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INSITE Summary Report

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Title: INSITE Summary Report.
Subtitle: A summary of INSITE activities in tracking SKB's spent fuel repository site investigations from 2002-2009 and of advice provided to the regulatory authorities on the status of site understanding at the end of the surface-based investigations
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SSM Perspective

SSM and its predecessor SKI employed a team of earth scientists who followed and reviewed SKB's investigations of the potential spent nuclear fuel repository sites at Forsmark and Laxemar. This group was named INSITE (INdependent Site Investigation Tracking and Evaluation) and began its work in 2002 and completed its task with the review of the final versions SKB's site descriptive models, SDM-Site, in 2009.

This report is a summary of INSITE's work over the eight-and-a-half year period of the site investigations and the lead-in and the wind-down to the work. It is intended to provide an outline and a record of how INSITE has worked and how its advice was generated and provided to SKI and, latterly, to SSM. Together with all the other documentation generated by INSITE, this report is intended to support the regulatory review of SKB's licence application for a spent nuclear fuel repository.

Project information

Project leaders: Öivind Toverud and Georg Lindgren
Project reference: SSM 2009/277

Content

1. Introduction

In Sweden, spent nuclear fuel will be disposed of in a deep geological repository in the ancient crystalline bedrock of the Fennoscandian Shield. The used fuel will be encapsulated in copper-clad iron containers and placed in excavated boreholes and tunnels at a depth of 400-600 m, with the waste packages being physically isolated from the rock by a buffer of highly compacted bentonite clay. SKB, the agency charged with implementing the repository, has been researching this disposal concept for more than 35 years, during which time it has investigated the properties and behaviour of crystalline bedrock such as granite and gneiss at a number of locations across Sweden, using both surface-based observations and testing in deep underground excavations. The principal focus of much of this work has been to develop an understanding of how fractures and discontinuities in the crystalline rock control the flow of groundwater at depth and the movement of solutes in these waters, as well as to assess the effects of thermal and mechanical stresses on the rock and on emplaced repository materials.

The Fennoscandian Shield and the variety of hard, fractured crystalline rocks that it comprises, forms the dominant geological environment across most of Sweden and SKB's approach has been that its disposal concept could, in principle, be deployed almost anywhere within these geological formations, provided that rock and groundwater conditions at depth were adequate. The basis for this approach was that the main drivers for the behaviour of the disposal system and the dominant processes that control performance are the same, regardless of variations in the geological characteristics of fractured crystalline rock. To clarify what would be considered sufficiently good conditions for disposal, SKB published its 'requirements of the host rock' in April 2000[1].

In parallel with its research and development programme, SKB embarked on a programme of site investigations in the 1990s, aimed at eventual site selection for the repository. The history of this programme is not described here, but it involved feasibility studies and referenda, with varying degrees of success, aimed at finding a group of sites that could be both technically suitable and locally acceptable. The outcome was a pool of eight possible locations in six municipalities. The culmination of this process was the announcement by SKB, in December 2000, that it would be focussing all its efforts on investigating three siting areas in central Sweden from within this pool: Forsmark, in the municipality of Östhammar, Simpevarp, in the municipality of Oskarshamn, and Tierp north, adjacent to Östhammar. The latter siting area was dropped by SKB without any further investigations, after a negative vote on the project in the municipal council, in April 2002. SKB began detailed site investigations at Forsmark and Simpevarp in 2002, with the latter area being subdivided into the Simpevarp Peninsula and Laxemar sub-areas. In 2005, after detailed, but incomplete, investigations, Simpevarp Peninsula was relegated in favour of Laxemar, as the preferred location within the Oskarshamn municipality, with Forsmark and Laxemar then being investigated in parallel until 2008. In June 2009, after completion of 6 years of surface-based site investigations, SKB announced its preference for the

[1] SKB Technical Report TR-00-12

Forsmark site, on the basis of a number of factors, but citing better geological conditions as being of key importance in the decision.

The regulatory authority, SKI, was responsible for the oversight of all aspects of SKB's programme related to the engineering and implementation of the repository to meet operational and post-closure safety requirements, with its sister authority, SSI, being responsible for ensuring compliance of the actual radiological impact evaluation that SKB would submit as part of its safety case for spent fuel disposal. SKI realised before the outset of the programme of detailed site investigations that it would need to keep abreast of the proposed 5-year programme of field work if it was to have a realistic chance of assimilating knowledge of the site so that it could respond with advice to government on a reasonable timescale, when SKB submitted its licence application to begin repository construction. SKI also realised that it would be very difficult to attempt to gain sufficient familiarity with site knowledge retrospectively, given the huge amount of information that was likely to be generated. It also wished to have some measure of influence on SKB, so as to ensure, for the benefit of both parties, that potential difficulties that might emerge in licence review could be identified early so that measures could be taken to fill information gaps and resolve misunderstandings during, rather than after, the site investigations. Part of this influence was to be sure, by close scrutiny, that SKB was deploying the appropriate techniques and an adequate quality of investigation, data management and interpretation. In addition, SKI appreciated that it would have to evaluate a number of milestone documents that would be produced by SKB during the course of the investigations. These concern the design of a repository and the assessment of its safety, with both topics depending heavily on knowledge of the properties and dynamic behaviour of the sites. All of this meant that SKI would need to track the investigations and maintain an up-to-date knowledge of the developing interpretations and understanding of the sites as the work progressed.

In order to help them with this work, SKI decided to employ an independent team of earth scientists who would review the SKB investigations continuously and in detail and provide SKI with advice. The output of this group would enable SKI to interact in a focussed manner with SKB, at regular consultation meetings about the sites. After an initial discussion meeting of SKI and its consultants in November 2001, at which SKB's plans for the site investigations were presented, the 'INSITE' (INdependent Site Investigation Tracking and Evaluation) group was set up in February 2002 as advisors to SKI. Subsequently, SSI formed a similar advisory group (OVERSITE) to look principally at the near-surface and biosphere aspects of site investigation and understanding, although this group operated at a lower level of activity than INSITE. In July 2008, as the site investigations were drawing to a close, the two regulatory authorities were amalgamated into a single authority, SSM, which will now have the task of making an integrated evaluation of all aspects of the operational and post-closure safety of the spent-fuel repository.

After six years of work, in two approximately 3-year stages ('initial' and 'complete' site investigations: see Section 1.1) SKB's comprehensive programme of surface-based investigations was completed in 2008-9 and the integrated understanding of the sites that were evaluated was summarised in a final iteration of the Site Descriptive Models (SDM) for each site. These 'SDM-Site' reports underpin the design and safety assessment work that will form part of SKB's application for a licence to construct a repository.

With the conclusion of the surface-based investigations, INSITE's remit is also completed. This report is a summary of INSITE's work over the eight-and-a-half year period of the site investigations and the lead-in and the wind-down to the work. It is intended to provide an outline and a record of how INSITE has worked and how its advice was generated and provided to SKI and, latterly, to SSM. Together with all the other documentation generated by INSITE, this report thus constitutes part of the formal record that will support the regulatory review of SKB's licence application during 2010-c.2012.

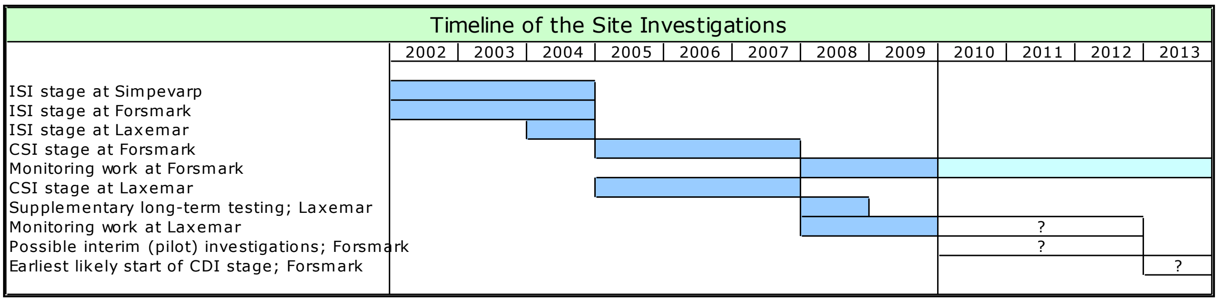
Sections 4 and 5 of the report summarise INSITE's views on site understanding at both Forsmark and Laxemar at this break-point in SKB's programme, also outlining the recommendations that we leave with SSM regarding future site characterisation work that will be needed as SKB begins to move underground at the Forsmark site. Section 6 comments briefly on SKB's rationale for the selection of the site and Section 7 assesses how site information and understanding has been used to justify the initial design decisions for the Forsmark repository.

Because Sweden is internationally at the forefront of site investigations and licensing for deep geological repository construction, the experience of the INSITE programme described in Section 8 and some of the conclusions drawn in Section 9 should also help provide guidance for other national programmes that will embark on similar siting studies in the next decade.

1.1. Timelines for the SKB site investigations

The surface-based investigations were divided into Initial Site Investigations (ISI) and Complete Site Investigations (CSI). Towards the end of the CSI stage, programmes of longer-term observations and confirmatory testing were undertaken and these became part of the long-term monitoring programme that will continue into the distant future (at least, at the Forsmark site). Throughout the investigations, a third stage has been referred to: the Construction and Detailed Investigation (CDI) stage, which will involve continued investigation of various properties of the selected site at Forsmark, as repository excavation progresses. There is also the possibility that interim investigations will take place to explore along the planned line of shafts, between the end of the CSI stage and the start of excavations and the CDI stage.

The diagram below outlines the timescales involved in the SKB field programmes at Forsmark, Simpevarp and Laxemar, with the future activities being our understanding of how work might progress over the next few years. The concurrent work of INSITE during the surface based investigations is shown diagrammatically in Section 2.7.



1.2. INSITE Terms of Reference and composition

Originally, the intention was that INSITE would comprise a Core Group and a team of other experts who could be brought in to evaluate specific topics in detail. In practice, only the Core Group had a regular work programme and Terms of Reference, although individual experts were consulted from time to time and attended some of the Core Group meetings.
The membership of the Core Group and their specific areas of responsibility were as follows:

Neil Chapman, Switzerland (Chairman; Strategy)	Adrian Bath, UK (Geochemistry)
Joel Geier, USA (Hydrogeology)	Ove Stephansson, Sweden (Rock Engineering)
Sven Tirén, Sweden[2] (Geology)	Chin-Fu Tsang, USA (Links to PA; Strategy)

Some members of the Core Group also carried out specific studies on behalf of SKI that were outside the remit of INSITE but whose results contributed to the INSITE objective of developing an understanding of the site. Such studies ranged from broader (i.e. of international, rather than just SKB work on a scientific topic) reviews and independent modelling of SKB data to explore, for example, alternative interpretations or provide deeper insight, to desk-based research on issues identified as potentially important by INSITE reviews that were not being addressed by SKB's own programme.

The Core Group Terms of Reference, established in 2002 and appended to the record of the first INSITE meeting, stated the following:

[2] Sven Tirén acted as consultant to SKI and formally joined the Core Group in early 2003.

1.2.1. Objective and Scope

The Core Group is appointed by SKI to provide them with specialist advice on the SKB site investigation programmes for a deep repository for spent fuel, which commence in early 2002.

SKI expects eventually (probably around 2007) to receive a licensing submission from SKB, requesting regulatory approval to focus its repository development activities at one or more sites. Although it has only a limited formal overview role until that time (principally through its periodic review of SKB's RD&D programme), SKI wishes to keep fully abreast of the SKB site studies. This will facilitate SKI's understanding of the sites (and how their properties might mould SKB's RD&D aims), help to identify important issues of potential concern to the regulators at an earlier stage and ensure that an eventual submission can be more efficiently assessed.
In this context, the Core Group will:

- comment on the scope of the investigations, the approach and the techniques deployed, the quality and amount of data obtained, and how information is managed;
- comment on developing interpretations of site properties and behaviour, their possible design and performance implications, and any uncertainties that may be involved;
- comment on developing conceptual models of the structural, hydrogeological, geochemical and rock mechanical aspects of the site, including alternative models, that will be used for repository design and performance assessment;
- advise SKI of the capabilities and tools that it will need in order to evaluate and interpret the data produced by SKB's site investigations;
- advise SKI about any important issues identified and suggest questions that SKI may consequently wish to raise with SKB in SKI's regular briefing meetings.

The objective of the advice provided by the Group is to provide SKI with timely views on the investigations, in terms of SKI's likely expectations of the content, quality and scope of an eventual licensing submission.

1.2.2. Membership

Individual members of the Group are appointed on the basis of their background and experience in one or more of the key technical or planning aspects of deep site investigations, or the use of site characterisation information in repository design or safety assessment.

The Group may request support, via SKI, from other specialist consultants employed by SKI, within limits imposed by the resources available.

1.2.3. Operation

The Group will meet two or three times a year, as necessary, to discuss the developing SKB investigations and their findings, and to provide advice to SKI. These meetings will be linked to separate discussion meetings with SKB staff and occasional visits to the sites being studied. Between meetings, the Group will keep up to date with the field and associated laboratory measurement and testing programmes through access to published and draft material from SKB. All technical material that cannot be obtained from published sources will be obtained and provided by SKI.

It is expected that the Group will meet with SKB at least once a year, with and arranged by SKI, to pursue particular matters and to be briefed on progress in the investigations. Members of the Group will only contact SKB and its contractors formally on matters associated with the investigations via SKI.

The Group will produce a written commentary after each Core Group meeting as a basis for SKI to develop its own views and interaction with SKB.

1.2.4. External Contacts

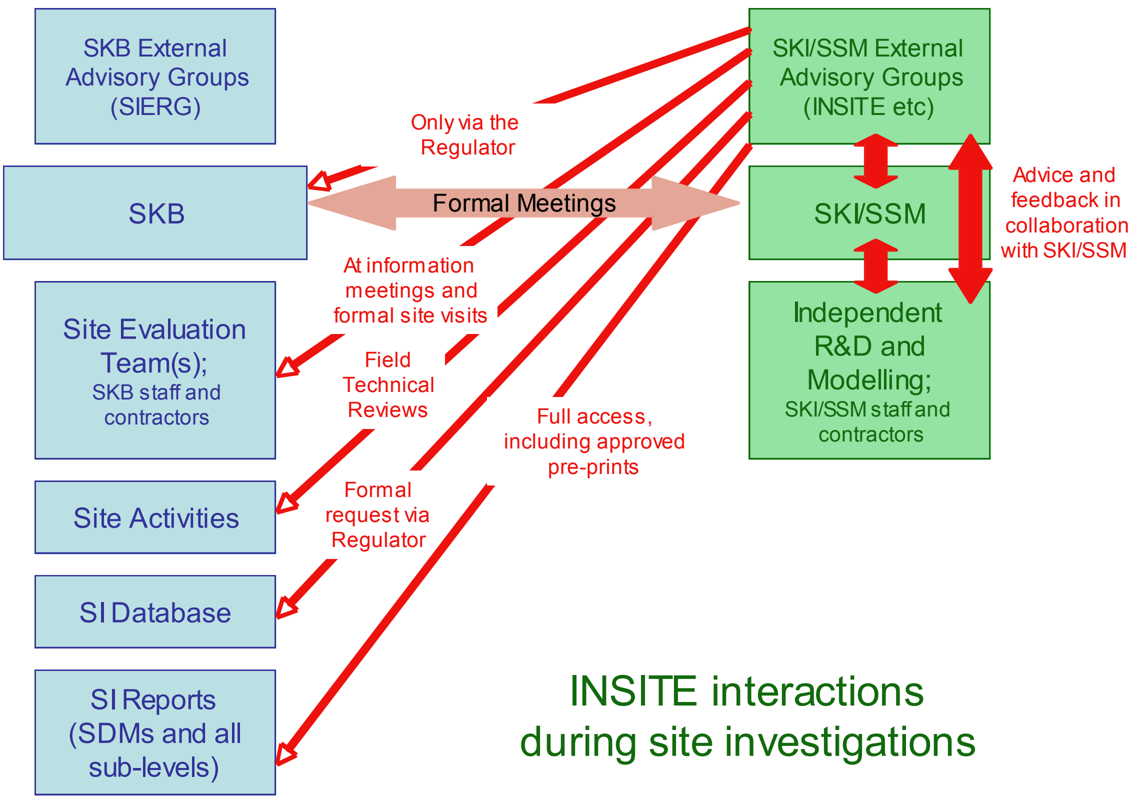
Members of the Group are free to comment or to respond as individuals to questions from third parties concerning the investigations, and will make it clear that their views are their own and not necessarily those of SKI. They will keep SKI informed of any third-party approaches that may be made to them in this context.

2. How INSITE worked

INSITE's work was performed outside a formal regulatory context. As SKB has not submitted a licence application, interactions between SKB and the regulatory authorities with respect to the site investigations were effectively informal consultations and information exchanges. Only where issues impinged on the regulators' statutory periodic review of SKB's regular RD&D programme documentation was there any formal standing for matters arising from INSITE's work.

SKI had regular, formal consultation meetings with SKB, at which INSITE members were not present. SKI formally provided SKB with their opinions and positions on various issues and asked for any information and clarifications that they required in their regulatory capacity. SKI and SKB together decided on the topics of any necessary Expert Workshops (see below) at these consultation meetings. It is important to note that these formal consultation meetings were the only officially recognised mechanism for regulator-implementer interaction during the site investigations. Although the authorities could ask for (and generally received from SKB) any information they required, all other interplay of the parties was informal and designed simply to aid understanding and facilitate the future formal licensing process. In this rather complicated phase, it was consequently important for INSITE to take great care in carrying out its work, so as to ensure its independence and consequent value to SKI.

An indication of the 'permitted' nature of interactions between the various groups that are discussed in more detail in this Section is given in the figure below.



2.1. INSITE meetings

The INSITE Core Group met two to three times a year to discuss the developing SKB investigations and their findings, and to provide advice to SKI. Meetings, which were attended by SKI staff concerned with the spent fuel project, generally lasted two or three days and gave ample time for discussion. A typical meeting programme would include:

- updates on the SKB and SKI work programmes and interactions between SKI, SKB and local communities;
- information on the results of formal, topical field technical reviews carried out by Core Group members during visits to the sites;
- information on 'expert meetings' held between the authorities and SKB (see below);
- discussion of major SKB reports under review by INSITE to enable joint views to be developed and appropriate advice to SKI to be formulated;
- information on the results of related SKI research projects (generally involving Core Group members);
- identification and discussion of key uncertainties and issues that required tracking as the investigations proceeded;
- planning a suitable work programme to provide SKI with advice at appropriate times.

These meetings were almost always linked to separate information exchange and discussion meetings with SKB staff and there were periodic visits to the sites to look at the investigations, material or rock exposures. The meetings with SKB were intensive, full-day events in which SKB would update both INSITE and the authorities on the detailed results of the investigations and their plans for future work. Generally, the focus would be on one of the sites, with only a brief update on the other, alternating sites between meetings, so that each site was dealt with in depth at least once a year.

Formally, INSITE provided no feedback directly to SKB at any of these meetings; as discussed above, this was done via SKI. While comments and views expressed in the direct discussions or expert workshops (see below) may have been valuable to increase mutual understanding of an issue, it was not INSITE's role to endorse SKB's approach or activities at these meetings. The meetings did not have any decision-making status. Similarly, lack of comment by INSITE was noted as not necessarily implying concurrence of views. The meetings did, however, provide the opportunity to receive information from SKB on specific topics and questions identified by INSITE and to provide SKB with the opportunity to clarify INSITE's views and understand better the advice that INSITE was providing to SKI.

From 2003, most of these meetings were joined by the newly formed SKB Site Investigation Expert Review Group (SIERG). These joint meetings allowed the SIERG members to be informed about the SKB work efficiently, along with SKI and INSITE, although the SIERG members were limited to asking questions of clarification, reserving any comments or discussion for their own closed meeting with SKB staff.

INSITE meetings thus also involved preparation for and evaluation of the meetings with SKB: discussion of the topics expected and our views on key information we hoped to get out of the meeting, preparation of any presentations that we intended to make to SKB on our work and post-meeting analysis of what we had heard during the day or seen on any associated field visit. For example, after a major document review it was often considered useful to explain to SKB our views and the advice that we were giving to SKI so as to clarify any suggestions that we might be making (e.g. to gather additional data) and to allow technical peers to talk directly to each other on complex matters.

On one occasion (April 2003), INSITE met formally with representatives of the Oskarshamn local community to explain what we were doing and how we worked. This also gave the opportunity for the community and its technical representatives to ask us questions. The meeting was with representatives of the LKO (Oskarshamn Community) Safety Group and their consultants and we made a presentation on the INSITE terms of reference and current activities.

