regulations (SKIFS 2004:1) concerning safety in nuclear facilities.

The QA plan includes a discussion of nonconformities (*Section 9*). Documents that describe how nonconformities are to be managed and resolved are noted but there is no discussion of how nonconformities are identified within SKB. Also, it is not clear if audits are undertaken to identify nonconformities.

SKB noted that data errors discovered, for example, during modelling work, are reported and addressed. Also, nonconformities can be identified and reported by all SKB staff and nonconformities relating to contractors' work are reported to SKB if they are relevant to the task. Internal audits and third-party audits are made according to the SKB audit plan, which is approved annually by the president of SKB.

2.2 SDK-003 Quality Assurance Plan for the Safety Assessment SR-Site

Version 2.0 of the QA Plan, approved on 03 July 2008 (document ID 1064228), was reviewed.

Steering and QA-related documents for SR-Site are listed in *Section 2.3*, and include reports of project QA audits. However, it is not clear how often project QA audits are carried out and there is no discussion of previous audits (e.g., the number of audits carried out to date and identification of, and response to, any significant non-conformities).

In response, SKB stated that QA audits are not carried out on a regular basis. SKB also explained that to date there have been two QA audits of the SR-Site Project. In the first, SR-Site was reviewed as one of several sub-projects to the Spent Fuel Project and there were few audit findings. The second audit was an internal QA review of the SR-Site Project carried out from 30 September to 1 October 2008. According to SKB, this second audit identified four nonconformities that were addressed as described below:

1. *Nonconformity:* Steering documents in the SR-Site QA plan have been issued late in the project or are in a preliminary form and, therefore, have not been fully implemented.

   Resolution: An assistant project leader with responsibility for QA issues has been appointed. The list of steering documents has been reviewed and a plan for the finalisation of all documents has been established.

2. *Nonconformity:* The definition of "Task Descriptions" to suppliers is not sufficiently detailed regarding input data and requirements on delivery.

Resolution: The definitions and requirements on the task descriptions have been made more specific and a template for the formulation of task descriptions has been established.

3. *Nonconformity:* The time plan is not sufficiently up-to-date and detailed to fully impact the project. Resources for handling and updating the time plan are lacking.

   Resolution: The newly appointed assistant project leader is responsible for managing the time plan. The time plan has been revised and activities have been further broken down, updated and linked as appropriate.

4. *Nonconformity:* There is no plan to explain the storage of documents and data within the various systems available to SKB. This limits the traceability and QA of project data and information.

   Resolution: A section on document handling has been added to the QA plan that describes the handling of data, reports and other project documents.

The assistant project leader for the SR-Site project is Kristina Skagius, who has responsibility for all QA issues in the SR-Site project. The SR-Site project is a sub-project of the Spent Fuel Project; Ingrid Aggeryd is assistant project manager for the Spent Fuel Project and is responsible for more general QA issues covering that project.

The discussion on peer review (*Section 2.6.2*) states that several reports will be subject to peer review in SR-Site but the criteria for deciding whether or not a report should be subject to such a review is not explained. However, as discussed in Section 0, SKB has stated that all reports included in the licence application, and supporting references to those documents, will be reviewed according to special procedures.

2.3 Instruction for Development and Handling of the SKB FEP Database – Version SR-Site

Version 1.0 of this instruction, approved on 19 March 2008 (document ID 1082126), was reviewed.

The development of the SKB FEP database for SR-Site focuses on the NEA FEP database. The review questioned why FEP databases that are not included in the NEA database, such as the database developed in support of the recent Yucca Mountain repository licence application, have not been considered.

SKB responded that it was felt necessary to freeze the input to the FEP work and considered that more recent FEP databases do not provide significant new input. SKB believes that this is also the case for the database developed in support of the Yucca Mountain repository licence application, because the conditions for this repository differ from those relevant to a Swedish repository (although SKB did note that earlier versions of the Yucca Mountain FEP database are included in the NEA FEP database).

2.4 Instruction for Developing Process Descriptions in SR-Site and SR-Can

Version 1.0 of this instruction, approved on 03 July 2008 (document ID 1082127), was reviewed.

The instruction states that FEPs and matrix interactions can be screened out if they are ‘of small importance for the evolution of the system’, and that a ‘motivation for such a judgment must be given’ (*Section 4.3*). Other sections of this instruction outline the handling of documentation for each FEP. However, the procedures and criteria to determine whether a FEP (or matrix interaction) can be screened out of the safety assessment calculations are not specified. For example, it is not clear if there are requirements for clear and traceable documented quantitative or qualitative arguments for concluding that a particular FEP or interaction is of little consequence to the dose calculations, or is unlikely to occur. Also, it is not clear if guidance is provided to the experts on what is considered to be of low consequence to the dose calculations or low probability of occurrence.

In response, SKB noted that the FEP handling procedure is described in *Sections 3.5 and 5.1* of the instruction and that there are requirements on documentation of the arguments in the FEP database. According to SKB, a judgment is made regarding whether the FEP or matrix interaction is important for the process in question. If so, it should be addressed in, or covered by, the process description where arguments for further handling of the process are given. No guidance is given to the experts on what is considered to be low consequence to the dose calculations, because SKB believes that judgments are primarily concerned with importance for the process and importance for the evolution of the system, but not the consequence to dose calculations.

The discussion of the structure and content of process descriptions (*Section 4.4*) does not mention if there is any requirement to ensure that the handling of processes and uncertainties in the safety assessment is consistent with the discussion and parameter values presented in the Data Report. If not, it may be possible that different experiments and parameter abstractions are used in the Process and Data Reports to derive different distributions for the same parameter.

SKB indicated that the role of the process description is to describe the process and how the process will be handled (supported by appropriate arguments), and to describe the types of uncertainties associated with the suggested handling of the process. However, no parameter extractions or quantifications of data or uncertainties should be made in the process descriptions; the Data Report will quantify data and uncertainties whilst the Model Summary Report will provide the parameters for which quantitative data are required.

2.5 Instruction for Model and Data Quality Assurance for the SR-Site Project

Version 0.11 of this instruction, a preliminary draft produced on 29 August 2007 (document ID 1082128), was reviewed.

The discussion of analysis documentation (*Section 10*) clearly defines the key information that should be recorded in the calculation reports, but it is not specified if there are requirements for review and checking of the analysis documents.

In response, SKB noted that the analysis documentation is used to record the results of computational tasks and that a template for the analysis documentation is provided in the QA document “Plan for Model and Data Quality Assurance for the SR-Site Project” (not reviewed during this project). However, SKB also noted that it is not compulsory to produce a separate analysis document because this information should normally be included in the report in which the calculations are described. As such, the documentation will be reviewed in connection with the review of the report.

2.6 SR-Site Model Summary Report Instruction

Version 0.4a of this instruction, a preliminary draft produced on 29 August 2007 (document ID 1082130), was reviewed.

The discussion on the assessment model flow charts (*Section 2.1*) states that minor calculation tasks performed in the assessment, such as post-processing of results, are not regarded as critical for the quality of the assessment and so are not included in the Model Summary Report. However, no mention is made of any requirements for checking these minor calculations or any checks that are carried out as part of the document checking and review process.

SKB responded that minor calculations are excluded from the Model Summary Report for practical reasons. The Model Summary Report defines such calculations as “…could be verified by simple hand calculations…” and the extent to which they are checked in the review process is controlled by the review criteria for the document in question.

2.7 Supplying Data for the SR-Site Data Report

Two versions of this QA document were reviewed. Initial comments were made on a preliminary version (Version 0.8, produced on 18 October 2007, document ID 1082129). Subsequent review comments were made on an approved version (Version 2.0, dated 20 October 2008).

The flow of information (*Section 1.4.3, preliminary draft*) for the Data Report allows comments to be made by the Data Report Team on the various supplier and customer deliveries. Issues raised in such commenting may have an impact on the material presented in the reports that supply the data. It is not clear if there are procedures for revising these reports and for ensuring that parameter values and distributions are used consistently throughout the safety assessment.

