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The SKI SITE-94 Project: An International Peer Review Carried out by an OECD/NEA Team of Experts

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(översättning av Executive Summary)

SITE-94 är ett forskningsprojekt som genomförts av Statens kärnkraftinspektion (SKI). Det syftar till att bygga upp organisationens kompetens och förmåga att utvärdera säkerheten i ett geologiskt slutförvar för använt kärnbränsle. SITE-94 fokuserar på utveckling av säkerhetsanalysmetodik och på tillämpning av denna metodik på ett hypotetiskt slutförvar, baserat på KBS-3-metoden, vid Äspölaboratoriet som drivs av Svensk kärnbränslehantering AB (SKB). Stor vikt läggs vid utvärdering av platsspecifika data, med sin inneboende osäkerhet, i säkerhetsanalysen. Särskilda insatser har också gjorts för att öka förståelsen av de mekanismer som kan komma att hota kapselns integritet.

Samarbetsorganet NEA (Nuclear Energy Agency) inom OECD har, på begäran av SKI, organiserat en internationell expertgranskning av SITE-94. Generellt sett var granskarna imponerade av kvaliteten och öppenheten i SITE-94-projektet och på det sätt SKI följt upp de frågor och synpunkter som givits i samband med granskningen av SKIs tidigare säkerhetsanalysprojekt, Projekt-90. Föreliggande rapport sammanfattar de huvudsakliga kommentarerna från granskningsgruppen vilka, i enlighet med anvisningarna från SKI, omfattar:

- *SITE-94-metodiken*

  - Med ytterligare någon förfining kommer SITE-94-metodiken att ge SKI ett värdefullt verktyg i sin roll som tillsynsmyndighet.

  - Konstruktionsförutsättningarna, utgångspunkten i metodiken, är i princip baserade på KBS-3-metoden, men uppvisar några viktiga avvikelser från denna. En välgrundad definition och en övergripande beskrivning av konstruktionsförutsättningarna, liksom en förklaring till avvikelserna från KBS-3-metoden, är delar som saknas i SITE-94.

  - Den metodik med vilken egenskaper, händelser och processer (FEP) analyseras utgör ett internationellt betydande bidrag inom detta område. Metodiken har potentialen att generera säkerhetsanalyser som är såväl spårbara som transparenta med avseende på teknisk granskning.

  - Den metodik med vilken scenarier genereras från externa FEP är logisk, men det kan vara till nytta att definiera ytterligare en grupp scenarier relaterade till avvikelser i slutförvarets inre egenskaper, d.v.s. avvikelser från konstruktionsförutsättningarna. Sådana "interna" scenarier skulle kunna utgöra ett användbart underlag för en dialog mellan tillsynsmyndighet och utförande instans (SKB).

  - Det finns fördelar att hämta med att beakta sannolikheten för olika grupper av scenarier. Denna förbättring av metodiken skulle underlätta såväl dialogen med utförande instans som tillsynsmyndighetens beslutsfattande, med avseende på de åtgärder som behövs för att hantera tänkbara scenarier med potentiellt allvarliga konsekvenser.

- *Tillämpning av metodiken:*

  - Tillämpningen av SITE-94-metodiken har gett SKI värdefull erfarenhet då det gäller platsutvärdering, men den har inte genomförts fullt ut och är något obalanserad. Spårbarheten har inte demonstrerats till fullo. Som exempel kan nämnas att det inte är dokumenterat varför vissa FEPs, som bedömts som

synnerligen viktiga, har uteslutits eller har tagits med i analyserna.

- Även om omfattningen är begränsad har analysen visat sig vara synnerligen resurskrävande. En lämplig metodik för en utförande instans skulle behöva inkludera en strategi för att fokusera resurserna mot demonstration av säkerheten. SKI skulle kunna använda sin metodik för att granska argument som sannolikt skulle komma att utnyttjas för att formulera en sådan säkerhetsstrategi.