INSITE also visited the ONKALO facility in Finland (June 7th 2005) to be informed about the approaches and the technical issues encountered by Posiva in the underground construction stage of a repository in a similar geological environment to the sites being investigated by SKB.
Between INSITE meetings, the Core Group kept up to date with the field and associated laboratory measurement and testing programmes through a variety of means:

- Access to published reports and draft material from SKB and to material stored on SKB's site investigation database. In addition, SKB lodged weekly and monthly progress reports on its web-based information system (a ProjectPlace tool), which could be accessed by the INSITE group. INSITE was also able to view publisher's proofs of some of the key documents in the latter stages of the programme to allow more timely review. All technical material that could not be obtained from published sources had to be obtained from SKB via SKI, with INSITE making requests to SKI.
- Carrying out detailed Field Technical Reviews (FTRs) of measurements on site and in the laboratory (e.g. structural remote sensing studies, fracture mapping, groundwater sampling, rock stress measurement, hydraulic testing, rock mechanics and thermal testing). Appropriately, most of these reviews took place in the earlier part of the investigations. Section 2.4 describes how FTRs were carried out and lists all the FTRs performed by INSITE.
- 'Expert Meetings', agreed by and convened jointly by the authorities and SKB. These were topical one-day meetings at key points in the site investigations designed to allow detailed technical and scientific discussion between relevant experts from INSITE, the authorities' R&D programme and SKB and its contractors. Depending on the topic being considered, these meetings could involve between 5 and 20 scientists. The objective was to assess the information available and attain a common level of understanding of key issues, although, as befits such informal, interim-stage interac-

tions in a regulatory forum, there was not necessarily any intention of reaching common views on the implications of an issue. The aim was that, at the end of the meetings, both the implementer and the regulator knew where their experts and advisors stood, technically. The Table below shows all of the Expert Meetings attended by members of INSITE.

April 2004	Geochemistry
April 2004	Regional flow modelling
March 2005	Geochemistry
April 2005	High rock stresses
April 2005	Rock mechanics and thermal properties measurements
May 2005	Geochemistry
March 2006	Large scale regional groundwater flow modelling
April 2006	Repository design
June 2006	Groundwater flow and transport modelling and use of large-scale field tests
September 2006	Stress and micro-cracking
December 2006	Mechanical and thermal properties of rocks
February 2007	The geochemical database: tracking and sourcing valid/representative geochemical data through both the ISI and CSI
October 2007	Geology and structural modelling: Forsmark
October 2007	SWIW and large-scale confirmatory testing, including plans for the future monitoring programme
December 2007	Design D-2
March 2008	Geology and structural modelling: Laxemar
April 2008	Geochemistry
April 2008	Forsmark rock mechanics and stress
October 2008	The use of SWIW and other tracer tests; the hydrogeological evaluation of Forsmark, with emphasis on large scale testing
February 2009	Repository design
May 2009	Laxemar hydrogeology: large scale testing and the results of the 3rd iteration of the DFN modelling

2.2. Information input to INSITE

Reviewing key, milestone documents, in particular the evolving Site Descriptive Models, was one of the main activities of the Core Group. The SKB programme generated an enormous number of documents, with the main interpreted output being in the ‘R’ report series. By August 2009, the investigations had generated about 1746 reports[3] – 1360 P-reports, mainly pertain-

[3] O. Olsson, SKB. Personal communication, August 2009.

ing to site data, (roughly 700 per site) and 380 TR- and R-reports mainly dealing with analysis and modelling, as well as more general process related and safety assessment issues. The pace of report production by SKB accelerated from 2005 onwards and, within two years of INSITE starting work, it became clear that we would not be able to review all of these reports in detail and produce individual reviews. The procedure became one of producing reviews of the main milestone R- and TR-reports that included comments on their supporting documents, as required, to explore points in depth. Evaluation of P-reports was largely restricted to field technical reviews (see Section 2.4), although we looked specifically and in some detail at the geochemical data.

Decisions on which documents to review and in what level of detail were made jointly with SKI staff, the eventual recipients and users of the reviews. Milestone document reviews were compiled from the work of all members of the Core Group, whereas discipline-specific reports were sometimes reviewed only by one or two members, but we have worked closely together through discussion meetings and all of our major review work has been closely integrated to ensure consistency of output and clear advice to SKI. Two main classes of SKB document were reviewed:

- interpretive reports, bringing together data and models into interpretations of specific aspects of site behaviour (e.g. groundwater flow, hydrochemistry), supporting detailed reports, and planning reports for future stages of the investigations;
- review for completeness and appropriateness of 'practical' SKB documents such as investigation methodology descriptions and procedures.

The main classes of information that INSITE has evaluated were:

- general documents related to the site selection process;
- planning documents for the site investigations;
- Field Procedures (Method Descriptions);
- Strategy and Methodology Guideline documents for the use of discipline-specific field and laboratory data to construct the Site Descriptive Models (SDM);
- SKB's monthly reports of the site investigations (these were incomplete);
- Site Descriptive Models;
- detailed supporting documents on data acquisition, interpretation and modelling for specific sections of the SDMs;
- documentation of critical computer codes used to develop the SDMs;
- documents related to performance assessment and the use of site-specific information.

The latter category was specifically the review of the use of site data in the SR-Can safety assessment, which is described in Section 2.6. From time to time, we have also been asked by the authorities to review in detail other reports related to, but not directly describing, the site investigations. These included SKB's 2007 RD&D (FUD) report and a series of reports related to what became known as the 'regional flow and siting issue' (see Section 3.4).

2.3. INSITE output

Our review reports (of both documents and field activities) were primarily aimed at use by the authorities, but they have also been issued by SKI as INSITE Technical Reports (TRD series) and, more recently, by SSM as memoranda (‘M’ series reports). The transition from TRD series reports to ‘M’ series occurred at the stage when the authorities were entering the pre-licensing period and the objective of our reports changed direction somewhat. The intention was now to an inwards focus for the reviews, for use by SSM in its formal licensing review, although the reports are still available on request by outside parties. This coincided with the cessation of information exchange meetings with SKB, as the site investigations came to a close and all parties entered the pre-licence application submission period.

A full list of all the TRD reports and those ‘M’ series reports that cover INSITE’s reviews is provided in Appendix 1. None of these has been printed or routinely disseminated, but they have been available on request from SKI/SSM. The current web access is at: http://webdiariet.ssm.se/

In addition to review reports, we have been asked from time to time by SKI to consider a specific issue and produce a topical report or position statement on a matter seen as particularly important to confidence in site understanding. Only a few of these reports have been produced:

TRD-03-01	Comments on Site Descriptive Models (SDMs) and Alternative Conceptual Models (ACMs)
TRD-04-09	Effects of borehole orientation on sampling of fractures at the Forsmark site
TRD-05-08	Need for Confirmatory Testing of Upscaled Flow and Transport Models
TRD-07-06	Some Insights from Simulations of SWIW Tests on a Complex Fracture

A record of each Core Group meeting (including analysis of the information exchange meetings with SKB) was produced and issued as an ‘M’ series report. The ‘M’ series also included the periodic updates of the Tracking Issues List and the CRI list (see Section 2.6). Separately, records of the semi-annual INSITE meetings with SKB were generated by SKB and then circulated to INSITE and SKI for amendment, with an agreed memorandum then being produced by SKB, but not formally published by either party. The same procedure was used to produce agreed records of each of the Expert Meetings involving INSITE members, the authorities and SKB.

2.4. Carrying out Field Technical Reviews

The objective of the Field Technical Reviews was to provide SKI with a view on the scientific and technical quality of the site investigation work and whether it was achieving necessary goals. In the course of the work, the expert reviews turned up practical issues, problems and questions that did need

to be considered by SKB: in this sense they could be as useful to SKB as to SKI. It took some time to gather sufficient experience of carrying out these reviews before an appropriate procedure was developed. For example, the reviews were initially termed field ‘audits’, a term that caused confusion, at a time when SKB was finalising full implementation of a quality management system that involved formal internal and external QA audits. The INSITE field evaluations did not constitute formal audits by the regulator or their agents and it was recognised that use of the term was incorrect; hence they were more properly re-named ‘Field Technical Reviews’ (FTRs).
The following FTRs were carried out and reported in INSITE technical reports or at Core Group meetings:

June 2003	Geochemistry procedures at the Simpevarp site	TRD-03-02
March 2003	Site Investigation Methodology and Application at the Forsmark Site: covering (a) bedrock geology, structure geology and geophysics and (b) hydrogeology and fracture mapping	TRD-03-03
April 2004	Rock stress measurement with the overcoring technique at the Forsmark site	TRD-04-07
April 2005	Testing and reported results of mechanical and thermal properties of rocks performed at the Swedish National Testing and Research Institute	TRD-05-04
August 2005	Neotectonic and lineament studies at Laxemar and the DFN data gathering (hydraulic testing) and SWIW work	Reported at 8th CG
May 2006	The DFN and minor deformations zones at Laxemar	Reported at 9th CG
June 2006	Field geochemistry activities at the Forsmark site	TRD-06-01

It became clear after the first reviews that there could be a requirement from SKI for a formal response to FTRs from SKB. To facilitate the process, the scope of FTRs was discussed with SKB in advance and SKI then established the requirements for the response with them. In addition, some of the issues arising from FTRs found their way onto the INSITE Tracking Issues List (TIL: see Section 2.5) for tracking and resolution and onto SKI’s own list of matters for their consultation meetings with SKB. An agreed formal response mechanism facilitated both discussion and resolution.

The FTR process evolved over the period of the ISI. To be of the highest value FTRs needed to be correct and free of misunderstandings between the reviewer and the SKB field teams. The written reviews were thus submitted to SKB in draft form to ensure that there had been no misinterpretations on the part of the reviewer. Following a response from SKB, they were updated if necessary by the reviewer and other members of the INSITE team and the FTR document was finalised. If any important issues were raised by the FTR, these are entered into the TIL for tracking (see Section 2.5).

2.5. Managing the issues arising from our reviews

It became clear early in our work that a formal means of identifying, classifying and recording issues arising from our review works would be needed. There would also need to be a way of communicating these issues to SKB and of tracking any further information they provided. The eventual intention would be that the issues could be resolved in some way. Our approach to this central aspect of our work evolved progressively through the site investigations.

At our second meeting, in November 2002, it was decided that our main issues of concern would be incorporated into two tables, intended to facilitate tracking as the investigations proceeded:

- **Category A Issues:** Important matters that we believed would either need to be tracked throughout the investigations or which would need to be resolved soon after they are raised, by further discussion between SKI and SKB.
- **Category B Issues:** Matters of less immediate concern or likely significance to the overall findings of the investigations, but which may need to be monitored regularly and should be resolved before the end of the work.

The first list that was generated comprised 18 Category A issues and 12 category B issues. SKB provided written responses to some of the Category A issues, which were found useful and, with a few exceptions, allowed us to close-out or reclassify the issues covered. The 'issues list' was then extended to show how the issues developed and were being dealt with. From April 2003 onwards, it was kept as a separate document (see below), which incorporated SKB comments and our own actions and recommendations to SKI.

2.5.1. The Tracking Issues List (TIL)

By January 2004 the list of issues had been formalised into the Tracking Issues List (TIL). This list summarised INSITE's key concerns in the form of technical review points and recorded SKB responses. It was a detailed, 'live' record of how issues were raised, tracked and dealt with during the site investigations and was the vehicle for putting issues to SKB and receiving their responses. A central activity at each of our meetings was to review and update the TIL, assess response comments prepared by SKB on the Category A issues and prepare a revised version, with all our key review comments being incorporated into the TIL.

Issues were broken down according to strategy or discipline area:

- Field Methodology (FM)
- Data and Model Management (DM)
- Geology and Tectonics (GT)
- Hydrogeology and Transport (HT)
- Geochemistry (GY)

- Rock Engineering (RE)
- Site Suitability (SS)

The TIL was the vehicle for INSITE to raise issues with SKB and to receive responses in a documented way. It was intended as a tool to assist SKI in their consultations with SKB. The TIL developed into a valuable record of how issues arose and were dealt with and it summarised INSITE's views and consequent advice to SKI. However, it had no formal status as a record of SKI's position or of agreements reached with SKB – these were only found in the record of the SKI-SKB consultation meetings. Thus, unresolved issues in the TIL could be elevated by SKI as issues in SKI-SKB consultation meetings and, when the issues appeared to have been agreed upon, a decision to this effect could be taken jointly by SKI and SKB at their consultation meetings and formally recorded.

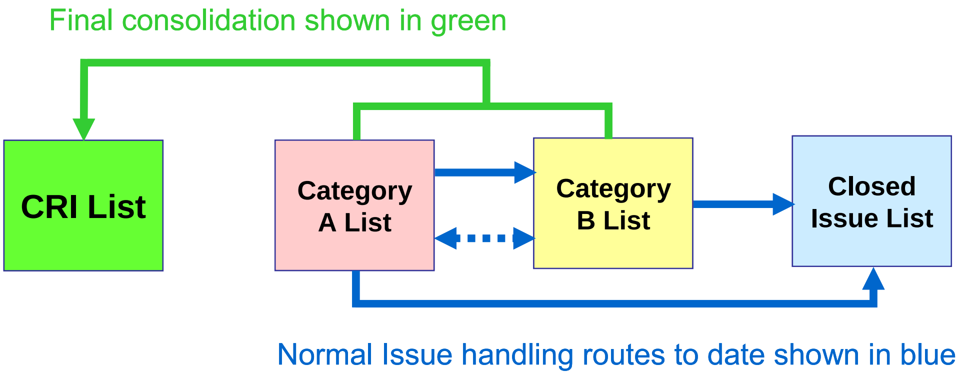
After each INSITE meeting the TIL was updated, with the final version being produced as an INSITE Memorandum[4] in March 2006, by which time it had developed into a 118-page document. At this stage, 49 Category A issues had been dealt with, with 21 of them still remaining open. For several of the issues, there had been up to six iterations of comment from INSITE and response with SKB. In October 2006, the TIL was significantly restructured to reflect the current stage of the SKB site investigations, with possibly only one full field season remaining in SKB's Complete Site Investigation (CSI) schedule. INSITE wished to prepare for the conclusion of the surface-based field programme by focussing the outstanding issues in the TIL for resolution in the next 12-18 months.

Until October 2006, the TIL had consisted of Category A Issues, Category B Issues and Closed Issues, with the Closed Issues list containing issues that have been removed from the Category A and B lists, since they were considered complete/closed or had been replaced by other (more specific) issues. From time to time, issues also moved backwards and forwards between the A and B list, depending on the findings of the field programme. In order to focus the discussions with SKB during the final year of the field programme, the remaining Category A and B issues were brought forward and consolidated into a small set of Consolidated Review Issues (CRIs).

2.5.2. The Consolidated Review Issues (CRI)

The CRIs were seen by INSITE as being the key matters remaining at the closing stage of the site investigations. These matters were frequently multidisciplinary, hence the need to consolidate previous issues. This approach also reflected the fact that issues that may have appeared technically isolated several years previously could now be seen in the context of the developing integrated understanding of the sites. The old TIL issues remained as a traceable record of issues that had been raised and addressed, leading to the CRI. The process for bringing the TIL to the CRI structure is outlined schematically in the diagram below.

[4] INSITE Memorandum M-06-03



It was expected that each of the Consolidated Review Issues (many of which were multidisciplinary) would need to be addressed to an extent regarded as satisfactory by SKI by the time of SKB's SR-Site safety assessment and its repository construction licence application. An original list of 20 CRIs in October 2006 eventually grew to 22, as shown in the Table below:

CRI-1	Alternative models, uncertainties and data bias
CRI-2	Conceptual understanding & uncertainties in the geological model
CRI-3	Neotectonics
CRI-4	Flow anisotropy, heterogeneity, correlations & the properties of HCDs
CRI-5	Confirmatory testing of upscaled properties and field tests to detect large scale flow properties
CRI-6	Planning of site characterization activities during excavation and in underground facilities
CRI-7	Confirming models of the site-scale groundwater flow system
CRI-8	Groundwater compositions at repository depth
CRI-9	Spatial variability of hydrochemical data
CRI-10	Geochemical and isotopic data for palaeohydrogeology and groundwater evolution
CRI-11	Mineralogical and petrographical characterisation of fracture and matrix minerals
CRI-12	Characterisation of colloidal, organic, microbial and gaseous species in groundwaters
CRI-13	Geochemistry of mineral phases and other media buffering long-term chemical stability

CRI-14	Data from pre-existing boreholes in and near the sites
CRI-15	Geochemical analogues of radionuclides
CRI-16	Stress measurements and stress interpretation
CRI-17	Thermal properties of rocks and rock masses
CRI-18	Horizontal deposition holes
CRI-19	Effect of stresses on flow
CRI-20	Strategy for modelling rock mechanical behaviour
CRI-21	Transport properties of transmissive fractures and the rock mass
CRI-22	Consistency of discrete-fracture-network models between disciplines

The CRIs were managed in the same fashion as the previous TIL, with regular updating by INSITE and responses from SKB. The final issue of the CRI List was produced in December 2008[5], after completion of surface-based investigation work at both sites and production by SKB of the final Site Descriptive Models (SDM-Site) that will support the SR-Site safety assessment, the justification for selection of a preferred site in 2009 and the subsequent licence application for construction at that site. After several iterations with SKB all 22 of the CRIs had been successfully closed, meaning that INSITE had adequate understanding of SKB's approach, reasoning and position at the end of the CSI (see further discussion of the definition of 'closed' below).

It was noted that some issues would be pursued further by SKB during continued investigations throughout the underground construction stage (the CDI phase, which will probably commence around 2013-2015, depending on the progress of licensing). The CRI list would thus form a useful starting point for any tracking programme equivalent to INSITE that might be decided upon by SSM, at that time.

2.5.3. The Structured Review Topics (SRT)

By the end of 2008, INSITE had moved into a review and assessment mode to consider the adequacy of the pre-licensing documentation on behalf of SSM; specifically, review of the SDM-Site report series. In this new situation, INSITE utilised the CRI List to provide structure to its review activities.

5 INSITE Memorandum M-08-09

A set of Structured Review Topics (SRTs) was developed from the CRIs and was used as an organisational basis for the review commentaries that were provided to the authorities on SDM-Site and were also proposed as a basis for later review of Underground Design Phase D2 and the Site Engineering Report (SER), and SR-Site.

The SRTs are shown in the Table below, with the intended application being indicated after each group caption (SDM-Site, D2/SER or SR-Site review).