In response, SKB acknowledged that a procedure to update the reports used to supply the data report with data is not defined and several of the reports to be used in the data report will already be published. However, for some key reports, SR-Site will provide formal review comments after assessment by the Data Report Team, in order to allow for such updates. If the delivered data are in contrast with already published data, the differences should be carefully described and justified in the Data Report. Where the differences in the data are due to different interpretations, SKB believes it may suffice to describe them in the Data Report, whilst simple errors found in already published reports (e.g., kilograms reported as grams) are to be treated by presenting an errata to the already published report. There are procedures in the SR-Site review process to handle differences between data values presented in unpublished reports and values presented in the unpublished Data Report, to ensure that the final data do not conflict.

In addition, SKB stated that an individual is assigned to "follow the data" from the Data Report, including its supporting documents, through to SR-Site modelling. Before delivery of the final version of the Data Report, this person, together with the Data Report Team, and if necessary the customer representative and supplier representative, will double-check that the data in the supporting documents have not been modified.

Section 2.4.1 (preliminary version) of the QA document discusses qualification of previously existing data. A 'value' is ascribed to previously existing data that reflects the reliability of the data. However, it is unclear how the 'value' of data is defined. It is not clear if value judgements are qualitative, or if there are procedures for assigning a value to data acceptability and for taking account of such values or weights in the safety assessment calculations. Also, it is not clear if there is a value at which data are considered unacceptable.

SKB pointed out that the term 'supporting data' is used in the later version of the QA document instead of the term 'previously existing data'. This is because the term 'previously existing data' is more appropriate when a data qualification framework is implemented prior to collecting all of the necessary data, which makes it simple to set a date that defines which data, obtained prior to this date, should be considered as previously existing. As such a framework was not implemented early in the SKB programme, it proved difficult to set a cut-off date and SKB therefore settled on using the term 'supporting data', although this does mean that the sorting of data as either 'qualified data' or 'supporting data' is more subjective. However, SKB stated that there are guidelines for how to handle data that *a priori* are considered as either qualified or supporting. These guidelines are set out in *Section 2.4.1* of the revised draft of the document.

Review of the revised QA document found the text has been extensively revised and clarified, with increased use of diagrams and examples to explain points. However, a few queries have been identified.

In Section 2, a statement is made that the "Data Report does not concern all data used in the SR-Site safety assessment, but [only] those which are identified to be of particular significance for assessing repository safety". However, there is no discussion of the criteria that are used to determine which data are to be included in the Data Report or who will make the decision on which data to include (i.e. the Data Report Team, the data supplier, or both).

Regarding experience from SR-Can, SKB notes that for SR-Site it is sufficient to state the conditions for which data were used in SR-Can modelling without justification as to why those conditions were studied (*Section 2.2.1*). However, understanding the conditions for which data are used is integral to the quality assurance of the data and, if not explained in the Data Report, detailed references should be supplied to the location of such a discussion. The revised discussion in *Section 2.4.1* states that data taken from 'widespread textbooks, which are considered to be established facts, need not to be scrutinised'. While such data may be widespread in use, appropriate references should be supplied.

Finally, in the revised QA document it is indicated that, when giving instructions to the supplier representative (who supplies qualified data to the Data Report), issues concerning natural variability of data or bias issues associated with data interpretation should be discussed at the discretion of the supplier representative (*Sections 2.7 and 2.8*). Such a decision should properly be discussed with the customer representative (the SR-Site team responsible for performing the safety assessment) and/or the Data Report Team (a subgroup to the SR-Site team) in order to determine the significance of the data set variability/bias.

2.8 Qualification of "Old" References

Version 0.1, a preliminary draft produced on 19 November 2008 (document ID 1186579) was reviewed. This document was reviewed at a later date than the preceding documents and, in the time available, it was not possible for SKB to provide a response to these comments.

The instruction on qualification of old or external documents for use in SR-Site is necessary to ensure that the work performed prior to the introduction of the data quality assurance system, or by organisations external to SKB, is demonstrably fit-for-purpose. The instruction recognises that "old documents or parts of old documents can be made quality approved by conducting a documented factual review of the document or parts of the document that are referenced" (*Section 1*), but it is subsequently stated that this is judged "not possible…considering the substantial amount of time and resources it would require". The proposed alternative procedure, which involves qualification of references in the report where the references are used and review of that qualification by the experts selected for factual review of the report in question, appears sufficient. However, the difference in the resources required for each approach is unclear and there is potential for the proposed approach to lead to the qualification process being applied to a supporting reference more than once if the reference is cited in different SR-Site reports.

The procedure for qualification of supporting references to the SR-Site process reports and the Climate Report is given. It is not clear if the same procedure will be applied to other SR-Site reports, such as the Data Report.
The instruction discusses the types of argument that can be made to demonstrate that a supporting reference is adequate from a QA perspective (*Section 3.2*). However, the instruction does not indicate what actions will be taken if the quality of the information presented in the supporting report is found to be inadequate. For example, it is unclear how information in a supporting document will be treated if it is found that the supporting document has not been subjected to a factual and quality review. It is stated that "any results or arguments adopted from supporting references, at least from those that lack a documented factual and quality review, must be written out; it is not enough to just refer to a result/argument in such a supporting reference" (*Section 3.1*). However, this approach may not fully demonstrate the reliability of the information: experimental or modelling results may require more demonstrably thorough checking to confirm their quality.

3. Data Quality Assurance

Based on the findings of the SR-Can QA review (Hicks and Baldwin, 2008), a more detailed study was undertaken of the reliability and traceability of parameter abstraction and evaluation for KBS-3 safety assessments, especially in support of safety function indicators. This detailed study initially focused on reports of early experiments carried out and analysed to derive the models of material behaviour that are currently assumed in safety assessments. The qualification of data arising from such experiments was examined.

The following sub-sections examine the traceability and reliability of data on canister, buffer and backfill properties. Issues are identified and discussed concerning:

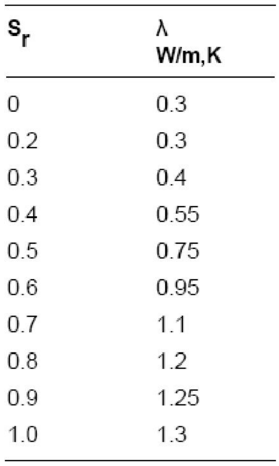
- Buffer and backfill thermal conductivity.
- Buffer and backfill hydraulic conductivity.
- Buffer swelling pressure.
- Buffer and backfill density and porosity.
- Canister emissivity.
- Canister defect distribution.

3.1 Buffer and Backfill Thermal Conductivity

The review of buffer and bentonite thermal conductivity has focused on examination of the traceability and justification of derived parameter values. The measured buffer thermal conductivity values presented by Börgesson *et al.* (1994, Table 6-2 and Figure 6-2) appear to underpin the thermal conductivity values used in the SR-Can safety assessment. However, it is not clear if these old data have been qualified for use in the safety assessment. The measurements were made on samples of MX-80 with densities of 1,690 to 1,970 kg/m^3, void ratios of 0.81 to 0.88, and saturations of 43% to 97%. The thermal conductivity was found to increase from 0.61 to 1.28 W/mK with increasing saturation.

These data were used by Börgesson and Hernelind (1999, Table 5-1 and Figure 5-1) to derive parameter values for thermo-hydro-mechanical modelling using linear interpolation between the measured values, and these derived parameter values were used in SR-Can (SKB, 2006a, Table 5-4, which is reproduced here as Figure 3.1), although the Data Report does not refer directly to the source data.

The derived thermal conductivity values do correspond with the measured values presented by Börgesson *et al.* (1994, Table 6-2) for bentonite saturations above 40%. However, it is not clear how thermal conductivities at saturations less than 40% have been derived; such degrees of saturation could occur during the repository thermal phase (Börgesson *et al.*, 2006). Also, the SR-Can Data Report (SKB, 2006a, Table 5-1) refers to Hökmark and Fälth (2003) in specifying a bentonite thermal conductivity of 1.1 W/mK at initial saturation (about 80%). Thus, there is a minor inconsistency between the value shown in Tables 5-1 and that shown in Table 5-4 of the Data Report.