- Data från SKBs ytbaserade undersökningar vid Äspölaboratoriet (förundersökningsskedet) utgör ett rimligt test av metodiken. SKIs analys av rådata är tekniskt sund. Ansträngningarna med att identifiera och propagera osäkerheter i den hydrogeologiska modellen, och framför allt i den strukturgeologiska modellen, är särskilt värdefulla. Omtolkningen av platsdata och utvärderingen av dessa data i säkerhetsanalysen har också resulterat i en värdefull återkoppling till SKB vad gäller platsundersökningsmetodik inför kommande platsundersökningar.

- Beslutet att kvantitativt analysera huvudscenariot är berömvärt eftersom detta har avslöjat de potentiellt allvarliga konsekvenserna av klimatförändringar, även om det är viktigt att granska hela den uppsättning bevis som stöder analysen.

- Vissa av utvärderingsmodellerna är alltför förenklade och kan behöva uppdateras (t. ex. modellen för beräkningar av utläckage av radionuklider genom ett litet hål (initial defekt) på kapseln).

- Det saknas argumentering för tillämpning av den enkla biosfärmodellen och en diskussion av de svårigheter som är knutna till biosfärmodellering.

- Förslaget att beräknade doser kan ge en anvisning om antalet skadade kapslar som skulle kunna tillåtas i ett slutförvar borde ha undvikits med tanke på att graden av konservatism i de olika modellerna inte har granskats kritiskt.

- Kunskaperna om platsutvärdering kommer att förbättras ytterligare om man analyserar de nya data som nu finns tillgängliga från tunneln under Äspö; detta är också något som SKI planerar att göra. Mera allmänt borde SKI beakta i vilken omfattning olika typer av data kommer att finnas tillgängliga vid olika faser av slutförvarsprogrammet och hur detta påverkar möjligheten att tillgodoräkna sig de olika barriärernas funktion i säkerhetsanalysen.

- *Kapselanalys:*

  - SITE-94 bidrar till att förstärka förtroendet för kopparkapselns korrosionsbeständighet och kommer att vara till nytta för att fokusera fortsatt forsknings- och utvecklingsarbete på speciella korrosionsmekanismer och miljöförhållanden som skulle kunna inkräkta på den annars mycket långa inneslutningstid som beräknats.

  - Större vikt skulle har lagts vid detta arbete i slutsatserna från SITE-94, även om granskningsgruppen håller med om att en direkt koppling av detta arbete till säkerhetsanalysberäkningarna inte är försvarbar så länge det saknas slutliga specifikationer för utformning, tillverkning och kvalitetssäkring av fullstora kapslar.

- *Dokumentationen av SITE-94:*

  - SKI har vänt sig till olika grupper med en mängd olika typer av projektdokumentation.

- SITE-94-dokumentationen är berömvärt öppen sett till dess sätt att fastställa sina begränsningar och utelämnanden inom SITE-94-projektet. Generellt kan sägas att det är en bra balans mellan omfattning och läsbarhet.

- Transparens uppnås endast delvis. Antaganden och förenklingar som görs i modellerna som används för de kvantitativa beräkningarna och det förtroende som SKI anser kan fästas vid dessa modeller och analyser borde ha beskrivits tydligare.

- Likheterna med och skillnaderna mellan SITE-94-metodiken och metodik som valts av andra organisationer (utanför Sverige) kunde med fördel ha diskuterats i projektdokumentationen.

• *Slutsatser från SITE-94:*

- Slutsatserna är tämligen öppna vad gäller bristerna i fullständighet hos SITE-94 och identifierar områden där ytterligare arbete behövs.

- Det är svårt att värdera den relativa vikten av olika tekniska områden utgående från resultaten från SITE-94. Följaktligen kan för närvarande få råd ges om lämplig fördelning av forsknings- och utvecklingsresurser.

- Det borde ha redogjorts tydligare att slutsatserna om "kritiska återstående säkerhetsfrågor" inte bara kommer från SITE-94-analyser utan även från SKIs allmänna erfarenhet.