Understanding of geological structure and past evolution of the site (SDM-Site)	
GSDM-1	Are the spatial distributions and variability in the character of the rocks (e.g. alteration, fracturing, sulphide content) and the geological structures (classification of structures, size distribution, use in geo-DFN) adequately described and well understood? Has SKB convincingly addressed any alternative structural interpretations (thus any alternative conceptual or structural models) and associated uncertainties in propagating this understanding to geological models?
GSDM-2	Is the relationship between structures (connectivity, intersections, channels, match between observations and DFN) adequately investigated and described, and is it well understood? Is there an adequate understanding of the population of minor deformation zones and smaller-scale fractures (MDZ/GeoDFN/HydroDFN) such that the DFN models used bound the uncertainty regarding frequency of discriminating features and their spatial variability?
GSDM-3	For major deformation and fracture zones, is there a good understanding and adequate data on the size and characteristics of the transition zone/disturbed zone into the host rock?
GSDM-4	Is there comprehensive information on the nature and variability of fracture mineralogy and its relationship to geological evolution and fracture reactivation?
GSDM-5	Does SKB understand the nature of the terminations of structures (e.g. blind; splayed; against other structures) and has it incorporated this knowledge successfully into the fracture models?
Geological structural aspects of initial state of repository and near-field host rock (D2)	
GD-1	Is there a sufficient understanding of the character and location of discriminating fractures for the selection of suitable deposition holes and tunnel layouts, with respect to space utilization, operations and input to safety assessment? Does SKB have a workable method for detecting and avoiding the discriminating features in the deposition tunnels? Are the criteria proposed for identifying discriminating features during construction (FPC/EFPC) likely to be successful in realistic underground conditions? Does SKB have an adequate understanding of the site-specific geological and geophysical characteristics of such features?
Dynamic structural evolution of the host rock (SR-Site)	
GSR-1	Has SKB used any evidence of past reactivation of structures and dealt adequately with the potential for their future reactivation and consequent change in character, as a result of: • external impacts of glaciation and earthquakes • repository thermal and excavation related impacts? *(Safety Functions: R2a,b; R3a)*
Understanding of current and past site hydrogeological (groundwater flow) system (SDM-Site)	
HSDM-1	Does SKB demonstrate an adequate understanding of the site-scale hydrogeological system? Are the main structures controlling flow recognized and characterized in terms of flow properties, heterogeneity and anisotropy (where important)?
HSDM-2	Is there evidence for the assumed relationship (coupling) of the HydroDFN to the site-scale hydrogeological system? Does the set of DFN models used adequately represent the network connectivity controlling variability of flows to the near-field? Are there likely model alternatives that would give significantly different transport behaviour (e.g. channelling) and, if so, has the likelihood of these models being correct been properly incorporated into quantitative flow modelling? Do these models for flow channelling bound the site-specific uncertainty?
Hydrogeological aspects of initial state of repository and near-field host rock (D2)	
HD-1	Are the criteria proposed for identifying hydraulically discriminating fractures during construction

	(FPC/EFPC/hydrotests) likely to be successful in realistic underground conditions? Will the results be adequate to bound the variability of flows to the near field which could affect, e.g. buffer saturation and buffer erosion? Does the CDI programme as presented at the time of SR-Site adequately cover any current deficiencies?
HD-2	Is it possible to estimate the hydrogeological drawdown and/or upconing due to excavation and the resulting effects on hydraulic gradients and groundwater movements during operational and post-closure periods within a reasonable range of uncertainty?
Future groundwater flow and transport at the site (SR-Site)	
HSR-1	**Site scale model:** Has the site scale hydrogeological model been confirmed adequately through relatively large-scale interference tests and tracer tests or other monitoring data so that it can be used in a predictive sense for evaluating the effects of future climate evolution? *(Safety Function: R2a-d)*
HSR-2	**Upscaled models:** Is there an adequate theoretical and information basis for the upscaled flow transport properties, accounting for potential channelling and anisotropy effects, which are used by SKB in SR-Site? *(Safety Functions: R2a-c)*
HSR-3	**Fast pathways:** Has the potential occurrence of fast flow and transport paths (e.g. via connected flow-paths or channelling due to strong heterogeneity, in an EDZ or as regional flow channelling) being fully explored? If fast paths cannot be excluded, has SKB discussed their potential effects on flow and transport (e.g. flow through a potential EDZ during glacial advance and retreat including the effect of connectivity in an EDZ that may have been enhanced during the thermal period? *(Safety Function: R2a)*
Understanding of hydrogeochemical properties and past evolution of the site (SDM-Site)	
CSDM-1	Are the groundwater compositions (for example with respect to salinity, Eh and redox-sensitive solutes, pH, inorganic and organic carbon, major and trace solutes, dissolved gases, micro-organisms, colloids) thoroughly characterised and their origins, history and interactions with rock well understood?
CSDM-2	Is adequate hydrochemical and palaeohydrogeological evidence presented in support of the model of the deep groundwater flow system (flow rates and directions, temporal stability) and is there isotopic support for ages of groundwaters and travel times to repository depth for various boundary conditions? Have hydrochemical and isotopic data been used appropriately for the calibration and testing of a palaeohydrogeological model for evolution of the groundwater system? Have uncertainties in data and in assumed initial and boundary conditions been realistically included in the modelling?
CSDM-3	Is there sufficient hydrochemical data for the shallow groundwater system and is there consistency between hydrochemical and isotopic indicators of recent groundwater movements and the shallow groundwater model (flow rates and directions, penetration of infiltration)? Have present-day recharge and discharge zones been successfully identified and is evidence presented for their changes over time?
CSDM-4	Is there convincing geochemical evidence (e.g. trace element analogues, rock matrix water compositions, sorbed ions on minerals) to support an understanding of solute retention and solute transport processes in the geosphere?
Geochemical aspects of initial state of repository and near-field host rock (D2)	
CD-1	Have all potential effects of excavation on geochemical conditions during operational and early post-closure periods been considered (e.g. redox changes, effects of mineral oxidation and introduced materials on water drainage composition, radon emanation)?

Understanding of the radionuclide transport properties of the site (SDM-Site)	
TSDM-1	Is there a sound theoretical basis for defining the solute transport and retention properties of fractures, intact rock mass and deformation zones and have the parameters controlling these properties been adequately quantified by field and laboratory measurements?
TSDM-2	Are the values of the solute transport and retention parameters in TSDM-1, which will be used in radionuclide transport models, supported by confirmatory field tests?
TSDM-3	Is there any direct observational evidence for the existence of fast transport pathways from repository depths to the surface?
Dynamic geochemical evolution of the repository and host rock (SR-Site)	
CSR-1	**Corrodants and EBS degradation**: Are the models for (a) the maximum concentrations of corrodant species (S, N, O) in deposition holes, tunnels, backfill and at buffer interfaces with canisters and (b) of species that could affect buffer/backfill behaviour (e.g. salinity) sufficiently robust? Have the models dealt adequately with known or potential heterogeneity, temporal variability with future evolution scenarios (e.g. maximum salinity at repository depth, sub-glacial fresh water infiltration) and the controlling influence of biogeochemistry (microbes, SO_4, NO_3, O_2, Fe, introduced materials, DOC, etc)? *(Safety Functions: R1a-f)*
CSR-2	**Solubility and Speciation:** Are the dynamic effects on each aspect of groundwater composition at repository depth relevant to radionuclide behaviour (solubility, speciation, complexation, interactions with backfill, buffer and introduced materials) well understood? Can the changes be predicted and bounded with confidence for: • external impacts of environmental evolution and glaciation (e.g. penetration of fresh water) • repository thermal and construction materials related impacts? *(Safety Functions: R1a-e; R2d)*
CSR-3	**Colloids**: Is there an adequate description of the interactions of radionuclides with colloids and the mobility of colloids in the host rock (sorption, filtering, abundance, stability)? Are potential impacts of future changes in the abundance and nature of colloids (colloidal bentonite and natural colloids) in the near field and far-field geosphere considered in radionuclide modelling? *(Safety Function: R2e)*
CSR-4	**Transport:** Does SKB provide a comprehensive description of groundwater chemistry, mineralogy and matrix interactions that affect radionuclide transport through the far-field geosphere: • identification and description of interacting solid phases, sorption, accumulation and co-precipitation; • speciation and complexation , including colloid formation and movement; • matrix diffusion; • estimation of transport resistance; • supporting arguments using data from the natural system? Have potential changes of interacting solid phases (alteration, precipitation, dissolution, accessibility of matrix) in future evolution scenarios been taken into account in uncertainties in the transport and retention model? *(Safety Functions: R2a & d)*
CSR-5	**Future transport pathways:** Is the description of potential travel paths from repository depth to the biosphere consistent with the site hydrochemical model? Is palaeohydrogeological interpretative evidence presented in support of chemical and hydraulic stability of these pathways? Are there sound descriptions of hydrochemical conditions at potential future discharge zones and at the geosphere-biosphere interface, and is the biosphere model consistent with these conditions? *(Safety Functions: R2a-c)*

Understanding of the rock engineering properties of the site (SDM-Site)	
ESDM-1	**Stress conditions in the near-field rock:** Is there a sufficient understanding of the in-situ stress regime at the site to allow appropriate design of the deposition areas and layout of the repository?
ESDM-2	**Rock mass strength and thermal properties:** Does SKB have adequate data on and understanding of the variability of these properties throughout the site?
ESDM-3	**Deformation zone properties:** Does SKB have an adequate understanding of the strength and deformability of the different classes of deformation zones that control the structural layout and design of the repository?
Rock engineering aspects of initial state of repository and near-field host rock (D2)	
ED-1	**EDZ:** Are the nature and the quantitative characteristics of the EDZ known sufficiently to allow rock support and grouting requirements to be bounded in advance of construction of the deposition areas?
ED-2	**EBS emplacement:** Do the known properties of the rock mass support the proposed design of the deposition area and the emplacement methodology for the EBS (deposition holes, deposition tunnel, emplacement technology)?
Dynamic rock-mass evolution of the repository host rock (SR-Site)	
ESR-1	**Excavation and thermally induced spalling:** Is the potential for spalling sufficiently well understood and accounted for in the assessment of the early evolution of the near-field? *(Safety Functions: R2a,b)*
ESR-2	**Swelling induced tensile fracture around deposition hole:** Is the potential for tensile fracturing after buffer swelling sufficiently well understood and accounted for in the assessment of the early evolution of the near-field? *(Safety Functions: R2a,b)*
ESR-3	**Shear-induced change of permeability from heat and glacial loading:** Does SKB present convincing data and models to scope possible permeability changes during the thermal period and, later, during glacial cycling? *(Safety Functions: R2a,b; R3)*
ESR-4	**Large-scale rock failure from thermal loading of repository:** Does SR-Site assess the likelihood and consequences of large-scale failure in the near and far-filed rock as a result of the total thermal load imposed by the repository? *(Safety Functions: R2a,b)*
Treatment of common issues in interpretative support of site understanding and/or safety assessment (SDM-Site and/or SR-Site)	
ISA-1	**Uncertainty identification, assessment and management:** Does SKB present a consistent and comprehensive treatment of uncertainties in all areas: e.g. model assumptions; simplification assumptions such as neglected features; parameter values; data completeness; interpretative models; upscaling artefacts? Are appropriate validation exercises and confidence assessments presented?
ISA-2	**ACM management:** How has SKB handled viable alternative conceptual models (ACMs) that emerge from site characterization in the safety assessment? Have viable ACMs received adequate analysis? Has a rational approach been used, such as logic-tree analysis and/or expert elicitation to establish relative weights for ACMs, so as to handle quantitatively ACMs that lead to significantly different predictions?
ISA-3	**Coupled THMC processes in flow and transport:** Does SR-Site deal consistently and in an integrated manner with the various THMC couplings that can occur as a result of the thermal period, permafrost development, glacial loading and seismic impacts?*(Safety Functions: R3 and R4)*

2.6. Contribution to other regulatory reviews

INSITE had collaborated with SKI's performance assessment group in 2005, when a joint discussion took place on what could be sensitive performance issues from the PA viewpoint of total system behaviour and the INSITE viewpoint of uncertainties in site characteristics directly relevant to PA. This collaboration was part of SKI's programme to deploy independent safety assessment capabilities to test SKB's own analyses of repository performance.

In 2007, INSITE was asked by SKI and SSI to participate in their joint review of SKB's milestone interim post-closure safety assessment project, SR-Can. SR-Can used the evolved SKB safety assessment methodology to evaluate the performance of a hypothetical spent fuel repository at both the Forsmark and Laxemar sites and was regarded as a test-bed for the way in which the eventual licence application safety assessment would be structured. The authorities established three external expert review groups to advise them on their own internal review process, with the groups covering the near-field (engineered barriers), performance assessment methodology and site characteristics.

The group looking at the use of site investigation information in SR-Can was a joint INSITE-OVERSITE group (Site Investigation Group: SIG). The SIG directed its review towards how site data and understanding of the sites had been incorporated into the safety assessment work. Specifically, SIG was asked to assess whether, in SR-Can:

- site specific information is accurately represented and fully utilised;
- there is sufficient understanding of site features and processes for purposes such as risk calculation and assessment of long-term site evolution (and, if not, what improvements will be needed for SR-Site);
- the site-specific information used in SR-Can is likely to be sufficient for SR-Site (taking account of any database improvements emerging from the previous item).

The SIG was asked to pay particular attention to:

- quality and quantity of site data with respect to their use in SA;
- data gaps with respect to the data requirements of models;
- how data were abstracted for use in SA modelling;
- handling of uncertainty;
- consistency in parameter choice and use across the various parts of the SA;
- understanding of site evolution and how it is described, as a basis for the SA;
- scenarios for future site evolution;
- feedback from the SA to continued site investigations.

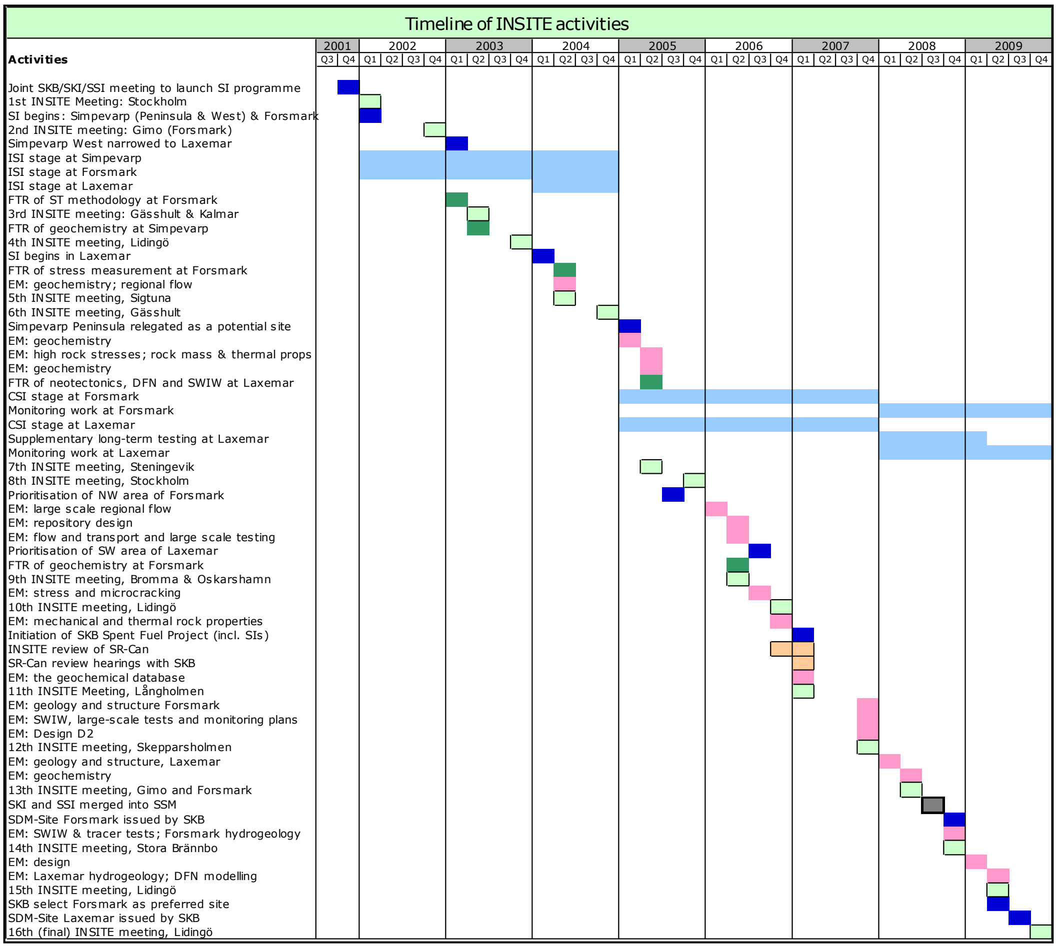
To a large extent, both INSITE and OVERSITE were already familiar with many of these points, having been tracking them continuously since the start of the investigations. Consequently, SIG had the advantage of a firm understanding of the sites and of SKB's understanding of them, before the review began.

INSITE reviewed the SR-Can report and much of the available supporting site-related documentation over the turn of 2006-7. Based around a checklist of structured questions and written responses from SKB, hearings took place in March 2007. At the hearings with SKB, the SIG had a full day in which to clarify matters arising from the review and from the written questions and SKB responses that had circulated in February and early March.

The results of this review were sent to SKI and SSI in a joint report of the SIG[6] in August 2007 and were used by the authorities to help them in their own review of SR-Can.

2.7. Overall record of INSITE activities

The chart below shows a timeline of INSITE's main activities from 2001 to 2009.



[6] International Expert Review of SR-Can: Site Investigation Aspects. SKI Report 2008:09; SSI Report 2008:11.

3. Major topics that arose during the investigations

Although the majority of our work was focussed on specific aspects of the emerging understanding of the sites (which are discussed in the next two Chapters), several over-arching matters arose. Predominantly, these concerned the interpretation of groundwater flow and solute transport in fractured rocks in the specific terrain of the Fennoscandian Shield. These issues raised debate, largely through written exchanges with SKB in the TIL and the CRI list, but also at some of the Expert Meetings. The details of the exchanges can be tracked by reading the final version of the TIL and CRI reports[7]. Some of the issues gave rise to topical technical reports, both from INSITE and SKB, which acted as position papers.

3.1. Alternative Conceptual Models (ACMs) in the management of uncertainties

This issue proved contentious throughout the SI programme, led to a series of clarifying exchanges between INSITE/SKI and SKB, and remained only partially resolved at the end of the surface investigations. The matter was first raised in 2001 when we included a TIL item described as follows: "Identification, testing and selection between alternative interpretations and models of site properties, behaviour and evolution and using this understanding to guide ISI & CSI field activities. This should be a clear component of each step of the SI and of each version of the site descriptive model." SKB believed that the matter was being dealt with in the way that SDMs were being developed, but INSITE disagreed.

By 2003 the issue was more clearly stated by INSITE, roughly as follows: "Forsmark SDM v.1.1 contains a good discussion of uncertainties and their tracking protocol. These uncertainties will be tracked all the way through to safety assessment. In principle, SKB will have kept all the information and can evaluate the impact of uncertainties. However, SKB appears to believe that there is a "best" model and the uncertainties are around the "best" model. INSITE believes that there are similarly likely models – alternative conceptual models (ACMs). Further, the ACMs are internally consistent models that satisfy available data. They are internally consistent in the sense that the structures, the boundary conditions and the state variable distributions (pressure heads and salinities) are physically consistent with each other. Thus keeping track of ACMs will ensure internal consistency for each ACM all the way to safety assessment. The way SKB is planning to do it is to keep track of these uncertainties one parameter (or characteristic) at a time. Then, when evaluating effects of uncertainties during safety assessment, they would have to combine these uncertainties and ensure internal consistency at that time. It is not impossible, but would be difficult".

[7] INSITE Memoranda: M-06-03 and M-08-09.

The issue seemed so fundamental to INSITE that it formed the topic of our first Technical Report[8], issued in 2003. Here we defined ACMs as follows: "Alternative conceptual models (ACMs) are alternative SDMs that are consistent with all or most of the available data, and there is no basis to prefer one to another. In this sense, ACMs are no different from the SDM, except that they may not have equal probability of reality. Sometimes, an ACM (or SDM) is not consistent with all the data, in which case the data in question should be clearly identified and evaluated, and perhaps additional measurements made to confirm the data".

We also noted that ACMs are not model refinements or model variants: "model refinements are improvements on a model when new information or new insights are obtained. They supersede the older model, which should thus be put aside. These are often labelled with different model version numbers. They are not ACMs. Model variants are obtained by varying the properties of some of the parameters or making minor adjustment on portions of the geometry".

We also noted in the report that: "… ACMs should be considered in the site investigation (SI) stage, and should not be left to be represented later, as a variant or as part of the overall uncertainty in PA or SA, because an ACM demands particular data gathering and interpretation, as well as providing feedbacks to the SI. For example, any alternative geometry would provide a different set of structures for the SDM, and different structures would necessitate re-interpretation of hydrogeological, mechanical and chemical data or require new site measurements to test the ACM. Further, a new model representation would also involve new parameters that describe the representation. These new parameters need to be measured, which is part of the site investigation programme. Often, a field test to obtain model parameters by calibration against a particular ACM is necessary and essential. This again is part of the SI programme".

The issue ran back and forth, with no real response from SKB until, when the CRI list was produced, it became the first issue in the list: CRI-1. However, by the end of 2006, SKB were in a position to reconsider their position and make a comprehensive response to the challenge on ACMs. In précis (our minor editing; for the full text see the final CRI report), they responded as follows:

> The SDM clearly identifies alternative models and hypotheses for further exploration. It also addresses whether these alternatives need to be considered in the Safety Assessment. The Alternatives Handling table will be updated in the final version of the SDM. All uncertainties, including the alternatives, identified in the SDM are directly considered in the Safety Assessment work. The initial state of the geosphere is described in the SDM, but this cannot always be used directly in the safety assessment. There may be a need to also consider non-site specific information, to add judgements on how to handle the uncertainties identified in the SDM and to make final selections of model input data.

[8] INSITE Report TR-03-01.