S_r	λ W/m,K
0	0.3
0.2	0.3
0.3	0.4
0.4	0.55
0.5	0.75
0.6	0.95
0.7	1.1
0.8	1.2
0.9	1.25
1.0	1.3

Figure 3.1: Thermal conductivity λ of the buffer material as a function of the degree of saturation S_r for a void ratio of $e \approx 0.8$. From Table 5-4 of the SR-Can Data Report (SKB, 2006a).

Relatively little information has been identified on the validity of the interpolation of thermal conductivity values over the full range of saturations or on parameter uncertainty. However, bentonite thermal conductivities derived using measurement data from the Temperature Buffer Test (TBT) and the Canister Retrieval Test at Äspö appear to confirm the saturation-dependence of the thermal conductivity (SKB, 2006b, Section 2.2.1 and supporting references Goudarzi *et al.* 2003a, 2003b, 2005). Thermal conductivities of 1.0 to 1.2 W/mK have been estimated from these tests and values close to heaters in the TBT were as low as 0.6 to 0.8 W/mK (SKB, 2006b, Section 2.2.1). However, it is unclear how well these values support the saturation-dependence of the thermal conductivity presented in Table 5-4 of the SR-Can Data Report.

An additional concern regarding thermal conductivity values is that measurements do not appear to have been made on the full range of bentonites that could be used as the buffer material. Börgesson *et al.* (1994) primarily measured the thermal conductivity of MX-80 bentonite, although a few measurements were made on SPV 200 bentonite, IBECA Na-bentonite and bentonite/quartz sand mixes. Recent work (Karnland *et al.*, 2006) has considered the properties of other bentonites but details of thermal conductivities were not reported. It is not clear if the thermal conductivity values obtained for MX-80 bentonite are applicable to other types of bentonite.

Other issues regarding thermal conductivity of the bentonite buffer have been noted previously by SKB. Börgesson *et al.* (1994, Section 9) concluded that investigations needed to be carried out to determine if bentonite thermal conductivity depends significantly on temperature and pressure, and to determine the influence of slots, cracks or moisture flow on thermal conductivity in low saturation bentonite. Research into these factors has not been identified in the present project.

The thermal conductivity values chosen for backfill also require greater explanation. The SR-Can Data Report (SKB, 2006a, Section 5.2.7) states that the thermal conductivity of bentonite in the backfill is calculated using the expressions $\lambda = 1.03 + (S_r - 0.58) \cdot 1.55$ (SKB, 2006a, Equation 5.2.7) for

70/30 bentonite-crushed rock and $\lambda = 0.57 + 1.23 \cdot (S_r–0.3)$ (SKB, 2006a, Equation 5.2.8) for Fridton clay. However, the sources of these equations are not cited and the bases for these relationships are not explained. The SR-Can Buffer and Backfill Process Report (Section 3.1.1) notes that the backfill thermal conductivity is usually set at 1.5 W/mK, citing Börgesson and Hernelind (2000). Börgesson and Hernelind (2000, Section 4.4) do assume a thermal conductivity of 1.5 W/mK in their model but the source of the value is not cited. It is recognised that SKB's selection and testing of backfill materials is ongoing, but the evaluation of material properties for use in a safety assessment should be traceable to underpinning measurements and data.

3.2 Buffer and Backfill Hydraulic Conductivity

The SR-Can Data Report (SKB, 2006a, Section 5.2.5) notes that establishing the exact value of bentonite hydraulic conductivity is a secondary concern when demonstrating that diffusive transport is substantially more significant than advective transport. Even so, the evaluation of bentonite hydraulic conductivity should be traceable to supporting experiments and analyses. Hydraulic conductivity values at temperatures from 20°C to 80°C are supplied in the Data Report in the context of coupled Thermo-Hydro-Mechanical (THM) modelling of the water saturation phase using the ABAQUS code (SKB, 2006a, Table 5-5). However, no source for the hydraulic conductivity values is provided, although it appears that the data are from the modelling report of Börgesson and Hernelind (1999, Table 5-3), which cites Börgesson *et al.* (1995) for the measured values, and also refers to Börgesson *et al.* (1994) and Börgesson and Johannesson (1995) with regard to the derivation of what is described as a preliminary material model. Börgesson *et al.* (1995) and Börgesson and Johannesson (1995) present hydraulic conductivity data that are reasonably consistent. Figure 3-9 of Börgesson *et al.* (1995) is a key graph from which the report generates its hydraulic conductivity data tables, but the data source is only identified as a "compilation of some hydraulic conductivity tests". It has not been possible to identify the actual experimental source of these data, nor the process by which the model parameters have been abstracted from the supporting experimental results. Börgesson and Johannesson (1995) include hydraulic conductivity measurements performed at a range of temperatures (20°C to 80°C), but again it has not been possible to identify the source of these data and it is not clear if the data have been qualified for use in the safety assessment.

A further concern is that the hydraulic conductivity values presented in the SR-Can Data Report (SKB, 2006a, Table 5-5) and Börgesson and Hernelind (1999) are half the values presented by Börgesson and Johannesson (1995) and Börgesson *et al.* (1995). No explanation is provided in the Data Report regarding this inconsistency in hydraulic conductivity values.

The SR-Can Data Report (SKB, 2006a, Section 5.2.3) notes that data used in the THM calculations of the buffer wetting rate are mainly from measurements on MX-80 bentonite at room temperature with non-saline water as the wetting fluid. However, the Data Report goes on to state that the influence of temperature, water salinity, density and bentonite type has also been investigated. Further, the Buffer and Backfill Process Report (SKB, 2006b, Section 2.3.2) presents graphs of hydraulic conductivity for MX-80 and Deponit Ca-N bentonites measured at different densities and with different ion concentrations in the saturating solutions. No report for this work is cited, but Karnland *et al.* (2006) does describe relevant experiments.

The SR-Can Data Report (SKB, 2006a) also presents the backfill hydraulic conductivity. Equation 5.2.2 of the Data Report is used to evaluate the hydraulic conductivity of a 30/70 bentonite and crushed rock mixture and of Fridton natural smectitic clay. However, the original source of these values is not cited.

3.3 Buffer Swelling Pressure

There is a minimum buffer swelling pressure requirement of 1 MPa in order to ensure that the hydraulic conductivity is lower than 10^{-12} m/s and that the pressure is high enough that irregularities are filled and the bentonite self-seals (SR-Can Buffer and Backfill Process Report, SKB, 2006b, Section 2.3.2). There is uncertainty in the magnitude of the swelling pressure in the water saturated state, where the possible deviation is judged to be ±30%, depending on the scatter in swelling pressure measurements and the uncertainty in certain material parameters. However, SKB (2006b, Section 2.4.1) regards the buffer swelling pressure process and the swelling/compression properties at full water saturation as well understood and modelled with sufficient accuracy.

SKB (2006b) states that continued validation of the buffer model has taken place in field tests at Äspö and laboratory tests by Börgesson *et al.* (1995) and Karnland *et al.* (2002) (also published as Karnland *et al.*, 2005); Karnland *et al.* (2006) is a further key update on swelling pressure data for a range of dry densities and water salinities. Börgesson *et al.* (1995) appears to be a key experimental work, which studied bentonite swelling capacity and pressure for saturated conditions, but the model presented by Börgesson *et al.* (1995) was regarded at the time as preliminary by the authors. To improve transparency and understanding, an up-to-date statement of the buffer model should be presented with references to the experimental data and analyses that support the model.

SKB (2006b, Section 2.4.1) considers the mechanical function of unsaturated bentonite to be complicated to model and that the models currently available are incomplete, especially for modelling volume change and swelling pressure. Examples of bentonite swelling pressure uncertainty in early validation work are cited in SKB (2006b), such as the discussion by Börgesson (1993) on the Stripa interim results, where a comparison of the measured and calculated results showed that the displacement of the canister and the swelling of the buffer could not always be adequately predicted.