I det stora hela representerar SITE-94 ett imponerande arbete. SKI har inte bara ökat sin kompetensnivå i att genomföra tekniska granskningar utan har även gett viktiga bidrag till aktuell praxis med avseende på metodik för säkerhetsanalys och för assimilering av platsspecifika data i en säkerhetsanalys samt i förståelsen av de mekanismer som skulle kunna hota kapselns integritet. Med ytterligare någon förbättring skulle SITE-94-metodiken kunna utgöra ett värdefullt verktyg för myndighetsgranskningar och kommentarer. Tillämpningen av metodiken på data från de ytbaserade undersökningarna vid Äspölaboratoriet har utgjort ett bra första test av SITE-94-metodiken. Identifieringen och propageringen av osäkerheter i strukturmodellen är särskilt berömvärd. Granskningsgruppen stöder den planerade utvärderingen av SITE-94-resultaten utgående från data som samlats vid underjordsarbetena vid Äspö, vilken kommer att ytterligare förbättra SKIs kompetens då det gäller platsutvärdering.

Granskningsguppen rekommenderar att SKI i sitt fortsatta arbete ska fokusera på åtgärder för att utvärdera och presentera trovärdigheten för sina resultat, samt, i ett vidare perspektiv, på åtgärder som underlättar dialogen mellan tillsynsmyndighet och utförande instans. Det sistnämnda omfattar bedömning av sannolikheter för scenarier med potentiellt allvarliga konsekvenser och beaktande av "interna" scenarier, baserade på avvikelser från konstruktionsförutsättningarna.

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Preface

As a regulatory authority with a responsibility to review and supervise the activities of the nuclear industry in Sweden, the Swedish Nuclear Power Inspectorate (SKI) is continually enhancing its competence in a range of technical areas, including the assessment of the final disposal of spent fuel and nuclear waste. The recently completed SITE-94 project is the SKI's latest effort directed at building competence and capacity in the assessment of safety of a spent-fuel geologic repository. Emphasis is given to the assimilation of site-specific data, with its associated uncertainties, into the performance assessment. Specific attention is also given to improving the understanding of mechanisms that might compromise canister integrity.

This report represents the common views of an International Review Team (IRT) established by the NEA Secretariat, at the request of the SKI, to perform a peer review of Site-94. The basis for the report is the understanding of SITE-94 and its background obtained by the IRT in the course of several months of study of SITE-94 documentation, internal discussions and a meeting with the SKI in Stockholm. The report is limited to the main findings of the IRT. More detailed comments have been presented to the SKI orally, and in the form of written questions, both prior to, and during the meeting. The intended audience of the report is principally the staff of the SKI and, accordingly, the style of the report is suited to a technical audience familiar with contents of the SITE-94 Project.

This report has not been checked by the SKI. The IRT has made its best effort to ensure that all information in this report is accurate and takes responsibility for any factual inaccuracies.

Executive Summary

SITE-94 is a research project, carried out by the Swedish Nuclear Power Inspectorate (SKI), aimed at building the organisation's competence and capacity in the assessment of safety of a geologic repository for spent fuel. SITE-94 focuses on the development of a performance-assessment methodology and on the application of this methodology to a hypothetical repository based on the KBS-3 concept and located at the site of the Hard Rock Laboratory at Äspö, operated by the Swedish Nuclear Fuel and Waste Management Company (SKB). Emphasis is given to the assimilation of site-specific data, with its associated uncertainties, into the performance assessment. Specific attention is also given to improving the understanding of mechanisms that might compromise canister integrity.

The Nuclear Energy Agency (NEA) of the OECD has, at the request of the SKI, organised a peer review of SITE-94 by a team of experts of international standing. In general the reviewers were impressed with the quality and openess of the SITE-94 Project, and that most of the issues identified in the review of Project-90, an earlier SKI project, had been addressed. The present report summarises the main comments of the review team, which, in accordance with the terms of reference provided by the SKI, concern:

- *The SITE-94 methodology*:

  - With some further refinement, the SITE-94 methodology will provide the SKI with a valuable tool to assist in its role as a regulator.