> A 'Data Report' was thus devised to compile input data, with uncertainties, for the SR-Can assessment calculations and for a wide range of conditions. A procedure for assessing data is applied, where, among other things, the question is raised whether there are alternative representations, e.g. those identified in the SDMs are addressed. According to the protocol, the various sources of information are combined into quantified data values and uncertainty estimates. Based on their previous assessment, i.e. also considering conceptual uncertainty and alternatives, justified uncertainty estimates of the applicable data are provided. Depending on possibilities and assessed importance, the uncertainty estimates are usually given either as a distribution function, subjective percentiles or as a range. However, in some cases it has instead been necessary to provide these estimates as a selection of alternative representations. Regarding input from the SDM, this has been the case regarding the hydrogeological models, where SR-Can assesses the implications of the CPM, fully correlated DFN and semi-correlated DFN of Forsmark.
>
> In SR-Can, these different representations are given equal probability, although out of principle it could be possible to attach different probability to different representations. Furthermore, in the risk analysis the implications of these different representations are assessed against the full uncertainty distributions of other input in to the analysis; i.e., there is not only an analysis of each uncertainty individually. Finally, the total risk is assessed for the alternatives resulting in the highest conditional risk, i.e. avoiding the problem of risk dilution by formulating too many (equal) alternatives. The alternative hydrogeological representations have strong implications on risk, and this is an important feedback to consider in the concluding phase of the SDM work.
>
> SKB also made the point that they do not, by definition, assume there is a 'best' model to describe the site, but noted that there can often be strong justification for a particular means of interpreting the field data, although alternatives may not be fully discarded. Alternatives need not be equally probable, although they can be. While several very different alternative hypotheses may be (almost) equally valid at an early stage of the site investigation, the potential for very large deviations in the description decreases when data density and cross-discipline analyses increase. For example, within the potential repository volumes, SKB has the ambition to reduce uncertainty in the deformation zone model to a question of details in orientation and properties of the larger zones, whereas a statistical representation of minor deformation zones would be sufficient, leaving little room for substantially different alternative representations.

Clearly, there was still not a 'meeting of minds' on this topic, but SKB certainly had a methodology for translating and tracking uncertainties from SDM to SR-Site. By this stage of the SI, it was too late for the approach that we had advocated (of letting ACMs help define SI work, as a means of model testing) to be deployed meaningfully. SKB had, instead, decided to take the approach of incorporating the uncertainties arising from different means of interpreting certain information into sensitivity studies within the safety assessment. We found ourselves to be generally satisfied that we understood SKB’s position and response (for the full texts, see the TIL and CRI reports), but waiting to see convincing examples – specifically, that SKB would be capable of incorporating interpretational uncertainties effectively into safety assessment calculations. Consequently, we note that the way in which this issue will be addressed in the upcoming SR-Site report and licence application will be an issue for SSM to track closely.

3.2. Fracture network modelling

Probably the most important single aspect of the site investigations was to build an understanding of the nature of the network of fractures that characterise the rock in this type of geological environment. Indeed, in the radioactive waste disposal world, this environment is typically categorised as ‘hard, fractured rock’, emphasising the key role of the fracture system. The fractures are the dominant control on groundwater movement, the mechanical response of the rock to stress and the engineering behaviour of eventual repository openings, and much of the safety case for disposal hinges around being able to forecast these dynamic processes.

After decades of experience in the ‘hard, fractured rock’ regime, SKB applied an approach to classifying and dividing up fractured rock domains that, described here simplistically, consisted of deterministic mapping of major fractures and stochastic representation of the small fractures that dominate the bulk of the rock mass. Different users of fracture information developed their own approaches to incorporate the ‘raw’ fracture data into their models.

Throughout the investigations, INSITE emphasised the importance of ensuring that sub-models used in these different disciplines (in particular structural geology, hydrogeology, rock mechanics, and repository design) were based on a single, consistent model of the geometry of geological features at each site, including both the large-scale features that could be described deterministically, and smaller-scale features such as fractures or dyke swarms that might need to be described probabilistically. The aim was to ensure that a consistent cross-disciplinary model was developed, for each variant of the underlying geometry and flow/transport properties that was considered.

This started off well but, by the middle of the CSI stage, we considered that, whilst the large-scale features were being handled consistently across disciplines, in terms of their geometry, there was a growing divergence of models for the geometry of the smaller-scale features which were treated stochastically (discrete-fracture networks, or DFNs), especially between geology (GeoDFNs) and hydrogeology (HydroDFNs). Whereas previous versions of the HydroDFNs had been derived from the GeoDFNs, ensuring geometric consistency, the HydroDFNs had now begun to calibrate size-distribution parameters directly to flow anomalies, which we considered to be poorly constrained. Alternative conceptual models, for instance channelised fractures, could give rise to HydroDFN models that would match the data equally well, but would have very different implications for geochemical stability of the near-field and radionuclide transport in the far-field. The detailed data sets, the statistical approaches that had been applied to model them and various other surrounding issues were discussed in depth at a number of expert meetings, but the issue was never completely resolved. This left INSITE with the view that SR-Site would certainly need to address the non-uniqueness of the DFN models by incorporating ACMs.

Coupled with this overarching issue were various rather intractable uncertainties stemming from the limitations of surface-based investigations to characterise the fracture systems comprehensively. There were difficulties at several scales. The properties of major deformation zones remained uncertain at the end of the site investigations: their length, termination style, internal structure and, in particular, properties (and exact location) at repository depth are difficult to characterise from borehole observations from the surface. We note that SKB will need to take a broadly bounded approach to sensitivity analyses of these factors when they model the role of deformation zones in controlling the flow field. This is especially important because the CDI stage will not be able to offer significantly more information on several of these factors, as only a few deformation zones will be intersected by excavations and, obviously, only at single points. Uncertainties in deformation zone location and properties in the repository volume mean that SSM should expect SKB's design to develop as data do arise.

An associated uncertainty about the fracture system at a large scale is the possibility for the existence of 'fast pathways' – highly conductive features or network connections through which flow and transport could occur at accelerated rates, representing extremes of the range of variability of hydraulic behaviour. Here, we identified a need for more careful determination and assessment of parameter variability ranges (the "σ" value and spatial correlation λ). SKB has devoted much effort to developing the mean values of property parameters, with only some discussion of variability. For example, in their transport modelling for the hydraulic rock domains (HRD), they state that their simulations are *"based upon average properties …F factors for typical flowpaths"*[9]. We believe that additional efforts need to be devoted to careful consideration and discussion of spatial (and temporal) variability ranges (the "σ" value and spatial correlation λ). If the properties of the rock at a site were homogeneous, with mean parameter values, it is highly likely that the site would satisfy all safety concerns. It is the end members of property parameter distributions, and their combinations, that may give rise to special safety-affecting cases such as solute transport fast paths. To evaluate such cases, good information on the possible end members of parameter spatial distributions is necessary. SKB has presented some values of variability ranges based on measurement or analysis data. These need to be studied and assessed carefully, based perhaps on some selected distribution functions. They then need to be further evaluated, based on other related site-specific knowledge to its suitability, since data points in most cases are not sufficiently spatially distributed to cover the whole region of concern. Since this question has much to do with site properties, it should not be placed

[9] SKB Report R-08-48, p. 54

within the Safety Assessment domain but should remain with the Site Investigation part of the SKB programme.

At a smaller scale, and possibly the most significant uncertainty in the whole SDM – also identified as such by SKB, is the acknowledged difficulty of producing a fracture size and intensity model representative of repository depth, based on surface observations of fracture networks supported by sparse borehole intersections. The high significance of this uncertainty stems from the central position of the rock mass fracture network model in calculating groundwater flow to and through the EBS/repository and radionuclide migration to deformation zones and the surface. SKB notes that this issue causes “perhaps the most disturbing bias” in the data used in Forsmark SDM-Site. We agree with this observation, but would in, most respects, support SKB’s position that there is no realistic way of reducing the uncertainty brought about by this bias until underground observations can be made in the post-licensing CDI stage. One caveat is that observations in the CDI stage may not remove all significant uncertainties, as underground observations are also subject to constraints and biases, particularly concerning the maximum scale of direct observation. Therefore, we expect that a robust set of ACMs concerned with fractures and fracture hydraulics will be needed at all stages of site characterisation. Further analysis of the existing, surface-based data to support ACMs is warranted, along with evaluation of these ACMs versus confirmatory testing data and data from ongoing monitoring.

An extension of this uncertainty was the limited knowledge of how the rock mass fracture network connects with major transmissive fractures of different size. The models developed have implications for the extent and upper and lower bounds of flow connectivity and channelling. As these uncertainties cannot at present be reduced, it makes it particularly important that SKB looks at different fracture network models and propagates all reasonable geometrical and property models through into hydraulic models and calculations to underpin the key areas of SR-Site. As mentioned above, the current Hydro-DFN model, which seems likely to be central in SR-Site, is not a unique interpretation. We consider that the consequent uncertainties on flow connectivity, the possibility of there being compartmentalised flow in and around the repository rock volume, channelised pathways and consequent near-field groundwater fluxes are important matters for SSM to track into the licence review.

In conclusion, it is interesting to observe that such a central matter, recognised as highly important by all parties from the outset, could not be fully resolved in the surface-based investigations. This is entirely a feature of the limitations of investigation techniques in this type of geological environment and can only be ameliorated by the opportunities provided for much more extensive observations as excavations proceed.

3.3. Use of large-scale flow and transport tests

In early 2004 we raised the issue of upscaling measurements concerning flow and transport properties so that information more representative of a large volume of rock could be obtained from the investigations. SKB were developing elaborate DFN (see Section 3.2) and larger-scale hydrogeological network models based on extrapolations from statistical analyses of borehole and outcrop data. A key question was how they intended to test the extrapolative models, in terms of the resulting predicted network behaviour. In addition, it was felt that large-scale tests would be the only way to get at the flow properties and the influence on the larger-scale flow field of major deformation/fracture zones. This issue was then to run throughout the remainder of the investigations and the 'large-scale confirmatory test' programme that SKB embarked upon eventually prolonged field activities at both sites and merged into the long-term monitoring programme.

When the topic was first raised, INSITE noted that SKB's activities at the time included many 'point' measurements along boreholes (~10 cm to ~2 m) and of core samples. While these were not only useful, but essential, they could not eliminate the need for long-term large-scale field measurements, which can be used to obtain calibrated parameters for a scale closer to that of interest to safety assessment. It was felt that such large-scale experiments would also be useful to confirm the existence or absence of major hydraulic features in the flow domains of interest.

In our initial discussions with SKB, they expressed the view that tracer tests are intrinsically burdened with uniqueness problems and are also limited by the fact that sorbing tracers are impossible to use on larger scales. In order to address upscaling of transport properties, sorbing tracers interacting with the matrix are needed. Thus, SKB believed that a transport strategy ranging from sampling in the field to application within safety assessment would need to rely on methods independent of tracer test calibration. Nevertheless, they recognised the need for a spectrum of methods and began to carry out single well injection and withdrawal (SWIW) tests to look at the rock mass immediately surrounding selected depth intervals within a borehole and also established plans to carry out larger scale cross-hole testing at the Laxemar site.

INSITE pressed this matter further, recognising that non-uniqueness arises in any large-scale, in-situ experiment. However, we regarded this non-uniqueness as a motivation for use of alternative models and conditional stochastic approaches to interpretation, rather than as a reason for minimizing the use of such tests. As with the issue of ACMs, INSITE felt that the topic of whether and how to use large-scale tracer tests was fundamental and we consequently produced a technical note on this in 2005[10].

SKB's plans developed as they began to consider large-scale tracer tests (100-500 m) in a major fracture zone at each site, to verify flow models and connectivity at larger scales, along with medium-scale (50-100 m) tracer tests/tracer dilution tests to test connectivity. SKB recognised the importance of assimilating not only data from the current SI tracer testing but also knowledge gained from the 30-year history of large scale tracer and hydraulic interference testing in Swedish basement rocks and produced their own position paper on this in 2007[11].

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[10] INSITE Report TRD-05-08
[11] SKB Report R-07-39

The first of a series of four Expert Meetings with SKB on large scale testing was held in June 2006. Our views had developed and we stressed our belief that such tests would help in providing confidence that (a) important hydraulic features had not been ‘missed’ in the investigations, (b) that important anisotropy effects, if any, were detected in the different hydraulic conductor domains, and (c) that any flow compartmentalization was found. A specific issue that was raised was that *in situ* tests could be used to detect larger effects, such as flow compartmentalization, and also for calibration of parameter data as a way to account for the accumulative effect of minor structures that have been ignored,. At the start of the discussions, SKB’s approach appeared to build up the flow model from small elements, such as fracture networks, and laboratory core data, which raised questions on the impact of the neglected smaller structures, such as lower cut-offs of fractures and omitted features. INSITE considered that it would be useful for SKB to complement their bottom-up approach with larger scale, *in situ* calibration experiments. Thus, the hydraulic interference tests and single-well tracer tests that SKB was beginning to run (interference tests for hydrogeological properties, and SWIW tests for transport/retention properties) appeared to be the most practical means of testing the behaviour of these models on the relevant scale of a fracture network.

By the end of 2007, SKB had made excellent progress in carrying out and interpreting these tests, reserving some of the larger-scale interference tests until the end of the CSI stage when they would not interfere with other important characterisation measurements. However, they did not have definite plans for a round of modelling to assess the outcome of the long-term tracer tests at each site at the end of the CSI or plans to compare models with data from ongoing monitoring work. SKB noted that the latter step was beyond the scope of the site-descriptive modelling and would need to be performed within other SKB activities.

SKB used the large-scale, conservative tracer tests mainly to verify connectivity among large-scale deformation zones in the fracture system, with tracer tests mainly being performed within interpreted deformation zones at the sites that were also included in the hydrogeological flow models. It was not considered fruitful to model these tests explicitly in the flow models; rather, breakthrough in an experiment along a zone verified the existence of, and provided information on the connectivity of the zone.However, when the tests were modelled using transport models, the porosities of the zones could be backed out. SKB said that the comparison of these back-calculated values with the values used in the flow modelling constituted a confirmative step in the integration between models of different disciplines.

SKB mainly used the smaller scale sorbing (and non-sorbing) SWIW and multiple-hole tracer tests to address transport properties and to confirm retention in a general sense. In some cases they were able to back-out parameter groups or individual parameters related to retention and compare them to the corresponding parameters derived in laboratory experiments performed on small-scale samples. They said that this constituted a “preliminary” confirmatory up-scaling assessment.

Towards the end of the CSI, SKB observed that, during the extended evaluation of the tracer tests it had become evident that the apparent diffusive effect required to explain the form of the tracer recovery curves needed to be substantially larger than had been recommended for safety assessment modelling on the basis of data obtained in the laboratory investigations. It was not clear which mix of processes was represented by this enhanced retention, owing to the inadequacy of current modelling approaches to fully capture the intricacies of hydrodynamic and solute transport processes operating on the timescale of field scale tracer tests. Although SKB noted that some of these processes might not be relevant on SA timescales, they concluded their field investigations with the intention of making a concerted modelling effort to understand fully the physical processes underlying the measurement results from the experiments.

With this conclusion, INSITE considered that the effort put into understanding the potential of large scale tests, by both SKB and ourselves, over the years of the investigations, the many meetings and the long discussions that ensued, had been well worthwhile. At the close of the INSITE programme, the use of this information will be a key point for SSM to track when the SR-Site modelling is eventually presented by SKB.

3.4. Palæohydrogeology

From the outset of the investigations, INSITE and SKB agreed that an understanding of the past evolution of the groundwater system would be an important means of underpinning the forecasts of future groundwater flow behaviour that would be essential for safety assessment purposes, especially when considering variable future environmental conditions. Sub-sets of geochemical and isotopic data for groundwaters and minerals could be integrated to develop interpretations of how the groundwater systems have evolved over time, i.e. palaeohydrogeology. These interpretations include descriptive or semi-quantitative estimations of groundwater ages and solute residence times and the use of parameters as natural tracers to calibrate or test quantitative palaeohydrogeological models for the regions and the sites. SKB collected and analysed groundwater samples for these purposes.

Gradually, this topic became enmeshed with a parallel issue of understanding the overall spatial variability of groundwater chemical compositions and properties within the sites – extremely important in its own right in terms of assessing the future behaviour of the repository barrier system, as the variability could be dynamic and there would be a need to understand and assess factors such as the potential for upward movement of saline waters to shallower, repository levels. However, even by the middle of the CSI stage, few data collected for palaeohydrogeological purposes had been reported, despite the weight that was being given to palaeohydrogeological modelling in the understanding of the sites – in particular, in support of understanding how hydrodynamic stability is affected by external factors and what are typical travel times for groundwater and solutes within segments of the flow systems. By the end of 2007, for example, there were still inadequate data to represent spatial variability of chloride and other solutes, stable isotopes, carbon-14 etc, relevant to calibration of the hydrodynamics, solute transport and palaeohydrogeological model for the Laxemar site. At the end of the CSI, we observed that, for both sites, variations of hydrochemistry were evident in the target volumes (e.g. increasing salinity at Forsmark and more general variations with apparent uncertainty about water sources and ages at Laxemar) and that, in reviewing SR-Site, SSM would need to assess SKB's arguments that any possible present and future variability of geochemical parameters affecting near- and far-field conditions have been reasonably constrained in terms of their potential impacts.

As the hydrochemical variability had proved difficult to constrain (especially at Laxemar), this meant that the hoped-for palaeohydrogeological interpretation was also hampered, all the way through the investigations. The palaeohydrogeological model that was developed by SKB simulated groundwater movements and hydrochemical evolution since 10,000 years ago, i.e. the postglacial period during which the surface boundary has been affected by Littorina Sea, land uplift and meteoric water intrusion. It did not simulate evolution through the last glaciation. This has been a major limitation and simplification of the model with regard to the range of all possible boundary conditions. Assumptions about the cumulative effect of ice sheet cover and permafrost on the flows and compositions in the system were contained in the initial compositions for both fracture waters and pore waters at 10,000 years ago. INSITE accepted that this model limitation was justified, because the hydrochemical and isotopic data with which the model had been compared predominantly reflected post-glacial water movements and water sources. Evidence for groundwater flow conditions in the past becomes more tenuous as the timescale lengthens, because relict waters have been flushed out or mixed. Therefore estimated distributions of components with glacial and pre-glacial origins, and unknown compositions, in fracture waters would be a weak constraint on a palaeohydrogeological model that included one or more ice ages. Post-glacial signals also dominated isotopic data that provided only qualitative and relative indications of water ages. However pore water data evidently do retain a 'stronger signal' of older waters. Our conclusion was that all of these hydrochemical and isotopic data and the concepts and scoping models that constrain likely groundwater movements and variations of salinity under ice cover and permafrost should be considered together and shown to be reasonably consistent as palaeohydrogeological indicators of possible scenarios for future groundwater evolution in the safety case.

SKB invested a lot of effort in making a palaeohydrogeological interpretation of observed water compositions, using statistical analysis of the site-wide data sets for component waters to detect evidence of how past environmental/climatic episodes affected the groundwater systems and using the data to test and calibrate a palaeohydrogeological model of the systems for transient boundary conditions. Nevertheless the lack of data for deep groundwaters further increased uncertainties and this was reflected in the rather weak understanding of the intensity of palaeohydrogeological changes and in the rather inconclusive matches between data and palaeohydrogeological model simulations. With the exception of absent data for the deep system, this outcome was perhaps the best that could have been achieved with this ‘inexact’ approach to integrating hydrochemistry and hydrogeology.

The difficulties that SKB had in developing a convincing palaeohydrogeological model were, perhaps, understandable in this geological environment, where groundwaters are in complex, variable and geologically ‘shallow’ fracture systems, with surficial boundary conditions that have been massively perturbed by multiple glacial cycles. This is a much less tractable system to analyse than, for example, a thick sequence of sedimentary rocks. Not only are the dynamics of the system behaviour complex, but SKB also had doubts about the value of the hydrochemical database for modelling past processes. Given the emphasis that both SKB and INSITE placed on palaeohydrogeology, the eventual situation on palaeohydrogeological understanding is, of course, disappointing, as a convincing model of past flow perturbations would provide greater confidence in forecasts of flow over the next 100 ka or so. The SR-Site safety assessment will need to be supported by a comprehensive integration of all of the lines of evidence and uncertainties, taking care to explore the implications for potential dynamics of the groundwater system in the long-term future. That some of this support for SR-Site forecasts will be rather weak is a matter that SSM will need to weigh when assessing the safety assessment results. The question arises of whether SKB might be able to improve this situation in the CDI stage.

The problems with developing confident palaeohydrogeological models for the sites underlines the fact that the SDM-Site reports are essentially ‘static’ descriptions of the sites. They describe properties and characteristics but, for the most part, have not dealt with the dynamic behaviour of any of the systems, even under present day conditions. Consequently, questions such as ‘where, and how much groundwater is moving now?’ were difficult to find answers to, even though we considered SKB to have a thorough grasp of the nature of, and bounding controls on, flow in the bedrock. The dynamic behaviour of the system will no doubt emerge in the modelling reports that will comprise SR-Site, as forecasts of future evolution. SSM will need to be convinced that the teams carrying out these forecasts produce results that have the support of the geoscientists who have actually investigated and interpreted the site properties.