SKB (2006b, Section 2.4.1) noted that unsaturated bentonite behaviour has been studied in a PhD project (Dueck, 2005, 2008). This project conducted a laboratory programme in order to improve the general understanding and the available models of the hydro-mechanical behaviour of unsaturated, swelling bentonite. However, it is unclear how the data obtained were used in the SR-Can safety assessment.

3.4 Buffer and Backfill Density and Porosity

The hydraulic conductivity of the buffer and backfill material is expected to increase and the swelling pressure is expected to decrease with decreasing density. The SR-Can Data Report (SKB, 2006a, Section 5.3.3) states that the engineering solutions for depositing the buffer and backfill material have not been chosen and so there are no firm data on expected buffer and backfill densities and porosities. Therefore, target densities have been proposed: the SR-Can Initial State Report (SKB, 2006c, Section 5.2), the Data Report (SKB, 2006a, Section 5.3.8), and the Buffer and Backfill Process Report (SKB, 2006b, Section 1.4) state that the target density for saturated bentonite is 2,000±50 kg/m^3. A reference to a discussion of the rationale for the choice of target density has not been provided.

Initial void ratio, porosity, dry density and saturation data are provided in the Initial State Report (SKB, 2006c, Section 5.2) and the Data Report (SKB, 2006a, Section 5.3.8). However, no reference to the source of these data is provided, although such data are reported in Johannesson *et al.* (2000).

The Data Report refers to Johannesson *et al.* (2000) for a demonstration that bentonite blocks of suitably high density can be manufactured by isostatic compaction. Johannesson *et al.* (2000) considered the density, void ratio and degree of saturation for isostatically compacted buffer blocks (MX-80 bentonite) on the scale 1:4. The average block density obtained for the beaker-shaped bentonite blocks was 2,059.2 kg/m^3 with a standard deviation of 4.6 kg/m^3, which is just outside the targeted density range. Johannesson *et al.* (2000) states that conclusions drawn on this reduced scale are relevant to the full scale and that “the experience at Ifö Ceramics AB clearly indicates that isostatic compaction is grossly independent of scale”, although no supporting evidence for this statement is provided. The report recommends tests are carried out on a substantially larger scale than 1:4 in order to verify these conclusions, but such tests have not been identified in this project.

3.5 Canister Emissivity

The SR-Can Data Report (SKB, 2006a, Section 4.1.1) discusses the emissivity of the copper outer shell, which is required in order to carry out thermal modelling of the repository. This allows determination of the temperature at the canister-buffer interface when a gap exists between the canister and the buffer before the buffer material is fully saturated. Heat transfer by radiation is linearly dependent on the emissivity. Based on the thermal analysis, the necessary distances needed between different canister positions in order to fulfil the temperature requirements may be calculated.

The Data Report (SKB, 2006a, Section 4.1.6) assumes an emissivity of 0.1 based on laboratory measurements on canister lids used in welding experiments, with reference to Roos (2003). In addition, the Data Report refers to a study by Hökmark and Fälth (2003) who back-calculated the emissivity of the copper canister based on measurements from SKB’s prototype repository and obtained an emissivity of 0.3. The Data Report (SKB, 2006a, Section 4.1.6) argues that as the manufacturing method has not yet been determined, emissivity values for the future production series cannot be determined with high accuracy; until there is an established manufacturing method for the canisters, the measurements by Roos (2003) show emissivity values for representative samples. However, there is no discussion as to why the 0.3 value from Hökmark and Fälth (2003) is any less representative of canister emissivity than the 0.1 value from Roos (2003).

Metal emissivity depends strongly on the properties of the metal surface, which may be influenced by the manufacturing process or the degree of oxidisation on the surface (SKB, 2006a, Section 4.1.3). This is indicated by the range of emissivity values summarised by Hokmark and Fälth (2003, p26): from an emissivity of 0.023 for polished copper (Cheremissinof, 1986) to a value of 0.26 for calorized copper (CRC, 1973), a value of 0.6 for oxidized copper (CRC, 1973), and a value of 0.63 for new copper (Ageskog and Jansson, 1999). The Roos (2003) emissivity data are based on a few measurements on canister lids used in the demonstration series for the canister welds and, pending development of the canister manufacturing methods, "these emissivity values must clearly be regarded as indications of the emissivities for canisters in series production" (SKB, 2006a, Section 4.1.4). However, there is no error range provided with these data and no indication of the data uncertainty. The Data Report (SKB, 2006a, Section 4.1.5) states that although emissivity values should, to some extent, be correlated for all canisters in the repository, differences in the oxidising layer on the copper shell may result in reduced correlation. No attempt to quantify the magnitude of the resulting range in copper emissivity has been identified in the SR-Can documents, and it is not clear whether the emissivity range will be large enough to impact the repository thermal analysis and canister distance spacing.

The Data Report (SKB, 2006a) does not provide direct cross-references to where the emissivity and other thermal data are used in SR-Can. Both the SR-Can Main Report (SKB, 2006d, Section 9.3.4) and the Fuel and Canister Process Report (SKB, 2006e, Section 2.2.1) note that the thermal evolution of the repository near field is based on the modelling analysis presented by Hedin (2004). Thermal sub-model data are presented in the Main Report (SKB, 2006d, Table 9-4) and Hedin (2004, Table A-1), but neither of these reports provide references for all of the data. For example, emissivity values for buffer, copper, iron and zircalloy surfaces and the gaps between the different interfaces are listed without reference to their derivation.

3.6 Canister Defect Distribution

The 50 mm thick copper canister shell provides a corrosion barrier to the cast iron insert (SKB, 2006a, Section 4.2). Discontinuities in the copper could reduce the thicknesses of the corrosion barrier and SKB judged that such discontinuities are most likely to occur in the canister lid weld. However, there is no discussion of the potential for discontinuities occurring elsewhere in the copper shell.

Two different methods for welding the canister lid to the canister body have been developed by SKB and in May 2005 the Friction Stir Welding process, FSW, was chosen as the reference method for the canister lid welds based on research carried out at SKB's Canister Laboratory and reported by SKB (2006f; in Swedish). As reported in the Data Report (SKB, 2006a, Sections 4.2.2 and 4.2.4) and SKB (2006f) a demonstration series of 20 canister lids was welded under production-like conditions and, after the lids were welded, each weld was examined using radiography and ultrasonic non-destructive testing (NDT) methods to find any defects. QA reviews of SKB's FSW and NDT techniques are discussed in Sections 0 and 0 respectively.

After NDT, the welds were further analysed using destructive methods. According to the Data Report (SKB, 2006a, Section 4.2.8) and the Main Report (SKB, 2006d, Section 4.2.4) a defect size distribution was derived based on the maximum defect sizes obtained for this demonstration series. The analysis led to the conclusion that, taking into account measurement errors, all canisters sealed under normal operations would have a minimum copper thickness of 40 mm at the weld, assuming that the welds in the demonstration series are representative of welds performed during canister production. It was not possible during the course of this project to review SKB (2006f), although Ronneteg *et al.* (2006), cited by (SKB, 2006f), does discuss the reliability of the welding and NDT processes, and the predicted reliability of the sealing system in a future production process. Ronneteg *et al.* (2006) also discusses the derivation of the proposed acceptance requirements for NDT.

Defects under normal operation were observed in the test series with maximum defect sizes of the order of a few millimetres, with the largest being 4.5 mm (SKB, 2006c, Section 4.2.4). The SR-Can Initial State Report (SKB, 2006c) defines normal operation as “conditions where the observable parameters of the sealing process are within a defined process window”, although the process window conditions are not discussed in the SR-Can reports.

4. Review of QA in Selected Experiments and Tests

The project included visits to SKB’s Bentonite Laboratory at Äspö and its Canister Laboratory at Oskarshamn (10th November 2008) to discuss QA aspects of specific experiments and tests on repository near-field materials. The meetings followed the format of previous QA reviews of experiments, and involved discussion of techniques and results, observation of facilities and equipment, and the use of a checklist of quality-affecting issues to record review findings (Hicks, 2007).

The meetings focused on tunnel backfill erosion experiments that had been undertaken recently at the Bentonite Laboratory, and the Friction Stir Welding and non-destructive testing experiments undertaken at the Canister Laboratory, as discussed in the following sub-sections.

4.1 BACLO Half-scale Experiments

QA aspects of the tunnel BACkfilling and CLOsure (BACLO) half-scale experiments were reviewed during the visit to SKB’s Bentonite Laboratory. SKB presented a description and results of the BACLO experiments, before the experimental facilities at the Bentonite Laboratory were viewed. The QA checklist for the review is included as Table A.1 in Appendix A.

The framework of the experiments was clearly explained. The experiment was undertaken to investigate water movement and potential bentonite erosion during tunnel backfilling operations. It was explained that the current plan was to use a backfill comprising bentonite blocks and pellets rather than a mixture of bentonite and crushed rock. The experiment was conducted by SKB staff under SKB´s Quality Management System.

The design of the experiment was presented clearly during the meeting. Bentonite blocks and pellets were placed between a wooden support frame and the walls of a steel tunnel. Dyed water was injected at fixed flow rates at different locations on the tunnel wall and seepage and flow through the tunnel face and floor were observed. Flow channels were created along the interface between the bentonite pellets and the tunnel walls. It is not clear if this behaviour would be representative of the interface between bentonite and rock, but further experiments were planned to investigate this. Also, the potential for the channels to persist is uncertain. It is possible that channel flow would stop once the tunnel is plugged.

Appropriate data management procedures were used, including data backups and daily logs. The experiments had not been reported at the time of the site visit, but plans for documentation and review were in place. The results of the experiment will give an indication of the backfill installation rate needed at different inflows in a tunnel section.

4.2 Friction Stir Welding

QA in Friction Stir Welding (FSW) was reviewed during the visit to SKB’s Canister Laboratory in Oskarshamn. SKB led a tour of the Canister Laboratory, before a discussion of QA issues. The QA checklist for the review is included as Table A.2 in Appendix A.

The design of the FSW equipment to fasten lids on copper canisters was explained. Experiments were being undertaken to test FSW as a method for sealing spent nuclear fuel canisters such that they can be disposed of safely in a repository.

The FSW technique involves drilling a pilot hole in the copper lid above the joint. A rotating probe is introduced and the frictional heat causes the copper to soften. The probe is then advanced towards the joint line and along the joint, before being moved upwards and removed. The column of hot metal created in the wake of the tool is pressed such that the copper pieces are bonded together.

SKB explained that a mature understanding of the FSW process has been developed through these experiments such that reliable welds are considered reproducible and repeatable. FSW is close to being ready for production conditions at the planned canister factory and encapsulation plant.

Regarding QA procedures for FSW, a plan is prepared for each lid weld and an operation list is used for the welding process. A welding procedure specification (WPS) is not currently used but would be developed for production. Data on each weld are stored digitally and data are stored on two hard drives on site as well as off-site. The welds are checked using NDT and destructive testing is carried out on some welds. Welding reports are produced and results are published in scientific journals and SKB reports, which are internally reviewed and peer reviewed.

4.3 Non-Destructive Testing of FSW

Non-Destructive Testing of FSW was also reviewed during the visit to the Canister Laboratory. Ultrasonic and x-ray inspection methods for FSW were discussed. The QA checklist for the review is included as Table A.3 in Appendix A.

SKB explained that NDT provides data on defect distributions for use in safety assessments as well as feedback on the welding technique. It was noted that x-ray works well for electron beam welding (EBW) but may not work for FSW because no information is acquired for compressed materials. Ultrasonics works well for FSW (the preferred welding technique) and therefore x-ray may not be needed.

Regarding QA procedures, routines in SKB's QA system and written instructions are used, but these currently apply to the development phase. There will be a need to move to common standards for production. NDT is carried out by certified engineers from SKB and its contractors. A reliability project is being undertaken to look at how human factors can be accounted for in NDT.

In canister production, NDT will form part of a qualified method for checking canister welding in order to determine whether a canister meets acceptance criteria. There would be a safety margin between what can be detected and what can be accepted. In production, the equipment would be used under radiation conditions and elevated temperatures, but SKB does not expect any problems with NDT under these conditions.

NDT data are stored locally and on a back-up server and welding trials are reported and tests are documented. A report on the reliability of welding has been produced. Three independent expert reviewers are used (non-SKB), and there is subsequently a safety assessment group review.

Results indicate that there are no significant defects in welds made using FSW and SKB expects that no canisters will have initial penetrating defects. Information on the distribution of defects could be used to provide a distribution of canister thicknesses for use in the SR-Site safety assessment.

5. Conclusions

SKB produced the SR-Can safety assessment for a spent nuclear fuel repository in preparation for the development of the SR-Site assessment that will be part of SKB's application for a final repository. SR-Can provided an opportunity for the Swedish regulator SSM to review and comment on SKB's safety assessment approach prior to SKB's compilation of SR-Site. SKB is now in the process of preparing the SR-Site safety assessment and SSM plans to continue to review and provide feedback to SKB on the development of the safety assessment. This report brings together recent work performed by GSL on behalf of SSM to review the QA procedures and instructions that have been prepared for the SR-Site assessment and to perform a quality audit of key experimental data used in the safety assessment.

5.1 SR-Site QA Procedures

The first part of this quality audit was to review the Spent Fuel Project QA plan and the associated QA-related documents. The aim was to consider whether these documents are sufficiently comprehensive that their application would ensure that the expected requirements of a QA programme would be met.

Several of the QA documents reviewed are preliminary versions and a number of instructions and procedures that are referred to in these documents had not been produced at the time of this review. These documents should be finalised as soon as possible to ensure full implementation of the QA system in the SR-Site Project.

The traceability and reliability of data and analyses that support the safety assessment are key issues that have been of concern throughout this and previous QA reviews of safety assessment documentation. SKB's approach of assigning an individual to track and check the use of data from the Data Report and its supporting documents through to SR-Site modelling is a positive development that will mitigate concerns over the reliability of supporting information and will generate greater confidence in the results of the SR-Site safety assessment. However, a similar approach is needed to track safety arguments and assumptions, not just data usage, throughout the suite of safety assessment documents to ensure that there are no deviating views or contradictions. Procedures are required that aim to ensure that such discrepancies are identified and resolved.

Implementation of the instruction on qualification of old and external references cited in support of the safety assessment is welcome and should further improve traceability and transparency of data abstractions and decisions about parameter value selection in the safety assessment. However, the methods to be used to qualify old data or analyses that do not meet SKB's current QA requirements should be explained.

Overall, the reviewed set of QA documents and instructions do provide reasonably comprehensive coverage of quality-affecting issues relating to the SR-Site safety assessment and, if implemented correctly, will generate confidence in the reliability of the safety assessment results. Further, the appointment of an assistant project leader with responsibility for QA issues in the SR-Site project provides some confidence that QA requirements will be met. However, progress in development of the QA documents and instructions has been relatively recent and it may be difficult for these to be fully implemented in the short period remaining before the planned licence application submission. Also, there will limited opportunity for any comprehensive QA audits of the SR-Site project in this period.

5.2 QA in Parameter Evaluation

In the second part of this quality audit, a detailed study was undertaken of the reliability and traceability of parameter abstraction and evaluation for KBS-3 safety assessments. This detailed study followed on from previous QA reviews and initially focused on reports of early experiments carried out and analysed to derive the models of material behaviour that are currently assumed in safety assessments. The qualification of data arising from such experiments was examined.