3.5. Regional groundwater flow

In the mid-stages of the SI programme, INSITE was asked by SKI to assess discussions that had arisen on the possible significance of ‘regional flow’ (in particular, areas of recharge and discharge) in the identification of a suitable repository site. From basic principles of hydrology, recharge areas are usually expected to be located well inland of the present-day coastline. It had been observed that they ought to provide longer transport pathways for any radionuclides released from a repository than would be found for sites in discharge areas, which might be expected to be concentrated at the coast.

The suggestion for this siting concept was initially raised in the report of a study commissioned by the SKI in November 2001[12], which indicated, based on relatively simple groundwater models, that such sites could have advantages in terms of long and/or slow pathways resulting in long return times to the biosphere for the radionuclides released from the repository into the geosphere. The Swedish authorities' evaluation of SKB's integrated plans for selection of sites for further investigation included a requirement that SKB should clarify its assessment of recharge and discharge areas, and of the depth at which saline groundwater is encountered, as factors in the siting process. The topic was looked at again by its original proponents, in review work carried out for SSI. In particular, the discussion centred on whether, by narrowing down to two coastal areas in 2001 and relegating a potential siting area inland (Hultsfred), SKB was missing a 'clearly better' (from first principles) siting solution.

SKB issued a series of reports on the regional flow topic, the last in the series being R-06-64, which was intended to address criticisms of their earlier studies, as set forth in reviews by INSITE, SKI, SSI, and stakeholder groups. Although the mandate of INSITE did not include review of the strategy and decisions underlying the preceding site-selection stage of the Swedish repository programme, the regional hydrogeological situation is one of the major elements in the characterization of any site, and was consequently of relevance to INSITE's work. For example, information on regional hydrogeology is needed in order to demonstrate overall system understanding, as well as to identify the range of possible future conditions for engineered barriers and to bound the potential for geosphere migration of radionuclides. Assumptions about regional groundwater flow may also play an important role in decisions that affect site investigations, such as choosing locations for boreholes to characterise effective boundary conditions for the candidate site. With this background, INSITE reviewed SKB's work on regional flow from the perspective of its significance for site understanding and site characterisation.

Nevertheless, after completing these reviews and observing the discussions between SKB and other stakeholders, we felt that it was important to make additional comments pertinent to discussions of the recharge-area siting concept. Our views are predicated not only on the modelling work carried out by SKB to look at the influence of major deformation zones in breaking up flow into small-scale local cells, but also observations on flow compartmentalisation by fracture zones in hard rock terrains elsewhere in the world, where the few data available tend to indicate that any deep flows are mixtures of groundwaters with different sources, 'destinations' and path lengths. In essence it seems unlikely that major transmissive features that are characteristic of such hard rock environments would permit long-range lateral flow in the more dynamic upper (few hundred metre) regions of the groundwater system – within rock blocks, flow is controlled dominantly by local topography and heterogeneity. In addition, there are no data that indicate that such large-scale fluxes do occur, even at greater depth. Our general view is that super-regional flow, in this environment, is purely a modelling concept that is not based on observational evidence and is practically untestable by any

[12] SKI Report 2001:44

reasonably feasible observations (e.g. hydrochemical studies in multiple, very deep – >1500-2000 m – boreholes). In addition, we raised a number of other questions, chief amongst which were:

- **Is it, in any case possible to site a repository in a distinct recharge area?** The flow modelling in all the areas studied shows a patchy distribution of recharge and discharge, even at the site and repository scale, that matches the patchy distribution shown at the regional scale. If the topography/fracture zone controlled flow model is correct, then no recharge area is more than a few hundred metres from a discharge area.
- **How important is the discharge path length?** If the concept of long, regional pathways from depths of <1000 m has no real support, then any release path from any location is going to be short (of the order of a few hundred metres). Even if path length proves to be a sensitive parameter in SR-Site, the potential variation to be obtained by shifting repository location will likely have an insignificant impact on performance.
- **Would it be an appropriate siting approach?** Finding a repository site that gives acceptable performance as well as being societally and politically achievable is a fragile and tenuous process. No country has yet been successful in finding a site by drawing a map of 'good' and 'bad' areas, based on technical considerations (such as recharge and discharge maps from largely untestable models). Many combinations of site properties can provide adequate radiological and environmental performance and such technically-driven approaches appear naïve or, at best, as providing just one level of input to a highly complex evaluation and negotiation process.

In summary, our view was that super-regional flow, in this geological environment, is a modelling concept that cannot presently be confirmed by observational evidence and is thus untestable. Consequently, endeavouring to make it a high-level consideration in the complex process of identifying a suitable repository site is inappropriate.

3.6. Ore potential at Forsmark

The Forsmark area is located within an ore province, Bergslagen. INSITE addressed this issue and agreed with SKB that the granitoids in the central part of the Forsmark lens have a dearth of minerals of economic interest. Nevertheless, the site is located in an ore province and ore-bearing lithologies occur just outside the granitoids, where mineralization has been mined on a small scale. In this environment a repository for spent nuclear fuel will form a geophysical anomaly (magnetic and gravity) that may draw the attention of future prospectors. As a part of SR-Site, we recommended that SKB should consider modelling the geophysical character of a repository to evaluate whether such an occurrence is feasible, or whether a repository would have geophysical characteristics that will indicate to future prospectors that the repository anomaly is not an ordinary mineralization, but something else.

Rock Domain 21 has ore potential and is located in a discharge position relative to the repository target area. This is currently mainly located below sea level and it has probably not been subject to mineral prospecting. The airborne geophysical measurements performed by SKB in the regional Forsmark area have not indicated the existence of any magnetic ore body in this rock domain. However, the existence of non-magnetic mineralization cannot, so far, be excluded. The possibility of future mining in Rock Domain 21 equally cannot be totally excluded. SKB indicated that this issue might be addressed in SR-Site if there are indications of the existence of a hydraulic contact between the target area and the Singö zone. This needs to be tracked into SR-Site.

3.7. Measurement of high rock stresses

The possibility that anomalously high horizontal stresses might be encountered at depth at the Forsmark site had been known at the time that the site was selected for investigation. Previous borehole investigations for the construction of the nuclear power plant and the testing of the first prototype of the Bore probe for overcoring stress measurements had produced indications of such stresses. High and anisotropic horizontal stresses are potentially important as they could cause spalling of deposition holes and tunnels (affecting both operational approaches and, potentially, the safety case) and force specific repository layout orientations on the designer.

For most of the ISI stage, INSITE was in discussion with SKB about the means that were being deployed in the early deep boreholes to try to measure stress in-situ, with INSITE recommending (in addition to the use of overcoring) use of the HTPF (hydraulic testing of pre-existing fractures) technique on individual, well defined fractures as an additional means of measuring in-situ stresses in boreholes. We also suggested use of the Integrated Stress Determination Method for the combined evaluation of overcoring, hydraulic fracturing and HTPF data. SKB endeavoured to make stress measurements at Forsmark throughout the second half of 2005 but encountered significant problems with the over-coring method and decided to drill a new deep borehole the following year and try again, with improved techniques for both the over-coring and hydraulic fracturing methods.

By the middle of the CSI stage, knowledge of the state of stress at Forsmark and Simpevarp/Laxemar continued to indicate high stresses at depth for Forsmark and areas of low stress in wedge-shaped rock blocks within the candidate areas at Simpevarp and Laxemar. A central question at the time was whether the stresses at Forsmark were attributable to the ‘tectonic lens’ in which the target rock volume lay and consequently unrepresentative of regional or even nearby local stresses. However, knowledge of stress magnitude versus depth and the stress gradients versus depth at Forsmark was uncertain and needed to be confirmed by additional measurements. As a consequence of the recorded stresses, SKB began studying the possibility of locating the repository at a shallower depth (400 m). They observed that modelling results indicated that the orientations of the deformation zones in the upper part of the crust (< 1km) could play a significant role in controlling the stress magnitudes. At a site where the orientation of the fracture zones allows for stress release at the ground surface, lower stresses in the blocks that had moved would be expected. SKB said that this had been demonstrated at Laxemar by both measurements and stress modelling. However, at Forsmark the orientation of the fractures zones was such that within the tectonic lens in the target area there are no features that facilitate this stress release mechanism. As a result the stress magnitudes are relatively high at shallow depths.

A massive campaign of stress measurements with hydraulic methods was carried out at Forsmark between June and October 2006. This was supported by a laboratory programme on the pilot- and cylindrical cores from the new deep borehole, to obtain an independent estimate of the elastic constants and the possible degree of damage of the samples caused by stress release during drilling. SKB continued to experience difficulties with the in-situ testing, with only 30% of the tests delivering useable results. Throughout 2006 and 2007 a series of workshops was held, including Expert Group meetings and joint efforts by SKB and Posiva (Finland) to tackle the problems of in-situ stress measurement. It was clear to INSITE that SKB was tackling the problems from different angles and with a holistic approach. By the end of 2007, SKB had commissioned and received a report to evaluate the status of the stress measurement programme[13]. The report compared the results from overcoring and hydraulic methods, with the comparison showing systematically lower stress magnitudes for the hydraulic methods and measured magnitudes of normal stress from the hydraulic methods close to the weight of the overburden. It was believed that the application of hydraulic method in vertical boreholes in a thrust regime was not appropriate. Significantly, the report found that, due to the likelihood of having systematic errors in one of the two methods, it was not meaningful to carry out integrated stress analysis. However, a comparison between the two methods did give good agreement in a borehole at the Laxemar site, with both methods resulting in lower stress magnitudes at 400 – 500 m depth compared to a similar depth at the Forsmark site.

The SKB report thus puts most weight on the overcoring data to derive high horizontal stresses at the depth intervals relevant for a repository at Forsmark. As more testing and interpretation was still ongoing in early 2008, INSITE reserved its opinion about the stress magnitudes at Forsmark until the results were available. Following the review of these reports and other information about the stress measurement results, INSITE reached its own conclusion in late 2008 about the evaluation of the stresses at Forsmark, which differs from that of SKB[14]. We put more weight and trust on the hydraulic methods and less on the overcoring methods. We also believe that the majority of borehole breakouts (which had been observed using a borehole televiewer) were drilling induced. Consequently, we regard the stresses at Forsmark to be much lower than the results of the overcoring stress measurements, with stress magnitudes that are normal for Fennoscandian hard rock terrains.

For Forsmark, the site actually selected for the repository in June 2009, the situation thus remained unresolved at the end of our work. SKB recognises that resolution of the actual stress conditions is critical for design and excavation work and is developing a stress measurement campaign that will be incorporated into the final stages of design and construction, so that, by the

[13] SKB Report R-07-26
[14] INSITE Memorandum M-08-06

time the access to the repository is reached, the stress magnitudes will be known with confidence.

4. Site understanding: Forsmark

We have tracked the development of the SDM concept, and of the Forsmark SDM specifically, for several years and seen it evolve in depth and detail with progressive versions. The final version that will underpin the documentation and analysis for the site licence application by SKB (in particular, the SER[15] and SR-Site), now that this site has been selected as the preferred option, is a massive report with extensive supporting documentation[16]. In this Section we present edited comments from our review of SDM-Site, presented to SSM earlier this year[17].

Having tracked the growing understanding of Forsmark and reviewed previous versions of the SDM, it is perhaps not surprising to find that the final SDM contains no major new interpretations or syntheses. From our foregoing review comments, it is clear that we agree with much of SKB's assessment of 'knowledge status' and uncertainties. The extracted 'confidence assessment' report (SKB R-08-82) provides a more candid commentary on the state of knowledge than does the main SDM-Site report.

In our review of SDM-Site, we assembled our conclusions and recommendations to SSM into two groups; issues that they will need to consider closely in the upcoming licence review and topics that they will need to ensure are tracked into the longer-term, in the CDI (underground) stage of site investigation and in SKB's already ongoing, long-term monitoring programme. In presenting these conclusions and recommendations, we recognised that SKB has already identified areas of uncertainty and has proposed means of addressing those that it considers significant by making future measurements and observations. As will be seen below, we generally concurred with SKB's identification of uncertainties, although we did not always agree with them concerning their significance, whether they are adequately bounded or whether they require further work.

4.1. Issues that SSM needs to consider in the licence review

The Forsmark SDM-Site presents a confident and well-justified description of the site and regional geology and the distribution of major rock types across the site and in the proposed repository volume. We note that there are uncertainties about the distribution of minor rock types and rock alteration that cannot sensibly be reduced by surface-based observation. As these will affect rock quality and thermal properties, they must be accounted for conservatively when calculating useable rock volume and actual repository layout. SSM should consequently expect that SKB's design will evolve as data become available from the more extensive volumetric observations that will be made as excavation proceeds in the CDI phase.

[15] Site Engineering Report: the basis for the repository design and the description of data transposition from the SDM into design decisions and the consequent justification for those decisions.
[16] SKB Report TR-08-05
[17] INSITE Memorandum M-09-06

Owing to the difficulties of making deterministic, or even reasonably constrained stochastic models of the distribution of minor rock types, the extent of vuggy granite development remains a possibly rather significant uncertainty. We note that it tends to be found in, or associated with, deformation zones (DZs) but its origins are not well understood so it is difficult to forecast how much may be present or where it may occur in or around the repository volume. If it is correlated in some way with transmissive DZs and the movement of deep fluids in the geologically distant past, then it is possible that it may form pathways that are connected over appreciable distances in or between DZs. It thus needs to be accounted for in sensitivity studies of potential migration pathways in SKB's safety analyses. Again, this is an issue that observations during the CDI stage may help to clarify.

The properties of major DZs are uncertain: length, termination style, internal structure and, in particular, properties (and exact locations) at repository depth are difficult to characterise from borehole observations from the surface. We note that SKB will need to take a broadly bounded approach to sensitivity analyses of these factors when they model the role of DZs in controlling the flow field. This is especially important because the CDI stage will not be able to offer significantly more information on several of these factors, as only a few DZs will be intersected by excavations and, obviously, only at single points. Uncertainties in DZ location and properties in the repository volume again mean that SSM should expect SKB's design to develop as data do arise.

Possibly the most significant uncertainty in the whole SDM is the difficulty of producing a discrete-fracture model representative of repository depth (including fracture size and intensity sub-models, which SKB identifies as significant uncertainties, but also sub-models of structural relations and possible spatial correlations among fractures), based on surface observations of fracture networks supported by sparse borehole intersections. The high significance of this uncertainty stems from the central position of the rock mass fracture network model in calculating groundwater flow to and through the EBS/repository and radionuclide migration to DZs and the surface. SKB notes that this issue causes "perhaps the most disturbing bias" in the data used in the SDM. We agree with this observation and would, in most respects, support SKB's position that there is no realistic way of reducing the uncertainty brought about by this bias until underground observations can be made in the post-licensing CDI stage. One caveat is that observations in the CDI stage may not remove all significant uncertainties, as underground observations are also subject to constraints and biases, particularly concerning the maximum scale of direct observation. Therefore, we expect that a robust set of ACMs concerned with fractures and fracture hydraulics will be needed at all stages of the process. Further analysis of the existing, surface-based data to support ACMs is warranted, along with evaluation of these ACMs against confirmatory testing data and data from ongoing monitoring.

An extension of this uncertainty is the limited knowledge of how the rock mass fracture network connects with major transmissive fractures of different size – deformation zones (DZs) and minor deformation zones (MDZs). The models developed have implications for the extent and upper and lower bounds of flow connectivity and channelling. As these uncertainties cannot at present be reduced, it makes it particularly important that SKB looks at different fracture network models and propagates all reasonable geometrical and property models through into hydraulic models and calculations to underpin the key areas of SR-Site. We note that SKB has looked at some alternatives to its baseline tectonic continuum fracture model from a geometrical perspective and believes that, for example, the size distribution and size-intensity correlations of fractures in the repository volume are already adequately bounded by alternative conceptual models. However, SKB has not endeavoured to convert these alternatives into parallel hydraulic models. We point out that the current Hydro-DFN model, which seems likely to be central also in SR-Site, is not a unique interpretation. We consider that the consequent uncertainties on flow connectivity, the possibility for there being compartmentalised flow in and around the repository rock volume, channelised pathways and consequent near-field groundwater fluxes are important matters for SSM to track in the licence review. SKB's discussion on uncertainty related to the effects of connectivity, complexity and channelling on distribution of flow in R-08-82 (Section 3.6.1, pp. 39-40) is good, but some of the issues are designated too lightly as being not important. They all need to be evaluated more rigorously and should be reviewed carefully by SSM (see also the final paragraph in this Section 8.1).

Potential post-glacial earthquake hazard to the EBS is likely to emerge as a topic for analysis in SR-Site, although SKB points out that there is no evidence that any of the DZs examined at the site have moved (to generate a major earthquake) in previous glaciations. A microtectonic analysis of fracture minerals could give information about the formation and deformation of fracture minerals, which could help to indicate the potential of reactivation of different sets of fractures. This may be helpful in constraining SKB's model of rock mass response to slip along a nearby DZ. Along with more data on fracture lengths, which are also a key parameter in the model, this type of information could be gathered in the CDI stage.

SSM and SKB should consider the possible effect of thermal loading from the repository on seismic hazard. It is the first time in history that such a large rock mass as that of a geological repository for spent fuel has been significantly heated as a result of engineering activities. The thermal load will expand the rock mass underground and cause changes of the stress field. These changes might lead to fracturing and/or reactivation of deformation zones, which can affect the performance of the EBS and result in seismic activity. Recently, seismic events have been observed related to the development of geothermal projects in central Europe, e.g., M 3.8 – 4.0 due to exploratory borehole operations at Basel, Switzerland and M 2.7 at the geothermal power station at Landau in southern Germany. The seismicity is caused by the pumping and circulation of large volumes of water into the rock mass, which causes redistribution of stresses. In petroleum engineering, induced seismicity is mostly related to cold water and gas injection during oil and gas production. There is a need to study the risk of seismic hazard from the repository heat load and to make an estimation of possible and likely magnitudes of induced seismic events. Although the maximum heat load appears about 100 years after closure of the repository, any potential for seismic hazard to both the repository EBS and to the Forsmark industrial energy production area needs to be assessed.

It is important for SSM to note that SDM-Site is essentially a ‘static’ description of the site. It describes properties and characteristics but, for the most part, does not deal with the dynamic behaviour of any of the systems, even under present day conditions. Consequently, questions such as ‘where, and how much groundwater is moving now?’ are difficult to find answers to in the SDM-Site documents, even though we consider SKB to have a thorough grasp of the nature of, and bounding controls on, flow in the bedrock. The dynamic behaviour of the system will no doubt emerge in the modelling reports that will comprise SR-Site, as forecasts of future evolution. SSM will need to be convinced that the teams carrying out these forecasts produce results that have the support of the geoscientists who have actually investigated and interpreted the site properties.

An example of the lack of a dynamic description, which apparently also reflects poor understanding of the associated hydrogeological system, is the omission of a convincing model of the recharge-discharge mechanisms and rates, and of the shallow flow around the geosphere-biosphere interface. Given the importance of this region in both controlling deeper fluxes and in affecting modelled dispersion of potential releases from the repository, we regard this as a significant weakness of SDM-Site, even accepting that the regolith and shallow aquifer regions are going to evolve considerably over the next 100 ka. SKB acknowledges uncertainties in near surface hydrology, but asserts “sensitivity analyses are likely to show that these are unimportant with regard to overall performance – even if the uncertainty locally affects the position of release points or concentrations of them”. This promised sensitivity analysis will need to be checked when it is presented.

We identify a similar omission in the partial modelling of the hydrogeological and hydrochemical impacts of glacial climatic cycling – partial, inasmuch as only one time slice of the most recent cycle has been dealt with and the starting conditions of the model are assumptions. The impact of past cycling on the composition and behaviour of the ‘older’ components of the deep groundwater system are unknown and it is not clear whether this will affect forecasts that extend over 100 ka into the future. More generally speaking, the difficulties that SKB has had in developing a convincing palaeohydrogeological model are, perhaps, understandable in this geological environment, where groundwaters are in complex, variable and geologically ‘shallow’ fracture systems, with surficial boundary conditions that have been massively perturbed by multiple glacial cycles. This is a much less tractable system to analyse than, for example, a thick sequence of sedimentary rocks. Not only are the dynamics of the system behaviour complex, but SKB also has doubts about the value of the hydrochemical database for modelling past processes.