A general concern identified in this review is that it was often difficult to trace parameter values and other information presented in the SR-Can reports to supporting experiments and analyses. Frequently, information has to be traced back through several documents to locate underpinning experimental data. For example, the route from the SR-Can Data Report to the source data on buffer thermal and hydraulic conductivities is not easy to follow. Also, in some cases the supporting data are old (e.g. from the mid-1990s) and it is unclear if these data would be qualified for use in the SR-Site safety assessment.

Summary findings from the review of buffer, backfill and canister data are as follows:

- The validity of the interpolation of bentonite thermal conductivity values over the full range of saturations is unclear. Experimental data were obtained for saturations at 40% and above, but conductivity values for saturations below this have been interpolated without explanation or justification.
- Buffer thermal conductivity values have been obtained primarily from experiments on MX-80 bentonite. Measurements do not appear to have been made on the full range of bentonites that could be used as a buffer material; it is not clear if values obtained for MX-80 bentonite are directly applicable to other types of bentonite.
- The buffer hydraulic conductivity data appear to derive from experiments in the mid-1990s, but there are inconsistencies in the values used, and it has not been possible to identify the original source experiments or the process by which the model parameters have been abstracted from experimental results.
- To improve transparency and understanding, an up-to-date statement of the buffer model should be presented with references to the experimental data and analyses that support the model.

- The basis for the selection of the value for copper canister emissivity is not clear.

5.3 QA in Experiments and Tests

Visits to SKB’s Bentonite Laboratory at Äspö and its Canister Laboratory at Oskarshamn provided opportunities to discuss QA aspects of recent experiments on tunnel backfill erosion, friction stir welding of copper canisters and non-destructive testing of canisters. Checklists were used during and after the meetings to ensure that the range of key quality-affecting issues was discussed and documented.

It was evident that each experiment and test had been conducted under an appropriate QA system. For example, in each case, appropriate QA procedures for conducting the experiment or test were in place and the work was undertaken by suitably qualified staff or contractors. Appropriate data management procedures had been used, including data backups and logs, and reporting included suitable document checking and reviewing processes.

It is evident that SKB has attained a good understanding of the FSW process and NDT techniques for checking welds: SKB considers reliable welds are reproducible and repeatable. Procedures need to be developed for using these techniques under production conditions.

The experimental programme on tunnel backfilling is less mature and SKB indicated that further experiments were being planned to investigate the phenomenon of flow channelling through bentonite pellets.

6. References

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Appendix A: Review of QA in Selected Experiments and Tests

QA reviews of a experiments and tests on tunnel backfill and canisters have been undertaken. The reviews were centred on meetings at SKB's Bentonite Laboratory, at Äspö, and the Canister Laboratory at Oskarshamn on 10th November 2008.

The QA review of experiments on repository backfill erosion carried out at the Bentonite Laboratory is summarised in Table A.1. Table A.2 and Table A.3 present the QA reviews of the friction stir welding and non-destructive testing experiments undertaken at the Canister Laboratory.

Table A.1: Tunnel BACkfilling and CLOsure (BACLO) Half-scale Experiments.

1. Framework of Experiment	
1.1 Purpose and objectives	
What experiment is being undertaken?	The BACLO half-scale tunnel experiment.
Why is the experiment being undertaken?	To investigate water movement and potential bentonite erosion during tunnel backfilling operations.
What is the role of the experiment in the repository programme?	The half-scale tunnel tests have been conducted as part of SKB's BACLO programme of work to develop repository backfilling operations, focusing particularly on water management and backfilling rate issues.
1.2 Resources and schedule	
Where is the experiment being conducted?	SKB's Bentonite Laboratory (inaugurated in March 2007) at Äspö.
Who is conducting the experiment?	SKB staff. Gunnar Ramqvist is managing the BACLO work concerning the experiments at Äspö.
What is the schedule for the experiment?	The half-scale was undertaken in July 2008 following similar smaller-scale experiments on water movement through bentonite blocks and pellets in a tunnel-shaped concrete tube.
When will results be available?	A final report will be produced in December 2008[2]. Further half-scale tests and experiments on rock slabs will begin in November 2008.
What constraints do resources such as cost and timing place on experimental planning and design?	The chosen scale and length of the tunnel limits costs and time for the experiment (the tunnel is 2.75 m wide, 2.75 m high, and 6 m long). Also, to limit costs, bentonite blocks and pellets were only placed around the perimeter of the tunnel, sealed in and supported by a plastic-lined wooden internal framework. The wooden framework replaced an original plan to use concrete blocks. The use of a wooden frame limited the timescale for the experiment (40 hours) because the bentonite swelling pressure could become sufficient to crush the frame.
1.3 Quality assurance	
What QA system and standards are used in the planning, design, execution, analysis, and reporting of the experiment?	SKB´s Quality Management System is used which complies with the requirements in ISO 9001:2000.
What material quality controls are used?	Water content in block and pellet before each test setup.
How is the expert team selected/trained for the experiment?	The same staff were used as in a previous test using a concrete tub.

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[2] Dixon *et al*. (2008)

2. Design of Experiment	
2.1 Variables	
What are the dependent variables (i.e. those being observed)?	Water flow pathways through the bentonite and bentonite erosion rates.
What are the independent variables (i.e. those that are varied to cause change in the dependent variables) and how are their values selected?	The location of inlet points along and around the tunnel and the inlet flow rates and duration. Injections at 0.25 and 0.5 l/min were used at different positions on either side of the tunnel. The injection water chemistry (Äspö ground water (saline water)), the length of tunnel backfilled (a tunnel length of about 4 m was backfilled in the present experiment), and bentonite block and pellet sizes, composition and arrangements (which are representative of those that could be used in the repository) can be changed for different experiments.
What are the control variables (i.e. those that are held constant) and how are their values selected?	The dimensions and length of the tunnel are fixed. The experiments are conducted at room temperature.
2.2 Experimental techniques	
What experimental techniques and instruments are being used?	Dyed water was injected at fixed flow rates and seepage and flow through the tunnel face and floor were observed. The injection pressures and flow rates were monitored. For injection, dosage pumps from Grunfos model DME were used. The injection pressures and flow rates were monitored with Tecfluid flowmeter series M-21 16-250 l/h and pressure with druck PTX 1400 0-40 bar. The measurement data was logged every minute.
Are they standard techniques?	Yes.
Are acceleration methods used?	No.
Have the techniques been validated and documented?	Experience from small-scale tests have been validated and improved before being used in this experiment.
Are the techniques being used under normal conditions?	Yes.
Has equipment been calibrated and checked?	Yes, equipment is calibrated before and after each test.

2.3 Uncertainty	
What are the key uncertainties in the experiment?	Flow channels were created along the interface between the bentonite pellets and the steel walls of the tunnel. It is not clear if this behaviour would be representative of the interface between bentonite and rock. Tests will be undertaken using a rock slab in contact with bentonite pellets in order to examine the significance of the rock surface on flow channel formation in bentonite. The influence of pellet type and size on flow is uncertain. Further half-scale tests will be undertaken using different types of bentonite and different sizes of pellet. A full-scale experiment will be undertaken in the Äspö hard rock laboratory. The potential for the channels to persist is uncertain. It is considered that the channel flow would stop once the tunnel is plugged.
2.4 Risks to success of experiment	
What are the risks to the success of the experiment and how are they mitigated?	A steel grid was used in the front to avoid hydromechanical damage of the pellets. Pressure was monitored to ensure that the wooden framework would not be damaged.
What are the critical decisions in the experiment?	What inflow to be used in relation to erosion rate.
Is there duplication in the experiment?	Yes, the same flow rates and test duration are repeated in several experiments.

3. Conduct of Experiment	
3.1 Data collection and quality control	
How are data collected?	The injection pressures and flow rates were recorded. The injection flow rates were fixed which resulted in fluid pressure build-up, periodically relieved by the creation of flow channels through the bentonite, until channel breakthrough at the bentonite wall. The breakthrough water was collected and the bentonite content observed to provide information on erosion rates. After the experiment, the bentonite was removed to observe saturated and dry regions and the traces of channels created along the steel tunnel interface as the dyed water penetrated.
How are data stored (e.g. filing, indexing)?	In an Excel spreadsheet during the experiment and in SICADA afterwards.
How are data checked (e.g. independently)?	Yes, they are independently checked by the project group before being stored in SICADA.
How are data backed-up?	On a computer during the experiment and in the SICADA back-up system after the experiment.
What data quality control procedures are used?	During operation an alarm system records unexpected values of pressure and flow.