Given the emphasis that both SKB and INSITE have placed on palaeohydrogeology, the situation on palaeohydrogeological understanding is, of course, disappointing, as it has been hoped that a convincing model of past flow perturbations would provide greater confidence in forecasts of flow over the next 100 ka or so. As noted above, this situation is understandable and the outcome as presented in the SDM is perhaps the best that can be achieved with this 'inexact' approach to integrating hydrochemistry and hydrogeology. Safety assessment will need to be supported by a comprehensive integration of all lines of evidence and uncertainties, taking care to explore the implications for potential dynamics of the groundwater system in the long-term future. That some of this support for SR-Site forecasts will be rather weak is a matter that SSM will need to weigh when assessing the safety assessment results. The question arises of whether SKB might be able to improve this situation in the CDI stage.

One way around this problem may be a specific study. We recommend that SSM asks for an additional report within the SR-Site suite that deals specifically with *'Future Evolution of the Site'*. Clarity in the understanding of evolutionary processes and the likely future state of the site are central to safety assessment and we perceive a danger that knowledge and forecasts will be spread across a range of reports by different groups, with no clear SKB position emerging. At present, no report with this topic is identifiable in the 'product' and 'report' structure diagrams for SR-Site.

In our view, SKB has made all reasonable efforts to acquire representative hydrochemical data for mobile groundwaters and we consider the spatial variability of the key parameters to be well characterised, with the range of variability within the target repository volume having only limited potential impacts on EBS performance-related matters. Critically, the evidence for no dissolved oxygen being present at repository depth is compelling. On the larger scale, the variability in salinity/density is reasonably well-characterised but not explained, leaving uncertainty on the extent to which understanding of the palaeohydrogeological system could underpin forecast of future large-scale, long-term flow at depth: as observed above. Groundwater colloid data are inconclusive but it is unlikely that SKB could have improved this situation, meaning that a conservative approach will have to be taken in performance modelling in SR-Site.

Groundwater compositions at depth below the repository rock volume are uncertain and SKB proposes taking what they regard as a conservative value, based on deep (1600+ m) data from Laxemar, for input to safety assessment. As potential upconing of deep waters needs to be analysed in SR-Site we suggest that a higher value needs to be included in SKB's sensitivity study. As discussed previously with SKB, a deeper hole at Forsmark would have helped resolve this matter, as well as contributing to understanding of whether postulated long-distance ('regional') deep groundwater fluxes are of any significance at the site over the timescales of interest.

We concur with SKB's assessment of hydrochemical uncertainties (e.g. compositions at repository depth, redox/Eh buffering controls, elevated U and occasional elevated sulphide contents) but, unlike SKB, we believe that all of them could be significant to safety assessment and certainly agree that attempts should be made in the CDI phase to reduce all of them.

Overall, SKB has provided a sound basis for defining the solute transport and retention properties of fractures, intact rock masses and deformation zones that represents largely the state of the art in this scientific field. Within the limitations of their ISI and CSI programmes, they have obtained as much information as can be expected on the parameters associated with their transport and retention model of the Forsmark site. However, the parameter data are not complete, and this will need to be addressed during the CDI investigation stage during construction of underground facility, or by assigning possible ranges through careful considerations, including perhaps an expert elicitation process. The latter could be considered as part of safety assessment and should be fully presented by SKB in SR-Site.

We would agree with SKB's positions that the uncertainties in migration properties of the rock matrix are sufficiently well bounded and straightforward to propagate into SR-Site and suggest that SSM monitors how this is done through SKB's proposed scoping calculations and sensitivity analyses. We observe some specific shortcomings in data and understanding that will require SSM's particular attention: possible different ways of simulating spatial variability in data; means of simulating complex fracture internal structure; the effect of locally elevated hydraulic gradients and channelling.

Whilst we have had several issues about the best means of gathering and interpreting stress data at Forsmark, we consider that SKB has made a convincing effort to characterise and understand the stress regime. In R-08-82, SKB identifies the magnitude of the horizontal stress as an issue with low confidence and we agree that it is a usefully conservative approach to propagate the results of two different measurement approaches into the design work. However, we regard the stresses at Forsmark to be lower than the results obtained from the overcoring stress measurements and consider that the stress magnitudes with depth are about normal for Fennoscandian hard rock terrains. Nevertheless, the treatment of elevated and anisotropic stresses will continue to be an issue that needs to be monitored closely by SSM through the design and construction stages.

Ensuring that all of the above uncertainties and alternatives are propagated visibly into SR-Site should be a focus for upcoming review by SSM. SKB has suggested a set of ACMs that need to be included here, which should be carefully reviewed as to its completeness.

It appears to us that the SER, itself based on SDM-Site, will be an important document, since it must justify SKB's choices of depth, location, design and layout (see Section 8.2). These matters will be critical for performance and safety and are based on the SDM, but possible alternatives are not discussed in the SDM itself. It is important in the licence review process that these matters do not thus fall into the gaps between reports/reviews.

Finally, we return to an issue that we raised right at the beginning of the programme: the importance of having ACMs that test the potential for forecasts of site behaviour being biased by the use of a single model. As discussed in Section 3 and in the text above, we have been particularly concerned by the use of a single conceptual model of fractured rock hydrogeology. We note that, within SKB's choice of paradigm, SKB has been logical and in keeping with much of the international work on this topic over the last decades. Their choice of paradigm has driven large parts of the SI programme and we consider that, within the framework they have thus established for themselves, SKB has done a remarkable job of data gathering and interpretation. However, we have identified a number of aspects of this hydrogeological paradigm that could be considered differently, producing a number of variant approaches. SKB needs to test the impacts on flow forecasts of using these ACMs and to compare them with its own reference DFN model. We observe that there is a danger that ACMs could be seen only as part of SI and SDM production, while, in fact, they are a crucial part of safety assessment. It is important for SSM to ensure that SKB looks closely at them and presents the results of their assessment in SR-Site. At present, there is a possible danger that this matter will be lost, somewhere between SDM-Site and SR-Site.

4.2. Topics for tracking into the CDI phase & ongoing monitoring

In its 'confidence' report, SKB identifies several areas where further work is foreseen in either the CDI stage or in ongoing monitoring. We would reinforce and add to these topics, recommending that SSM maintains a close watch on how data are being produced and interpreted and, specifically, on the extent to which currently identified uncertainties are being reduced. To INSITE, this is an important issue, as there is a risk that enthusiasm to 'get on with the job' of construction could inadvertently subordinate continued, careful scientific observations to a low priority. Further, if conducted without due consideration, construction may compromise the possibility of performing good scientific observations. Our concern is reinforced by the fact that SKI/SSM has so far been unsuccessful in obtaining a clear plan from SKB on how they plan to design and implement measurements in the CDI stage. We recommend that SSM makes the production of a detailed and reasoned plan a condition of licensing.

In connection with this, we note that the Design Premises (D2 stage) and the draft SER propose that, in progressing with the excavations, use is made of an approach known as the Observational Method. This, among other things, requires SKB to make forecasts of the variability of ground conditions and engineering/design responses to the variations that they predict might be found. Clearly, applying this approach, which requires measurement of a range of parameters, should be closely linked to any programme of additional data gathering aimed at (a) addressing residual site understanding and PA-related uncertainties and (b) developing the strategy for confirming deposition hole locations. At the time of preparing this review, the SER was available only in draft form and consequently had not been reviewed by INSITE. It is important that this document is properly evaluated by SSM as it will be clear, from the way in which SKB deploys this methodology, to what extent our comments and concerns on what ought to be measured/monitored in the CDI stage would be addressed by the Observational Method approach.

With this caveat, in the following section, we list topics that need to be addressed in (a) the ongoing and future monitoring programme, (b) shaft pre-excavation pilot drilling and (c) the CDI stage of excavations.

4.2.1. Continuation of monitoring

SKB has a programme of monitoring that continues observations of baseline condition. We have not seen comprehensive documentation on the extent of this programme, nor have we reviewed the programme. The list below identifies topics that we are aware to be within SKB's monitoring programme and others that we have identified as needing monitoring, from our own review of the SDM:

- GPS strain at site and regional level, linked to 'rock blocks' identified by DZs;
- seismic monitoring from the Swedish national seismic net;
- baseline hydrogeological responses of monitoring boreholes to seasonal changes and, eventually, to excavation perturbation;
- baseline hydrochemical responses of monitoring boreholes to seasonal changes and, eventually, to excavation perturbation;
- evidence for changes in recharge and discharge in data from shallow boreholes;
- evidence for possible 'fast path' discharge from depth to surface water bodies (especially offshore) using thermal linescan monitoring.

4.2.2. Shaft pre-excavation drilling

As well as providing additional data (of a type identical to that already gathered in the deep cored boreholes) on fracture properties and the distribution of minor rock types, this is an opportunity to extend a borehole to >1000 m to obtain groundwater samples from well below the repository volume. Such a borehole can also give valuable data about possible onset of borehole breakouts or other instabilities and thereby provide important information about the stress state at the site.

4.2.3. Underground

Once again noting the caveat on the potential overlap with the use of the Observational Method, we identify the following topics as requiring further observations, underground, in the CDI stage:

- tunnel mapping, technique for sampling of fracture data in tunnels and shafts to characterise DZs, structural relation between DZs and data on rock types and rock alteration;
- prediction of rock type distribution, rock engineering quality, rock alteration, fracture intensities and location and properties of any DZs intersected ahead of excavation and verification using pilot holes; to refine both statistical models (e.g. thermal conductivity variability) and deterministic models (e.g. DZ property control on layout);

- fracture orientations, lengths, structural relationships, intensities, apertures and mineralogy to flesh-out the currently limited knowledge and justify selection of the most appropriate hydro-DFN model, especially when the repository host volume is reached;
- fracture or fault structure, including occurrence of low-permeability fracture cores, high-permeability transition zones, channels and estimation of surface areas carrying most of the flow;
- prediction of inflows into tunnel sections based on the site hydrogeological model, the Hydro-DFN (and variants) and predictions of DZ transmissivities;
- search for potential fast flow pathways from observations of inflows and fracture connectivity in tunnels and vaults;
- evaluation of the nature and extent of the 'process zone' around different DZs;
- fracture microtectonic analysis to assess which, if any, fracture sets that may be prone to reactivation in seismic events;
- hydrochemical sampling ahead of excavation to seek evidence of compartmentalisation of water bodies and their causes and evidence of variability in redox/Eh, uranium and sulphide content in groundwaters;
- sampling of undisturbed pore waters to find evidence for the extent of matrix diffusion using analogue elements;
- in-situ stress measurements at depth intervals;
- developed methodology to detect discriminating fractures;
- strength and deformability of DZs.

In addition, in situ active experiments should also be considered in the CDI phase for confirmatory testing and for obtaining additional data, such as the effects of property variability and spatial correlation ranges on transport.

4.3. How well is the Forsmark site understood?

Finally, we return to the high-level questions that we prepared for ourselves at the mid-point of the CSI and which were presented in our CRI/SRT documentation. These 'questions to ourselves' were intended for use at the end of the CSI to provide an overall view on our confidence in site understanding as the licensing process begins. Bearing in mind the uses to which site information are to be put, we asked ourselves the following questions, the answers to which we have included below as bullets.

After reviewing SDM-Site, would we consider that, at the end of the CSI stage, SKB has:

1. An **adequate understanding of the 'natural state' of the site** as it is today, in terms of its undisturbed characteristics that are of relevance to design, operation and long-term safety? These characteristics include the stress field, the short- and long-term strength and deformability of the rock mass, the thermal properties of the rock, the distribution of groundwater chemical compositions through the host rock volume and

the hydraulic properties of the rock mass and of different types of fracture and deformation zone.

- Whilst there are still some gaps, in overall terms, the answer to this question is certainly 'yes'. In almost all areas, SKB has used the best available methods to make property measurements and has also devoted considerable resources and deployed first-rate teams and expertise to their interpretation. Forsmark is probably among the best-characterised and understood (from purely surface-based investigations) volumes of ancient crystalline rock anywhere in the world.

2. An **adequate understanding of the time-dependent driving processes** that will control safety critical properties of the site over the next ~100,000 years? These properties include the stress field, the groundwater flow field and the mechanical and hydrochemical properties of different volumes of rock.

   - We are less positive about this aspect of site understanding and consider that the SKB site investigation team needs to develop a report that discusses the dynamic evolution of the site during the Quaternary, focussing on changing flow, mechanics, chemistry and regolith properties. Information is available to do this, but has not been combined into an integrated description that could support forecasts of behaviour over the next 100 ka or more.

3. A sound grasp of **uncertainties and variability** in (1) and (2)?

   - Whilst there are numerous residual uncertainties, many of these are unavoidable using a purely surface-based investigation approach. SKB has identified the most critical uncertainties. SSM needs to ensure that their implications are properly evaluated in SKB's safety assessment and design work.

4. Sufficient **information of appropriate quality to develop a repository** design and operation scheme that will meet both operational and long-term safety requirements?

   - We consider that SKB now has sufficient information of appropriate quality that they can enter the licensing stage leading to a construction permit in the knowledge that a rational, workable design and operational plan can be presented.

5. Sufficient **information of appropriate quality to support the proposed structure and data requirements of the SR-Site** safety assessment?

   - There are certainly enough data available to support SR-Site in all key aspects. The question remains as to how SKB will deploy this information in terms of sensitivity analyses of uncertainties and use of alternative models. We spotlight the necessity for SKB to assess quantitatively the impacts of ACMs – an important example being their fracture hydrogeological model, when developing flow forecasts in SR-Site. SSM should encourage SKB to adopt a sensibly conservative approach to scoping the impacts of these uncertainties; this will also help to refine future measurement work (see 6 below).

6. An achievable plan for **filling gaps in information** and narrowing down any unacceptably wide uncertainties, both identified in (3), during the underground investigation (CDI) phase, and before licence application?

   - Whilst SKB has highlighted many types of information it wishes to obtain over the next years, we have not yet seen such a plan and recommend that SSM makes the production of a detailed and reasoned plan a condition of licensing.

5. Site understanding: Laxemar

We have already reviewed several previous versions of the SDM for Laxemar and SDM-Site is the culmination of the progressive development of site understanding by SKB over a period of more than seven years. Indeed, the SDM approach was first explored by SKB when it produced a report on testing the SDM methodology in 2002 that was based upon pre-existing information on the Laxemar area[18]. This was reviewed by INSITE in 2004. The first comprehensive SDM for Laxemar based on the current site investigations was produced and reviewed in 2006[19]. Consequently, when we began the review of SDM-Site, we already had a detailed knowledge of the site and a checklist of issues from previous reviews and discussions with SKB from which to make a start.

Geologically, Laxemar differs from Forsmark principally in the degree of metamorphism to which the rocks have been subjected and in the range of metamorphic rocks that are represented. Whilst Laxemar is a relatively high-grade metamorphic gneiss terrain, Laxemar is characterised by a lower intensity of metamorphism of rocks that were predominantly volcanic in origin. In our parallel review for Forsmark SDM-Site (see Section 4), we assembled our conclusions and recommendations to SSM into two groups; issues that SSM will need to consider closely in the upcoming licence review and topics that they will need to ensure are tracked into the longer-term, in the CDI (underground) stage of site investigation and in SKB's already ongoing, long-term monitoring programme. For the Laxemar review, we do not subdivide our conclusions in this way, as the site has now been relegated as a repository site in favour of Forsmark, so no further work will take place, other than the continuation of some monitoring. Instead, we present them as a simple set of comments, which summarise our main conclusions about the state of knowledge of the Laxemar site, as depicted in SDM-Site:

- We have observed, and SKB has also recognised, that the uneven distribution of boreholes across the site (especially their relative paucity in the eventual target area) is one of the main areas of bias in the site database and the SDM developed from it. SKB acknowledges that they have too few data in a number of areas, or did not have enough time to do certain tests (e.g. long term interference tests).
- A consequence of the above is that many of the structures located at repository depth in the focused rock volume are not verified by any borehole, or are intersected only by a single borehole. The number of detected structures is strongly related to the spatial distribution of boreholes and the number of boreholes. There is a general uncertainty in the intensity/spatial distribution and length distribution of fractures at depth. The overall fracturing in the rock is irregular and high, even outside modelled fracture zones, which is why it appears to be hard to apply SKB's definition of deformation zones strictly.

[18] SKB Report TR-02-19
[19] SKB Report R-06-10; INSITE Report TRD-06-02

- Uncertainty about practically all aspects of the Minor Deformation Zones (MDZs) seems to be a particularly important issue. MDZs might be up to 1000 m long according to SKB, but they are not able to identify any way of improving their understanding of them from surface based observations (even from more observations) and they are not convinced that MDZs could affect deposition hole acceptability. This latter point is difficult to understand, as some of the shorter MDZs must surely be relevant to this. Sorting these matters out would necessarily have had to form a focus for a CDI phase, were one to have taken place.
- As for Forsmark, uncertainty in the overall fracture size-distribution models is recognized as a key issue, but the models considered do not necessarily bound the uncertainties for safety assessment purposes. Uncertainties regarding fracture clustering (scaling) and variation of fracture scaling parameters depending on fracture domain are recognized and raised by SKB's analysts as alternative GeoDFN models, and should be followed up in any further site modelling. Variation of fracture intensity variation relative to nearby deformation zones is not considered. All of these issues may have consequences for fracture network connectivity, which is important for hydrogeological understanding and forward modelling.
- In our review of the Forsmark SDM-Site we discussed at length the uncertainties associated with the discrete fracture network model development, associated both with the availability of information and the specific approach taken by SKB. We also discussed the role of the deformation zones in groundwater flow. The comments that we made there apply equally here and are not repeated, but we make the additional point that it is less clear about how DFN models at Laxemar are carried into the hydrogeological modelling, which is largely due to the delay in reporting. As we have noted for Forsmark, despite a state-of-the-art approach to hydrogeological modelling at Laxemar, there are still substantial uncertainties in how variability of flows to the near-field will be controlled by the fracture network. Evidence for the assumed coupling of the HydroDFN to the site-scale hydrogeological system is scant, due to the practical limitations of investigations from boreholes and the time scale that was allotted for the surfaced-based investigations.
- The consequent residual uncertainties affecting near-field flows are substantial. They could be addressed by evaluation of alternative conceptual models to bound the uncertainties. The suite of model variants considered in hydrogeological modelling to date addresses only a few of the important uncertainties regarding size distribution, spatial clustering, channelling and structural, as well as statistical, relationships of fractures to deformation zones.
- SKB has made all reasonable efforts to acquire representative hydrochemical data for mobile groundwaters and we consider the spatial variability of the key parameters to be well characterised to below repository depth, with the range of variability within the target repository volume probably having only limited potential impacts on EBS performance-related matters, although this would remain to be tested and confirmed in any future safety assessment study for the site.

- Present-day shallow groundwater compositions and their variations are well known. The modelling of transport paths from deep groundwaters into shallow groundwaters and into the biosphere in the Laxemar area would have to represent the hydrogeological heterogeneity, but it is apparent that the hydrochemistry of both deep and shallow parts of the groundwater system provides only qualitative indications of that heterogeneity and does not give quantitative constraints on flow dynamics and distribution.
- The palaeohydrogeological modelling and supporting dataset that have so far been reported are inadequate. Alternative models and systematic exploration of how uncertainties propagate into the flow and transport model are not reported. However, we expect to see reports published soon on a new phase of deterministic palaeohydrogeological modelling that represents a substantial modification of the parameters for the site-scale groundwater system and a greatly improved understanding of the heterogeneity of the system according to geological and/or structural units or 'domains'.
- We consider that the bedrock thermal properties and uncertainties in conductivity distribution and variability probably played a key part in relegating this site, as repository size would be larger and more uncertain. SKB has been very active, and also successful, in developing novel stochastic methods for modelling thermal properties of the different rock types and rock domains at the Laxemar site. SKB has satisfactorily presented the thermal properties of three rock domains covering the major part of the SDM-Site Laxemar rock domain model. However, we note that thermal conductivity is affected by the degree of alteration of the bedrock and 20-25% is altered to some extent, in a variety of styles. SDM-Site does not have a 3-D model of the distribution and overlap of the different types of alteration.
- SKB has developed a methodology to use lithological data to determine thermal rock classes (TRCs) within each rock domain and to use the results for determining thermal properties and uniaxial strength. We encourage SKB to continue this approach during the CDI stage at Forsmark and to use direct tensile testing for determination of tensile strength of the different rock types.
- SKB did not give as much attention to Laxemar (as it did to Forsmark) in assembling its final conclusions about uncertainties, as it gives identical text in its 'confidence' report to that provided for Forsmark. This cannot be the case, given the differences between the two sites.

Overall, the paucity of data in some areas highlighted by the uneven borehole coverage leads to a conclusion that SKB started their programme rather late in Laxemar and could probably have developed a more comprehensive understanding and finalised the publication of their interpretive reports if they had allowed themselves more time. Although the basis for site selection was consequently somewhat uneven, we consider that this is highly unlikely to have affected the final outcome of the site selection, as the basis for selecting Forsmark above Laxemar was becoming clear during the last year of investigations. Whilst SKB thus used a strategically pragmatic and sensible approach, it does leave several unresolved matters, should Laxemar ever re-emerge as a potential geological repository site in the future.

6. The selection of the Forsmark site by SKB: “the bedrock has spoken”

SKB’s rationale for deciding upon which was to be their preferred site between Laxemar and Forsmark was:

1. The site that provides the best conditions for realizing long-term safety will be selected.
2. If there are no significant differences with respect to conditions for realizing long-term safety then the site will be selected that, from all other aspects, is considered most suitable for accomplishing the spent fuel project.

In June 2009, SKB selected the Forsmark site as their preferred location for the spent fuel repository, under the media headline “the bedrock has spoken”, stating that:

> *“The Forsmark site offers rock at the repository level which is dry and has few fractures. These properties are of a major significance for long-term safety. In addition, a repository in Forsmark would require less space compared to a repository in Laxemar, which is an advantage. This means that less rock needs to be excavated and less material will be needed for backfilling”.*

At the time of the announcement, a more detailed justification was also issued in Swedish by SKB[20], with an English translation being published towards the end of 2009[21]. Below we have extracted the technical aspects from the summary of this report, related to the site characterisation programme and SDM results (the document discusses other differences between the sites, for example, to do with environmental impact of construction and waste transport, that are not included in the extracts below).

> *Forsmark’s advantages in terms of prospects for satisfying the requirement on long-term safety are very clear.* The main reason is that there are *few water-conducting fractures* in the rock at repository depth. Based on what we now know about the sites, we can expect that conductive fractures occur with an average spacing of over 100 metres in Forsmark, while the equivalent spacing for Laxemar is 5–10 metres. In Forsmark, this means that *the groundwater flow through the repository will be limited*. This provides great safety advantages for the long-term performance of the copper canister and the bentonite clay.
>
> We cannot today rule out the possibility that *the bentonite clay will be eroded if the surrounding groundwater has too low salinity*. In Forsmark this cannot occur under present-day conditions. During a future ice age, however, the salinity could be sufficiently low on both sites, although this is less likely in Forsmark. Moreover, since

[20] SKB Öppen Rapport 1207622, 4th June 2009
[21] Final repository for spent fuel in Forsmark – basis for decision and reasons for site selection. SKB doc 1221293

the groundwater flows are lower in Forsmark, fewer deposition holes would be affected there than in Laxemar. If the bentonite clay in the buffer should disappear, the canister may after a very long time be damaged by corrosion caused by sulphide. The corrosion rate, and thereby the number of canisters that would be damaged, depends mainly on the groundwater flow. In Forsmark, our analyses show that the groundwater flow in most deposition holes is so low that only a few canisters could be damaged, and the first one only after hundreds of thousands of years. The much higher groundwater flow in Laxemar entails that a greater number of canisters could be damaged. If all canisters remain intact, no releases of radioactive substances will occur.

Another risk that has been assessed is damage to canisters caused by *earthquakes*. On both sites the repository is designed to withstand large earthquakes in any of the nearby fracture zones. Owing to this, the risk that a canister could be damaged in connection with an earthquake is judged to be very small on both sites.

In Laxemar, the *rock stresses* are so low that they are not judged to have any negative impact on long-term safety or the construction of the final repository. The rock stresses are higher in Forsmark, and extensive analyses have been done to determine what this could entail. When canisters have been emplaced in deposition holes, the *rock is heated* and fracturing may then occur that can reach 5 several centimetres out into the rock wall (thermal spalling). Spalling increases the exchange of solutes between buffer and water in fractures in the rock. Since the groundwater flow around the deposition holes is very low in Forsmark, the impact on long-term safety is nonetheless insignificant.

Due to the high rock stresses in Forsmark, the layout of the repository must be adapted to avoid stability problems in tunnels. In certain tunnels oriented in unfavourable directions, the rock stresses can nevertheless lead to an increased need for rock support.
The dry and fracture-poor rock at repository level in Forsmark also entails advantages for the *execution* of construction and operation compared with Laxemar, where conductive fractures occur frequently and can require extensive grouting to seal the rock.
In contrast to the rock at repository level, the *surface rock in Forsmark* down to about 100 metres is fractured and can be *highly conductive*. Special measures will therefore be required to seal the accesses (shafts and ramp) to the repository in the surface rock to an acceptable level. Such measures may require more time but are not deemed to be of such a character that they influence the choice of site.

It is possible to *emplace canisters more densely* in Forsmark than in Laxemar. This is mainly due to differences in the thermal conductivity of the rock. Heat is conducted away from the canisters more efficiently in rock with high thermal conductivity than in rock with lower thermal conductivity. The difference in thermal conductivity is the most important reason why a repository in Forsmark will be 30% smaller than one in Laxemar.

……………………

> Since the comparison shows clear advantages for Forsmark, SKB believes it is *time to select a site* now. Even though the safety assessment will be concluded later, we are confident that Forsmark will meet the safety requirements with ample margin. The differences compared with Laxemar with regard to long-term safety are so great that even if more effort is devoted to further analyses, the choice would be the same.
>
> It is possible that ongoing research will alter our pessimistic assessment of bentonite erosion so that this process can be dismissed. If this should be the case, the calculated radiological risk would be lower on both sites and the sites would then be more equivalent from a safety point of view. But it is difficult to imagine that the safety ranking between the sites would be changed. Furthermore, differences remain in the practical execution of the repository. Great development efforts would be required to improve the prospects for Laxemar. These would have to include development of the grouting methodology and the backfilling technique, or choosing a greater repository depth. The latter change entails a greater area requirement, since the in situ rock temperature is higher, and also entails greater technical risks.

INSITE can agree, in principle, to the simple statements made above, although we reserve our opinion on those comments related to significance in safety assessment, as these will need to be tested against the results to be presented in SR-Site. We also reiterate our view that stress conditions at Forsmark may prove not to be as troublesome as SKB currently anticipates. Consequently, we understand SKB's rationale for preferring Forsmark over Laxemar. Overall, our position on site selection at the end of the CSI is that:

- site choice is, of course, entirely a matter for SKB, but they must now justify the choice clearly by showing the implications of the chosen site conditions for both long-term performance (in SR-Site), operational safety and appropriate design (in the SER report);
- from our knowledge of the geological properties of the sites, in principle, both could be feasible locations for a geological repository for radioactive wastes although it is, as SKB states, less difficult and thus involves less project risk, to develop a repository and its associated safety case at Forsmark.

The latter point is potentially important for the Swedish waste management programme, as it is possible that, in decades to come, a second geological repository location may be required and that Laxemar may then be reconsidered. In this case, knowledge and views about the site today are likely to be revisited.

7. Site information in the design of the Forsmark repository

We evaluated a range of design-related documentation and heard frequently from SKB's design team in the latter half of the site investigation programme and were generally impressed with the quality of the work being developed. An important milestone document in the development of the spent fuel repository at Forsmark was the Site Engineering Report (SER), subtitled 'Guidelines for Underground Design Step D2'[22]. We reviewed a proof version of this report at the very end of the INSITE programme, in late 2009. Our understanding was that, the site having been selected, this report would describe in some detail how information about site understanding, derived from the extensive site characterisation programme, would be used to help manage the next step at the chosen repository site – the CDI stage, of construction and continued detailed investigations in the underground, and the interface with staged repository design work.

On review, we found the SER to be far from complete, consistent, congruent and clear – it would need major improvements before it was given to the designers of the repository at Forsmark. However, its actual status was far from clear, as SKB's approach to managing the design work seems to have changed completely since the SER concept was conceived.

Problems that we identified included the following:

- Important issues, such as feedback to different organisations within SKB's project organisation, including consultations and EIA, are omitted from the report. The SER report gives very limited information how the information collected during the surface investigations and the CDI should enter into the layout and design process.
- SKB has the intention of using the geotechnical part of the EURO-code in design and construction of the repository. In addition SKB will use a design methodology recently developed as a doctoral project at the Technical University of Graz. It is not clear whether the methodology has been applied to any large underground projects and, if so, what lessons have been learned. Both Sweden and SKB have a long way to go before the new EURO-code is adjusted and implemented among consultants, contractors and other stakeholders.
- The actual use of the Observational Method from the EURO-code that is central to the SKB approach is not properly illustrated in the SER. There is no example of the specification of the expected bounds of behaviour of a parameter (i.e. forecasts) and no specification of acceptable and unacceptable behaviour bounds, and how these would have been determined. SKB should use the primary data from all of the extensive field and laboratory testing being conducted and should present them along with the range of variability, by applying statistical methods. Engineering judgements can be applied at the late stage of the design process. For some of the parameters

[22] SKB Report R-08-83

intended for use by the designers, SKB has made engineering judgement; for other parameters, such as hydraulic transmissivity and fracture frequency, primary data from the SDM are used. This mixture of approaches in presenting the engineering data is confusing and, if the designers were to start applying statistical methods, it could easily lead to erroneous results.

- It is not apparent what, or how much, influence the design/layout group had on the acquisition of data for SDM-Site, or will have on the CDI work (e.g. feedback between the design/layout group and the geo-scientific groups). It is not clear that the design/layout group will participate and support the data acquisition (i.e. what site specific data are essential for the layout) at an early stage of the underground characterization of the rock in the near-field of the repository.
- The methodology for identifying layout discriminating fractures – a key aspect affecting where to place spent fuel containers (by avoiding flow rates in excess of what can be allowed for safety considerations) – is not well explained, although SKB has been working on this issue for several years. The premises for the relation between the design/layout of a repository and structures in the bedrock must be clearly expressed and we consider that the design/layout team should, at an early stage of the construction of the underground facilities, be active in the characterization of the bedrock and the selection of the location of the repository area/location of deposition tunnels. As SKB has not presented a CDI programme to complement this report, this issue remains a substantial concern for licensing review.
- There is no basis for assurance regarding the possibility to estimate groundwater drawdowns and upconing, and consequent effects on hydraulic gradients and groundwater movements. In general, the process of adapting hydrogeological information to site engineering needs to be more closely supported by the results of site descriptive modelling.
- There is essentially no discussion of geochemistry and how it might affect construction method or material to be found in the SER. The only mention of chemistry is an uncommented observation on groundwater salinity variation with depth and a note that inflow seepages will need to be monitored to evaluate support types. Given the risk of corrosion of rock reinforcement, we recommended that SSM should ask when SKB intends to specify the selection of material for the different reinforcement and grouting types – the description of methods, materials and procedure is currently vague and superficial.
- The topic of EDZ is not discussed at all. Clearly, it is closely related to spalling, and the final depth and extension of the spalling will be the sum of the excavation damage, EDZ and the stress induced and thermally induced spalling around the underground openings.
- INSITE does not support SKB’s introduction of a completely new way of defining the stress state based on uniaxial compressive strength. SKB has to spend more time and efforts in trying to merge the EURO-code for design with their own development in the design work.

Consequently, the need for, and the role of, this report were found to be ambiguous and we made a strong recommendation that this matter needs to be clarified by SSM, in discussion with SKB. Possibly, when we carried out the review (some months after we had attended a Design expert meeting) SKB was still working out how the design, early construction and CDI stage will fit together. We consider these matters to be central to repository licensing and urgent enough that SSM needs to consider them well before entering the licensing documentation review process.

8. Practical experience of operating INSITE

In this Section, we evaluate our experience at the end of the long period of work undertaken on behalf of the regulatory authorities. Apart from being of value for SSM in terms of planning how to carry out review activities for other major stages of the radioactive waste management programme in Sweden (even though these may be far in the future: e.g. the proposed SFL 3-5 deep repository) we also hope that this assessment might be of value to other national programmes that are reaching the same stage that Sweden had reached in 2001. Our major observations are drawn together in the conclusions presented in Section 9.

8.1. Development of understanding of sites

The site investigations began amid considerable enthusiasm and interest from everyone associated with them. During our first meetings we were concerned with how to interact with SKB (see Section 8.7), how to evaluate information and which information to evaluate. The amount of information that would eventually be produced was certainly not foreseen (see Section 8.2).

It is interesting to observe that, at the preparatory meeting held in November 2001, issues were identified that ran throughout the subsequent investigations. At this meeting, SKB presented its nascent plans for the investigations (at this time, no site work had started; indeed, access permissions were still to come from one area) to the authorities and their consultants, who later were formalised into the INSITE and OVERSITE groups. For example, INSITE already noted that hydrochemical data acquisition would need to be prioritised (data density and representativity proved a running issues for the next 6 years), that the approach to stress measurement would be important and that establishment of baseline conditions and a monitoring programme would need consideration. We were also concerned that, even before work began, SKB seemed focussed on a 'single model with variants' approach to what would become the SDMs. The topics we regarded as 'obvious candidates' for what we at that time termed 'multiple models' were geological structure, fracture network and flow and hydrogeological system evolution.

Clearly, our own understanding of the sites developed in parallel to that of SKB, although generally lagging by about six months. In a number of areas, we identified possible interpretations or data handling approaches that might lead to alternative views on some factors and these led to specific R&D topics that were passed into SKI's programme of associated work (see Section 8.5). A critical aspect of developing understanding is that some interpretations involved subtleties in correlating and integrating extensive and diverse datasets, testing of different views and the progressive emergence of likely explanations of site properties or behaviour. As we note in our conclusions, it would not be possible to come at these final answers unprepared, at the end of the investigations, and come away now with as thorough and deep an understanding of the credibility (confidence) and constraints of the models and explanations produced. Essentially, it was invaluable to ‘grow into’ the data and go along the same learning curve as SKB. This did not mean we came up with the same conclusion; indeed we often came up with differing opinions and are now certainly in a better position to recognise the strengths and weaknesses of the SDMs.

At the end of the project, team members have a comprehensive knowledge of the databases, the quality of the data, the sites and the interpretations. Whilst certainly not anywhere near as deep as the understanding of SKB’s site teams, this knowledge will make review of the LA not only more efficient but, critically, more secure.

8.2. Handling of site investigation documentation

In the early stages of the ISI we read all of the documentation that was being produced by the investigations. This included not only interpretation reports, but also the underlying methodology descriptions and the first raw data reports. We also examined the SICADA database of SKB and how information was being included in it. We felt that it was very important to get a firm grasp on this early, formative period. We needed to understand the methodologies and the data flows; critically, we needed to understand how SKB’s site contractors worked and how the overall data acquisition approaches and their practical implementation were likely to affect data quality. In due course, this led to the first field technical reviews (see Section 8.3).

From the first full meeting of INSITE in 2002, we appreciated that the best way to handle the documentation would be to produce a mixture of written reviews, to inform SKI, and some type of written ‘issue resolution’ documentation, to facilitate interaction with SKB and promote better understanding. As recorded in Section 2.5, this led quickly to the development of the TIL. With use, the TIL formally became the single means of eliciting written responses from SKB to allow us to establish their position or view properly. How well did this process actually work? For some issues, it worked extremely well and there was a progressive, constructive interchange that grew our understanding and allowed issues to be written off (‘closed’). Elsewhere, SKB was less forthcoming and they withheld comment, in some cases for many iterations of the TIL. In the middle period of the investigations, ‘no comment’ returns became so prevalent that SKI asked SKB to address the TIL more rigorously. For some issues we recorded our own developing understanding, based on information we had gathered from reports or FTRs, rather than from any specific, extra information from SKB. We found SKB’s approach in this period to be rather unhelpful and frustrating. In retrospect, it would have been useful for SKI formally to request full responses from SKB to the TIL, as a matter of course.

By the time we had developed the CRI list (consolidating, as it did, the residual TIL issues), SKB had returned to making full and, frequently, extremely helpful responses to all the issues. This really helped us to close down all of the CRIs by the end of the programme. It is important to note that 'closed' had a special meaning at the end of the investigations. We defined it to mean that INSITE had adequate understanding of SKB's approach, reasoning and expected position at the end of the CSI, noting that, nevertheless, the treatment of many of these issues by SKB in SDM-Site, design work and SR-Site is expected to be a focus for SSM review and is reflected in the Structured Review Topics.

In the mid-stages of the programme our ambition level in terms of reviewing documentation became limited by the amount of material emerging from SKB. However, we continued to provide written reviews of major documents, particularly those that involve a large measure of integration or those that addressed problematic issues. Generally, we were close enough to the investigations to be able to identify ourselves those documents that it would be most useful for us to review for the authorities and discussions with SKI staff at our Core Group meetings made sure that the selection was useful and appropriate to their needs. Typically, each member of the INSITE team would read all of a report and provide general comments, and would also be assigned the task of reviewing and commenting on a discipline specific section. Overarching sections would be commented on by the whole team. The INSITE Chairman had the additional task of compiling and editing the commentaries and producing draft recommendations or conclusions. The reports would then be iterated around the team before finalisation. For major reports, we would also discuss the findings of our reviews at Core Group meetings, before the reports were finalised. The major steps in producing iterations of the SDMs involved the production by SKB of many supporting, interpretive reports. These were usually discipline-related (e.g. structural modelling, hydrochemical interpretations, flow modelling) and many of these were several hundred pages long. Review of these would be assigned to the discipline-specific expert on the team. By the end of the CSI the resulting comments were all combined into the review of reports of the top-level SDM-Site documents.

It is important to note that INSITE was not formally involved in any review of SKB's quality assurance (QA) programme. This issue is a matter for the authorities themselves to monitor. Nevertheless, some of our activities did look closely at both the quality of data and the arrangements for managing it within SKB's overall quality framework. In the next section we discuss one of these mechanisms.

8.3. Value of FTRs

The first Field Technical Reviews were carried out in 2003 and were initially called field 'audits' of site investigation methodology. It soon became clear that the term 'audit' caused confusion, owing to its connotations of QA auditing, especially at a time when SKB was finalising the implementation of a quality management system that should inevitably involve formal internal and external QA audits. The original intention was to submit our 'audit' reports to SKB as a commentary, with questions from SKI as follow up if needed. In late 2003, we were obliged to clarify the situation and admit to having inadvertently caused some confusion. In our 4th Core Group report we stated that these field evaluations did not (and were never intended to) constitute formal audits by the regulator or their agents, and that our use of the term was incorrect. From then on these activities were referred to more properly as 'field technical reviews' (FTRs).

The objective of these FTRs was to provide SKI with a view on the scientific and technical quality of the SI work and whether it was achieving necessary goals. In the course of the work, the expert reviews turned up practical issues, problems and questions that did need to be considered by SKB: in this sense they proved to be as useful to SKB as to SKI. A requirement was initiated by SKI for a formal response to FTRs from SKB. To facilitate the process, the scope of FTRs was discussed with SKB in advance and SKI established the requirements for the response with them. Some of the issues arising from FTRs found their way onto the INSITE TIL for tracking and resolution and onto SKI's own list of matters for their consultation meetings with SKB. An agreed formal response mechanism facilitated both discussion and resolution.

INSITE members who participated in FTRs found them one of the most successful means of getting to understand field investigation issues and of being able to get to the root of them with the scientists and technicians who were actively involved on the ground.

8.4. Interaction with SKI and SSM

During the eight-year course of the INSITE programme, SKI staff associated with managing INSITE changed responsibilities and SKI amalgamated with SSI to form the new authority SSM. Up to late 2007, interactions between INSITE and SKI ran smoothly and the objectives of the work were clearly identified and followed. From 2007, in the run-up to the amalgamation, there were significant changes in SKI staffing and the whole, complex process of amalgamation caused some distractions within the authorities. This proved not to be a serious problem, as the INSITE group was extremely experienced by this stage and was also motivated to complete the original programme of work, within the terms of reference set for it.

The lesson that can be drawn from this experience is that change, of one kind or another, is practically inevitable over the course of such a long site investigation programme and should be planned for and accommodated by the regulatory authorities. Happily, in setting up INSITE, SKI had succeeded in establishing a sufficiently robust structure that it was able to work effectively within the changing boundary conditions.

8.5. Interaction with the SKI R&D programme

Our review work generated a number of spin-off R&D projects that were aimed at clarifying particular issues that were identified by SKI as important to their overall regulatory programme. Studies were then carried out that involved individual members of the INSITE team. These included independent assessments of the regional controls on geological structure of the sites, a study of the potential biases in fracture network modelling brought about by the observational limitations of vertical boreholes, evaluation of possible anisotropy in near-surface flow, modelling of stress impacts on fracture permeability, alternative approaches to modelling the results of tracer injection tests and the development of an independent and comprehensive hydrochemical database. We were also involved in helping the PA evaluation group to identify appropriate calculational cases based on site property information and to scope the data requirements of the modelling.