3.2 Records of experiment	
Are notebooks being used for the experiments?	Yes, daily logs.
Are notebooks checked independently?	Yes, by coordinator.
Are planning, execution and analysis correspondences kept (e.g. emails)?	Yes, project meeting documents etc. in SKBdoc.
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)?	A hydraulic conductivity value for the pellets has been calculated by using Darcy´s Law. Calculations were performed using an Excel spreadsheet. The water content and density of block and pellet were calculated according to standard methods.
How are uncertainties and sensitivities analysed?	Data from the Half-scale test have been compared with data from the Concrete tube test to identify possible scale effects.
4.2 Reporting and review	
How are data and observations reported?	A final report will be produced in December 2008[3].
How are interpretations reported?	Included in the final report.
What are the limitations on the use of data and results and how are they reported?	In the experiment, only water movement in pellets, blocks and the pellet/block interface can be studied. The pellet/rock structure interface cannot be studied.
How are reports reviewed (e.g. independently)?	The report is reviewed by independent experts.
How are review results managed/responded to?	According to review procedures described in SKB´s QA-system.

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[3] Dixon *et al*. (2008)

5. Usability of Results	
5.1 Verification	
How are experimental outcomes checked against requirements of the experiment?	The final results are compared with a preliminary prediction made in advance.
How are experimental results verified?	Results from similar test-setups will be compared.
5.2 Use of results	
How are results abstracted for use in the repository programme?	Results will give an indication of the backfill installation rate needed at different inflows in a tunnel section.
Are results extrapolated for use on repository length and time scales?	Comparisons are made with the results from smaller-scale tests, which supports analyses to scale up to full repository size.
What checks are made that data and results are used appropriately and within prescribed limitations?	The data from these experiments will be compared with the other activities in the backfilling progress.

Table A.2: Experiments on Friction Stir Welding.

1. Framework of Experiment	
1.1 Purpose and objectives	
What experiment is being undertaken?	Experiments using friction stir welding (FSW) to fasten lids on copper canisters.
Why is the experiment being undertaken?	To test FSW as a method for sealing spent nuclear fuel canisters such that they can be disposed of safely in a repository.
What is the role of the experiment in the repository programme?	The FSW experiments form part of SKB's programme of work to develop a process that can be used to seal copper canisters in the planned encapsulation plant.
1.2 Resources and schedule	
Where is the experiment being conducted?	SKB's Canister Laboratory in Oskarshamn. The FSW method for welding copper was originally developed in collaboration with The welding Institute (TWI) in Cambridge, England, in the late 1990s. SKB acquired its own purpose-built FSW equipment in 2002 and began welding experiments in Oskarshamn in 2003. SKB is also part of an international consortium undertaking research on FSW.
Who is conducting the experiment?	SKB staff. Lars Cederqvist is the project manager and development engineer for FSW at the Canister Laboratory, and is developing the method as a PhD study.
What is the schedule for the experiment?	A series of small experiments has been completed involving FSW of 68 canister lids (full size and short) and 294 welds in total. A mature understanding of the FSW process has been developed through these experiments such that reliable welds are considered reproducible and repeatable. FSW is close to being ready for production conditions at the planned canister factory and encapsulation plant.
When will results be available?	FSW results have been published periodically over the last decade in scientific journals and SKB reports. A production line report will be produced that describes the status of FSW.
What constraints do resources such as cost and timing place on experimental planning and design?	In order to limit costs, experiments are carried out on short rings rather than full-scale canisters. Also the welded copper is machined on site for re-use in subsequent FSW experiments.
1.3 Quality assurance	
What QA system and standards are used in the planning, design, execution, analysis, and reporting of the experiment?	A plan is prepared for each lid weld and an operation list is used for the welding process. A welding procedure specification (WPS) is not currently used but would be developed for production.
What material quality controls are used?	The copper must be characterised before welding as part of the acceptance testing of components. The copper quality is checked and the geometry of the joint is examined to check for correct machining. The welding tools are also checked. Non-destructive testing (NDT) is carried out to check the quality of the weld.

How is the expert team selected/trained for the experiment?	Expertise on FSW has been developed at SKB through collaboration with TWI and an international consortium. The method is being developed as part of Lars Cederqvist’s PhD study.

2. Design of Experiment	
2.1 Variables	
What are the dependent variables (i.e. those being observed)?	The weld temperature, which is correlated with defect probability.
What are the independent variables (i.e. those that are varied to cause change in the dependent variables) and how are their values selected?	The power input, which determines the weld temperature.
What are the control variables (i.e. those that are held constant) and how are their values selected?	The speed of rotation of the spindle, the welding speed, and the compression forces on the canister and lid. The power input can be controlled to keep the temperature constant. In production, the values would be selected and kept constant to ensure process stability and reproducibility.
2.2 Experimental techniques	
What experimental techniques and instruments are being used?	A purpose-built FSW machine is being used, although it has been built using standard components. The FSW technique involves drilling a pilot hole in the copper lid above the joint. A rotating probe is introduced and the frictional heat causes the copper to soften. The probe is then advanced towards the joint line and along the joint, before being moved upwards and removed. The column of hot metal created in the wake of the tool is pressed such that the copper pieces are bonded together. The welding temperature is measured using thermocouples and an infrared camera.
Are they standard techniques?	The methods are standard, having been originally developed by TWI in the early 1990s.
Are acceleration methods used?	No.
Have the techniques been validated and documented?	FSW of copper has been tested over the last decade and checks have found the welding to work. FSW is used industrially (e.g. aerospace and shipbuilding), but mainly for aluminium welds.
Are the techniques being used under normal conditions?	Yes. Radiation is not expected to be a problem during production.
Has equipment been calibrated and checked?	The equipment is calibrated annually and can be checked more often. No deviations or difficulties have been found in the calibration process.
2.3 Uncertainty	

What are the key uncertainties in the experiment?	Welding parameters are known, but the potential for operator error introduces uncertainties. There are also uncertainties associated with radiation and thermal issues.
2.4 Risks to success of experiment	
What are the risks to the success of the experiment and how are they mitigated?	A skilled welding operator is required to control power input. However, Lars Cederqvist is developing an automated process as part of his PhD work.
What are the critical decisions in the experiment?	Selection of power input and tool rotation speed.
Is there duplication in the experiment?	Yes, 294 joints have been welded.

3. Conduct of Experiment	
3.1 Data collection and quality control	
How are data collected?	Data on about 15 to 20 welding parameters are collected for each experiment.
How are data stored (e.g. filing, indexing)?	Data on each weld are stored digitally.
How are data checked (e.g. independently)?	Key parameters are plotted for every weld and results for each weld are analysed. Also, the welds are examined visually for any deviations.
How are data backed-up?	Data are stored on two hard drives on site as well as off-site.
What data quality control procedures are used?	Data are checked and no fluctuations have been seen in calibration checks.
3.2 Records of experiment	
Are notebooks being used for the experiments?	An operation list is used and a welding report is produced (Microsoft Word).
Are notebooks checked independently?	Håkan Rydén (SKB's Manager of Encapsulation Technology) checks the reports.
Are planning, execution and analysis correspondences kept (e.g. emails)?	Correspondence regarding the design of experiments is kept. Also, annual reports are produced by the international consortium working on the development of the technology.
Are copies of records kept?	Yes.
3.3 Equipment	
Is equipment tested, inspected, and maintained?	Yes. New welding tools are used for each experiment (i.e. the part that's in contact with the copper). The same would be done in production to avoid the tool corroding or breaking.

4. Analysis and Reporting of Experiment	
4.1 Data interpretation	
What data interpretation methods are being used (models, software packages, model simplifications)?	Relationships between parameters are examined (Micrsoft Excel). NDT is used to look for defects, and feedback on defect location is provided.
How are uncertainties and sensitivities analysed?	Changes in power input introduce defects. Sensitivity to power changes is evaluated and checked using NDT.
4.2 Reporting and review	
How are data and observations reported?	Welding reports are produced.
How are interpretations reported?	Scientific journals (e.g.., Cederqvist and Öberg, 2007; Cederqvist, 2009) and SKB reports.
What are the limitations on the use of data and results and how are they reported?	No limitations are noted. The welding process is representative of the welding that would be done under production conditions.
How are reports reviewed (e.g. independently)?	Reports are peer reviewed. Håkan Rydén undertakes internal reviews.
How are review results managed/responded to?	Comments are responded to and the review process is documented by SKB.

5. Usability of Results	
5.1 Verification	
How are experimental outcomes checked against requirements of the experiment?	Welding is completed according to the welding plan.
How are experimental results verified?	The welds are checked using NDT. Destructive testing is carried out on some welds.
5.2 Use of results	
How are results abstracted for use in the repository programme?	Interaction between FSW and NDT of welds generates information on the probability of creating and detecting defects. Results indicate that there are no significant defects in welds made using FSW. It is expected that no canisters will have initial penetrating defects.

Are results extrapolated for use on repository length and time scales?	Production has been mimicked to demonstrate that canisters can be welded at the required rate. A minimum copper thickness at the weld was assumed in the SR-Can safety assessment; information on the distribution of defects could be used to provide a distribution of canister thicknesses for use in the SR-Site safety assessment. The long-term properties of welds are assessed using tensile, creep and corrosion tests.
What checks are made that data and results are used appropriately and within prescribed limitations?	NDT provides information on weld properties for use in safety assessments. Appropriate use of FSW results is checked through feedback from NDT.

Table A.3: Non-Destructive Testing of FSW.

1. Framework of Test	
1.1 Purpose and objectives	
What test is being undertaken?	Ultrasonic and x-ray inspection for friction stir welding (FSW).
Why is the test being undertaken?	To detect defects in welds and to confirm the quality of welds.
What is the role of the test in the repository programme?	NDT provides data on defect distributions for use in safety assessments as well as feedback on the welding technique. In canister production, NDT will form part of a qualified method for checking canister welding in order to determine whether a canister meets acceptance criteria. There would be a safety margin between what can be detected and what can be accepted.
1.2 Resources and schedule	
Where is the test conducted?	Tests are conducted at SKB's Canister Laboratory in Oskarshamn. For canister production, the equipment would be used at the planned canister factory plant, and similar equipment would be used at the encapsulation plant.
Who conducts the test?	Certified engineers from SKB and contractors.
What constraints do resources such as cost and timing place on testing?	NDT is not a critical part of the welding process in terms of cost and timing. Weld inspection takes a few hours and evaluation takes a few hours. In practice no failures are expected, but if a canister were to fail the acceptance criteria, then the failed canister would be cut open.
1.3 Quality assurance	
What QA system and standards are used in the planning, design, execution, analysis, and reporting of the test?	Routines in SKB's Quality Assurance system and written instructions are used, but these currently apply to the development phase. Calibration is carried out according to specific requirements and data are qualified. There will be a need to move to common standards for production.
What quality controls are used?	The copper must be characterised before welding as part of the acceptance testing of components. Copper quality and grain size are checked. The relationship between grain size and weld quality is being studied. Calibration is carried out before each test.
How is the team selected/trained?	Required qualifications are defined in instructions (e.g., number of hours training, formal NDT certificate, qualified to use equipment).

2. Design of Test	
2.1 Variables	
What is being observed?	Structure and any flaws in the weld.
2.2 Techniques	
What testing techniques and instruments are being used?	Ultrasonic (phased array technique) and x-ray.

Are they standard techniques?	Yes, the techniques are used broadly in industry. Training to certified levels is straightforward.
Have the techniques been validated and documented?	Yes, through use in conventional weld inspection (e.g pipe line inspections).
Are the techniques being used under normal conditions?	Yes, although in future the equipment will be used under radiation conditions and elevated temperatures, but no problems are expected.
Has equipment been calibrated and checked?	The equipment is calibrated before every use by checking materials with known defects. The equipment is also sent for annual calibration. No tuning has been required to date. Transducers may need repairing.
2.3 Uncertainty	
What are the key uncertainties?	The variable properties and shapes of defects. X-ray works well for electron beam welding (EBW) but may not work for FSW because no information is acquired for compressed materials. Ultrasonics works well for FSW (the preferred welding technique) and therefore x-ray may not be needed.

3. Conduct of Test	
3.1 Data collection and quality control	
How are data collected?	Automatic data acquisition (waveform).
How are data stored (e.g. filing, indexing)?	Data are stored locally.
How are data checked (e.g. independently)?	Data are checked if something unusual is detected as a deviation from normal patterns. Such findings would probably be double-checked in production.
How are data backed-up?	A back-up server.
What data quality control procedures are used?	Written instructions are used.
3.2 Records	
How are tests recorded?	Inspection reports.
Are planning, execution and analysis correspondences kept (e.g. emails)?	Welding trials are reported and tests are documented.
Are copies of records kept?	Records are stored electronically. There are few hand-written notes.
3.3 Equipment	
Is equipment tested, inspected, and maintained?	Yes. There are check plans for everything according to requirements.

4. Analysis and Reporting

4.1 Data interpretation	
What data interpretation methods are being used (models, software packages, model simplifications)?	Evaluation is done according to standard methods. A colour scale is used to aid focusing on certain levels that could indicate defects. This process could be automated.
How are uncertainties and human factors analysed?	A reliability project undertaken by BAM (Federal Institute for Research) in Berlin will look at how human factors can be accounted for.
4.2 Reporting and review	
How are data and observations reported?	A test report is produced for each weld. Summary reports are also produced, with the last being written two years ago and another being written now.
How are interpretations reported?	Status reports.
What are the limitations on the use of data and results and how are they reported?	A report on the reliability of welding has been produced which discusses results (Ronneteg, 2006).
How are reports reviewed (e.g. independently)?	Independent expert reviewers are used (non-SKB), and there is subsequently a safety assessment group review. For example, the report on reliability of canister sealing (Ronneteg, 2006) was reviewed by three independent experts: Christophe Mattei (Bodycote Materials Testing), Nader Tajvidi (Australian National University), Carl Sorensen (Brigham Young University, Utah). Review records were made available by SKB. SKB also provided review plans for a report on the reliability of friction stir welding of canisters that will be a supporting document to the SR-Site safety assessment. The report will be reviewed by five experts with the following affiliations and key skills: Barend van den Bos (Bodycote Materials Testing; general expertise), Nader Tajvidi (Lund University; statistics), Carl Sorensen (Brigham Young University, Utah; welding), Christophe Mattei (Bodycote Materials Testing; NDT and reliability) and Karin Pers (Kemakta Konsult; regulatory requirements).
How are review results managed/responded to?	All documents follow a review plan. Comments and responses are stored and there is a comment resolution process. Review records for the report on reliability of canister sealing (Ronneteg, 2006) showing comment responses were made available by SKB.

5. Usability of Results	
5.1 Verification	
How are test results verified?	The verification of results is being addressed in the reliability project being undertaken by BAM in Berlin.
5.2 Use of results	
How are results abstracted for use in the repository programme?	Interaction between FSW and NDT of welds generates information on the probability of creating and detecting defects. Results indicate that there are no significant defects in welds made using FSW. It is expected that no canisters will have initial penetrating defects. A minimum copper thickness at the weld was assumed in the SR-Can safety assessment; information on the distribution of defects could be used to provide a distribution of canister thicknesses for use in the SR-Site safety assessment.
What checks are made that data and results are used appropriately and within prescribed limitations?	The use of results in the safety assessment is reviewed. The results are used in the Data Report and there is an opportunity to review decisions on canister defects.

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