Generally, this approach proved to be a successful way of picking up and tracking down issues that SKB were either treating differently, or not looking at at all. At the end of our work we have identified a number of further issues that SSM may wish to follow up in the move towards a CDI phase.

8.6. Interaction with other SKI and SSI review groups

We interacted intermittently with other review groups established by SKI during the course of the work. As described in Section 2.6, our closest interactions were at the time of the SR-Can review, when we held joint meetings with groups established to look at engineered barrier behaviour (the BRITE group) and at performance assessment methodology and results. Individual INSITE members also worked with the PA review team to provide site data for independent assessments being developed for SKI. Only in the last two years of the programme, when BRITE became more firmly established, did exchange of information take place in the form of meeting records. In general, these interactions could have been more regular and thus more effective, but we appreciate that the arrangements for development of the other groups have not been as advanced as our own.

The OVERSITE group was established at the same time as INSITE by SSI. OVERSITE was a slightly smaller group than INSITE and met less regularly. Broadly, INSITE was to look at sub-surface geological properties of the sites and OVERSITE at the surface and near-surface biosphere environment. OVERSITE members attended some of the information exchange meetings with SKB but also had their own meetings with them. We only worked closely with OVERSITE during the SR-can review, when we combined our efforts into the SIG group. The fact that two groups existed is entirely due to the separation of actual responsibilities between SKI and SSI and of the topical areas of interest that each organisation perceived to be within their own domain. Inevitably, there was some overlap of expertise and there were many times when a common view could usefully have been taken of ‘interface’ issues (e.g. groundwater recharge and discharge). In fact, this only happened during the SR-Can review. Our observation is that, even with the separated organisational responsibilities, it would have been more technically effective and more efficient to have had a single group looking at all the site investigation work.

8.7. Interaction with SKB

Throughout the work we needed constantly to remind ourselves that the regulatory authorities were simply observing the investigations with a view to keeping abreast of them and making licensing review more efficient. Nevertheless, the rationale of keeping the information flow 'one way', from SKB to SKI, was not always logical, especially if it was felt that some comments and responses on a topic would help ensure that misunderstandings, or even non-compliant information, did not emerge during LA review. As active geoscientists, INSITE members, of course, had their own views on what should or could be done in the course of the investigations and how it might best be achieved. It was important to step back from these positions and evaluate objectively what SKB was actually doing, especially if it was using a different approach: was it a sound alternative method, did we believe it was adequate to gather the requisite data, was SKB likely to miss something, should we suggest other approaches? Likewise, SKB clearly had to tread a sometimes difficult path between running their programme as they wished and accounting for what they accepted as important concerns expressed by INSITE/SKI. There was not always consensus on what were going to be critical issues, or how to deal with them and this led to sometimes intense discussions. Our views and those of SKB did not always match up and, at the end of the programme, we are aware that there are still some topics where we had questions on the choice of methods for gathering data, or interpreting them to help resolve important issues, where SKB had chosen not to follow them up. It will remain to be seen whether or not some of these topics (e.g. some of the issues discussed in section 3) will prove to be problematic in the LA review, when the data are factored into safety assessment and design.

The regular one-day meetings with SKB were essential to our work. Normally, these would focus on one of the sites, with shorter updates on the other(s). We also used these meetings as occasions upon which to visit the sites and get a general impression of activities and see rock core material, outcrops and other features on the ground. Both Forsmark and Laxemar were visited two or three times on this basis, as well as by individual team members carrying out FTRs. The information exchange meetings were intense, with dense, information-rich presentations that put a premium on time. Once the investigations built up their pace, meetings were routinely attended by 50-80 people: INSITE, SKI, SSI, SIERG, SKB staff and numerous contractors. Although it was rarely felt that there was inadequate time for discussion, the rather overwhelming size of the meetings did occasionally cramp free interchanges. However, the Expert Group meetings gave more scope for tackling specific topics in detail.

We found the Expert Group meetings, involving SKB, SKI, INSITE and SKB's field contractors to be extremely valuable in building our understanding. They acted as relatively informal fora for discussions that considerably aided comprehension, but were also able to defuse some difficult issues and misunderstandings. Were these misunderstandings to have remained unknown, only to resurface in, say, 2011, it would be difficult for SSM and SKB to resolve them – especially if they would require gathering additional data (not always possible from deep boreholes, for example). Expert Group meetings only began three years into the investigations and only became intensive in the fifth year. In retrospect, it would probably have been useful to begin these detailed discussions earlier.

SKB devoted considerable resources to keeping SKI and INSITE up-to-date with the investigations and were almost always accommodating of requests for information and presentations. We believe that there was a considerable degree of openness in the exchanges that we had – certainly in all technical respects – which facilitated our work enormously. As a counterpoint, we also believe that the regular one-day information exchange meetings that we held with SKB were also found to be valuable by the field investigation teams, especially where they could use the regulatory review group as a sounding board for their developing concepts. Again, whilst this by no means undercuts the eventual requirement for 'regulatory distance' when those concepts are judged, it does mean that SSM should have a better degree of understanding of their strengths and possible weaknesses.

Nevertheless, towards the end of the CSI we considered it necessary to create more distance between SKB and ourselves. By this stage, the investigations had merged into the confirmatory and supplementary testing stage and SKB was crafting the SDM-Site reports that would underpin the LA. At the end of 2008, apart from attending some outstanding Expert Group meetings, it was considered no longer appropriate to hold information exchange meetings with SKB about topics for which they were finalising their licensing position. Consequently, the exchange meeting held in December 2008 was formally the last of its kind.

9. Conclusions

During the eight years of the project, SKB has moved from preliminary selection of a group of potential siting regions, through narrowing down to two target areas within two of the regions and finally to selection of its preferred site, with the whole process driven by a comprehensive programme of field investigations. At the end of this long programme of work, SKB now has the information it needs to submit to the regulatory authorities and the government a design, environmental impact assessment and detailed safety case for its spent fuel repository – all in support of its licence application for construction. It will take the authorities and the government around two years to evaluate and respond to this application. Every aspect of this process and the documentation that will be submitted is underpinned by knowledge of the properties and characteristics of the sites – finally, of the Forsmark site.

The whole purpose of INSITE has been to position the regulators so that they can respond effectively and efficiently to the LA when they receive it and thus be able to provide their recommendation to government in a timely fashion. Because INSITE has been able to track the full derivation and interpretation of data, and provide a view to SSM on the quality, completeness and applicability of the site information, the regulators will now not have to go back to the base level when they commence their review. Effectively, they will be able to move directly to the high level design, environmental impact assessment and detailed safety case documents and focus on the critical arguments that they contain, with confidence that they have a clear picture of site understanding and where the strong and weak points lie. We believe that this will save possibly two years in the review process, but, more crucially, we believe that it would not actually be possible to develop the same depth of understanding needed for a proper review if site evaluation had to start from scratch, today. Parallel tracking of the long programme of field investigations has proved worthwhile in terms of the quality of knowledge upon which the LA review can be based and the consequent safety of the decisions that will be made, as well as in terms of the time saved.

Based upon the vast amount of information we have seen and the insights we have gained through many days of discussions and evaluation, taking the highest-level view, we believe that there is sufficient information and understanding of appropriate quality to support SKB's application submission for Forsmark. Whilst there are some important uncertainties yet to deal with in the safety case and in the CDI stage, we detect nothing intrinsic about the site that would currently argue against a successful outcome, provided the LA process can be negotiated successfully by all parties.

To negotiate the LA review, SKB will need to show how it has used the site data in design and safety assessment and SSM will need to be convinced of the arguments made and the forecasts presented for the future behaviour of the site. In this respect, INSITE has identified a number of critical topics that must be handled with proper attention by SKB and which SSM must consequently focus upon in their assessment. The range of these topics is not reiterated here, but much will revolve around the way that SKB conducts uncertainty assessment, such as uncertainties associated with fracture network and flow connectivity. At much more detailed levels, we have commented on the use of every type of information that will find its way into SKB's LA justification arguments.

An additional outcome of our work has been a set of recommendations to SSM on topics that will need to be kept under review with SKB as they enter the pre-construction and construction stages of repository development. Again, this is at a detailed level and concerns programmes of measurements, observation, forward prediction and monitoring, both in excavations and in existing and new boreholes and other surface installations.

We believe that the experience of tracking a major site investigation programme holds useful lessons for other national programmes, both from the regulators' and the implementer's perspectives. Several programmes around the world are at the point of, or within a few years of, starting their own programmes of site identification and characterisation, and regulatory authorities may be pondering how to interact with implementers during the site investigations. We hope that this report and the substantial record of INSITE public documentation will form a basis from which others can develop their own models of how to proceed to the point of site licensing.

9.1. Acknowledgements

The INSITE project involved the input of many people and interactions with numerous scientists working both for the regulatory authorities and SKB. The original concept of tracking the investigations closely was developed by Fritz Kautsky of SKI and he steered the project through more than half of its existence. We would like to offer our special thanks to him, along with Eva Simic (now with Swedish National Council for Nuclear Waste), who recorded and together enlivened many of our meetings, for their enthusiasm and commitment to the work. Equally, Öivind Toverud has been involved with our work from the beginning and took over the key, linking role between INSITE and SKI/SSM from Fritz Kautsky at the beginning of 2007, steering us skilfully through the crucial final years of the work. Both Bo Strömberg and Georg Lindgren attended our Core Group meetings regularly and provided an invaluable link to SKI's R&D programme and the independent safety assessment and repository engineered barriers tracking that paralleled our own work. We would also like to thank Gisela Hytte, who made all the excellent logistical arrangements for our meetings and field visits. Carina Wetzel helped to organise some of our later meetings.

In concluding this report, it is appropriate that we also express our thanks to SKB and, in particular Olle Olsson, for their considerable efforts to provide information, facilitate FTRs, initiate Expert Group meetings and make the regular one-day exchange meetings valuable for INSITE. Whilst it could be said that SKB was obliged to participate, or that there was strategic advantage to them in so doing, there was no formal regulatory stipulation for them to do so. From February 2002, SKB provided detailed information and access to the experts with first-hand knowledge of each aspect of the site char-

acterisation. SKB staff and contractors, too numerous to itemise here, provided information and joined in these discussions. We would, however, like to thank in particular the leaders of the two site investigation teams for their assistance: Kaj Ahlbom at Forsmark and Peter Wikberg (and later, Anders Winberg) at Simpevarp/Laxemar. We had opportunity to discuss data and interpretations and visit the sites to observe the work in progress. This greatly facilitated our work and we are well aware that it involved deployment of large resources by SKB – a commitment that, we believe, has greatly assisted the regulatory review process. For such detailed and lengthy site investigations and interpretations, it would not have been possible for the regulatory authority to gain a thorough understanding of the technical underpinning of the LA without this continuous tracking.

Appendix 1: INSITE Technical Reports

TRD-03-01	Comments on Site Descriptive Models (SDMs) and Alternative Conceptual Models (ACMs)
TRD-03-02	Audit for SKI/INSITE of Geochemistry Procedures at SKB's Simpevarp Site
TRD-03-03	INSITE Field Audit: Site Investigation Methodology and Application at the Forsmark Site
TRD-04-01	Compiled INSITE Core Group Comments on the SR-Can Planning Report (SKB TR-03-08)
TRD-04-02	INSITE Review: Selection of Prioritised Site in the Oskarshamn Area, SKB R-03-12, and Geological Basis for Selection of Prioritised Site within the Area West of Simpevarp, SKB P-03-06.
TRD-04-03	Review of Method Description for Rock Stress Measurement with Hydraulic Fracturing
TRD-04-04	Review of Thermal Site Descriptive Model – A strategy for the model development during site investigations, Version 1.0 SKB R-03-10
TRD-04-05	INSITE comment on: SKB TR-02-19: Testing the Methodology for Site Descriptive Modelling
TRD-04-06	INSITE review of SKB TR-02-28: Preliminary safety evaluation based on initial site investigation data. Planning document
TRD-04-07	INSITE Field Technical Review: Rock Stress Measurement with Overcoring Technique at the Forsmark Site
TRD-04-08	INSITE Review: Hydrogeochemical site descriptive model – a strategy for thr model development during site investigations (SKB Report R-02-49)
TRD-04-09	Effects of borehole orientation on sampling of fractures at the Forsmark site
TRD-04-10	INSITE review of: Hydrogeological Site Descriptive Model – a strategy for its development during site investigation (SKB R-03-08)
TRD-04-11	INSITE review of: Geological Site Descriptive Model – A strategy for model development during site investigations (SKB R-03-07)
TRD-04-12	INSITE Document Review: Preliminary Site Description Forsmark Area – Version 1.1 (SKB Report R-04-15)
TRD-04-13	INSITE Document Review: When is there sufficient information from the site investigations? (SKB Report R-04-23)
TRD-04-14	INSITE Document Review: Grundvattnets regionala flödesmönster och sammansättning – betydelse för lokalisering av djupförvaret (SKB R-03-01) On the role of mesh discretisation and salinity for the occurrence of local flow

	cells (SKB R-03-23) Modelling of groundwater flow and flow paths for a large regional domain in northeast Uppland (SKB R-03-24)
TRD-04-15	INSITE Document Review: Transport properties site descriptive model: Guidelines for evaluation and modelling. SKB R-03-09
TRD-04-16	INSITE Document Review: Strategy for the use of laboratory methods in the site investigations programme for the transport properties of the rock. SKB R-03-20.
TRD-05-01	INSITE Document Review: Comments on Preliminary Site Description – Simpevarp area version 1.1. SKB R-04-25
TRD-05-02	INSITE Document Review: The Potential for Ore and Industrial Minerals in the Forsmark Area. SKB-04-18
TRD-05-03	INSITE Document Review: Deep Repository. Underground Design Premises. Edition D1/1. SKB R-04-60
TRD-05-04	INSITE Field Technical Review: Testing and Reported Results of Mechanical and Thermal Properties of Rocks performed at the Swedish National Testing and Research Institute
TRD-05-05	INSITE comments on: SKB Report R-05-14: Forsmark site investigation: programme for further investigations of geosphere and biosphere (January 2005)
TRD-05-06	INSITE Document Review: Preliminary Site Description: Simpevarp Area – Version 1.2 (SKB Report R-05-08) Preliminary Safety Evaluation for the Simpevarp subarea (SKB Report TR-05-12)
TRD-05-07	INSITE Periodic Report: The Initial Site Investigations
TRD-05-08	Need for Confirmatory Testing of Upscaled Flow and Transport Models
TRD-05-09	INSITE Document Review: Respect Distances: Rationale and Means of Computation (SKB Report R-04-17)
TRD-05-10	INSITE Document Review: Preliminary Safety Evaluation: Forsmark Area (SKB Report TR-05-16)
TRD-05-11	INSITE comments to scientific workshop on the application of geotechnical experience from the underground research laboratory in Canada to the Forsmark site in Sweden
TRD-05-12	INSITE Document Review: Preliminary Site Description - Forsmark area Version 1.2 (SKB Report R-05-18)
TRD-05-13	INSITE comments on: A comparison of two independent interpretations of lineaments from geophysical and topographical data at Forsmark (SKB Report R-05-23)

TRD-06-01	INSITE Field Technical Review: Field Geochemistry Activities at SKB's Forsmark Site
TRD-06-02	INSITE Document Review: Preliminary Safety Evaluation: Laxemar Area (SKB Report TR-06-06)
TRD-06-03	INSITE Document Review: LAXEMAR Preliminary Site Description: Laxemar Subarea – Version 1.2 (SKB Report R-06-10) Programme for Further Investigations…. Laxemar Subarea (SKB Report R-06-29)
TRD-06-04	INSITE Document Review: Review of supraregional modeling of groundwater flow in eastern Småland (SKB Report R-06-64)
TRD-06-05	A numerical study of strength, deformability and permeability of rocks for repositories of spent nuclear fuel at Forsmark and Simpevarp Sub-area sites with a DFN-DEM methodology: Phase 1; Numerical investigation of effects of in situ stresses on rock permeability
TRD-06-06	Review of the 2007 CSI plans: SKB PM-1062256: Additional investigations during the final phase of the site investigation at Forsmark SKB PM 1062254: The CSI programme of the site investigation in Oskarshamn – investigations performed & current plans for remaining work
TRD-07-01	INSITE Document Review: Final repository for spent nuclear fuel: Underground design Forsmark, Layout D1 (SKB Report R-06-34) Preliminary assessment of potential underground stability (wedge and spalling) at Forsmark, Simpevarp and Laxemar sites (SKB Report R-05-71)
TRD-07-02	Structural interpretation of topographic data – Rock block configuration on regional scales and the distribution of earthquakes in the regional surroundings of the Forsmark and Laxemar areas, Sweden
TRD-07-03	INSITE Field Technical Review: Field Geochemistry Activities at SKB's Forsmark Site
TRD-07-04	A numerical study of strength, deformability and permeability of rocks for repositories of spent nuclear fuel at Forsmark and Simpevarp sub-area sites with a DFN-DEM methodology: Phase 2; Numerical investigation on effect of in situ stresses on deformability properties and strength of rocks of both Forsmark and Simpevarp sub-area sites
TRD-07-05	INSITE Document Review: Review of Forsmark and Laxemar Site Descriptive Models v2.1 (SKB Reports R-06-38 and R-06-110)
TRD-07-06	Some Insights from Simulations of SWIW Tests on a Complex Fracture

M-08-01	INSITE Comments on SKB's FUD 2007 Report
M-08-02	INSITE Comments on SKB R-07-26: Quantifying in situ stress magnitudes and orientations for Forsmark, Forsmark stage 2.2
M-08-05	INSITE comments on SKB P-07-206: Stress measurements with hydraulic methods in boreholes KFM07A, KFM07C, KFM08A, KFM09A and KFM09B, Forsmark Site Investigation
M-08-06	INSITE comments on SKB P-07-234: Evaluation of overcoring stress measurements in boreholes KFM01B, DBT-1 and DBT-3 and hydraulic stress measurements in boreholes KFM01A, KFM01B, KFM02A and KFM04A at the Forsmark site, Forsmark site investigation
M-08-07	INSITE comments on SKB P-07-235. Detection of potential borehole breakouts in boreholes KFM01A and KFM01B, Forsmark site investigation
M-09-01	INSITE comments on SKB R-07-31: Rock Mechanics Forsmark. Site descriptive modelling Forsmark stage 2.2
M-09-02	INSITE comments on SKB R-07-42. Thermal site descriptive model. A strategy for the model development during site investigations – version 2
M-09-04	Hydrogeological Confirmatory Testing at the Forsmark and Laxemar Sites
M-09-05	Review of Models for Discrete-Fracture Network and Minor Deformation Zones
M-09-06	SDM-Site Forsmark: Review of SKB TR-08-05 (Site description of Forsmark at Completion of the Site Investigation Phase) and supporting documentation
M-09-07	SDM-Site Laxemar: Review of SKB TR-09-01 (Site description of Laxemar at Completion of the Site Investigation Phase) and supporting documentation
M-09-08	INSITE Summary Report: A summary of INSITE activities in tracking SKB's spent fuel repository site investigations from 2002-2009 and of advice provided to the regulatory authorities on the status of site understanding at the end of the surface-based investigations (Identical to this report)
M-09-09	Review of the Forsmark Site Engineering Report (SER)
M-09-10	Comments on SKB Report TR-08-08 on the EDZ

Note: from 2008, as the authorities entered the pre-licensing period, INSITE reports were issued as memoranda ('M' series reports) instead of Technical Reports (TRD series). This table lists only those M-series reports that cover technical reviews. The other M-series reports are regular updates of the TIL or CRI list and records of the INSITE Core Group meetings. All of these can be requested from SSM.

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The Swedish Radiation Safety Authority has a comprehensive responsibility to ensure that society is safe from the effects of radiation. The Authority works to achieve radiation safety in a number of areas: nuclear power, medical care as well as commercial products and services. The Authority also works to achieve protection from natural radiation and to increase the level of radiation safety internationally.

The Swedish Radiation Safety Authority works proactively and preventively to protect people and the environment from the harmful effects of radiation, now and in the future. The Authority issues regulations and supervises compliance, while also supporting research, providing training and information, and issuing advice. Often, activities involving radiation require licences issued by the Authority. The Swedish Radiation Safety Authority maintains emergency preparedness around the clock with the aim of limiting the aftermath of radiation accidents and the unintentional spreading of radioactive substances. The Authority participates in international co-operation in order to promote radiation safety and finances projects aiming to raise the level of radiation safety in certain Eastern European countries.

The Authority reports to the Ministry of the Environment and has around 270 employees with competencies in the fields of engineering, natural and behavioural sciences, law, economics and communications. We have received quality, environmental and working environment certification.

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