  - The Design Basis, the starting point of the methodology, is principally derived from the KBS-3 design, but with some significant deviations from this concept. The lack of a well-argued definition and comprehensive description of the Design Basis, and the lack of explanation for deviations from the KBS-3 design, is an omission in SITE 94.

  - The methodology by which Features, Events and Processes are analysed represents an internationally significant contribution to this field. The methodology has the potential to generate performance assessments that are both traceable and transparent to technical examination.

  - The methodology by which scenarios are generated from external FEPs is logical, but it may be useful to define a further set of "internal" scenario classes that consider deviations from the Design Basis. Such internal scenarios could provide a useful basis for a dialogue between the regulator and the implementer.

  - There are benefits to be obtained by considering the likelihoods of different scenario classes. This enhancement of the methodology would facilitate dialogue with the implementer, and decision making by the regulator, regarding the measures necessary to deal with possible scenarios with high potential consequences.

- *Application of the methodology*:

  - The application of the SITE-94 methodology has provided the SKI with valuable experience in site evaluation, but is limited in scope and is somewhat unbalanced. Traceability has not been fully demonstrated. For example, the basis is not recorded for decisions whereby some Features, Events and Processes, identified as highly important, are omitted from the analysis, whereas others are included.

  - Although limited in scope, the analysis has proven to be highly demanding in terms of resources. A methodology appropriate to an implementer would include a strategy to focus resources towards safety demonstration. The SKI could use its methodology to explore arguments that are likely to be employed in formulating such a safety strategy.

  - Data from the SKB's surface-based investigations at the Swedish Hard Rock Laboratory (the pre-investigation phase) at Äspö provide a reasonable test of the methodology. The SKI's analysis of raw site data is technically sound. Efforts to identify and propagate uncertainties in the hydrogeological model and, in particular, in the structural model, are especially valuable. Also valuable is the feedback to the SKB on further site-characterisation activities, provided by the re-interpretation of raw site data and their assimilation in performance assessment.

  - The decision to analyse quantitatively the Central Scenario is commendable, having revealed the potentially high-consequence impact of climatic evolution, although it is important to review the full body of evidence supporting this analysis.

  - Some of the assessment models are disproportionately simplistic and may need to be updated (for example, the pinhole near-field release model).

  - Justification for the use of a simple biosphere model and discussion of the problems inherent in biosphere modelling is lacking.

  - The suggestion that calculated doses provide an indication of the number of failed canisters that would be admissible in a repository should have been avoided given that the degree of conservatism in the various models has not been critically examined.

  - Competence in site evaluation will be further enhanced by considering data from the underground exploration phase at Äspö; this is currently planned by the SKI. More generally, the SKI should consider to what extent various sources of data will be available at different phases of repository development and the implications that this has for the credit that can be taken for the different barriers in a performance assessment.

- *Canister analysis*:

  - SITE-94 builds confidence in the corrosion resistance of the copper canister and will serve to focus future R&D work on particular corrosion mechanisms and environmental conditions that could compromise the otherwise very long predicted containment times.

  - More credit could have been taken for this work in the SITE-94 conclusions, although it is agreed that, in the absence of final specifications for design, manufacture and quality-assurance procedures for the reference full-scale canister, direct coupling of the work to performance-assessment calculations would not have been justifiable.

- *The documentation of SITE-94*:

  - The SKI has addressed different audience levels with a wide range of project documentation.

  - SITE-94 documentation is commendably open with respect to stating the limitations of, and omissions within, the SITE-94 project and, in general, strikes an appropriate balance between comprehensiveness and readability.

  - Transparency is only partially achieved. The assumptions and simplifications made in the models that are applied to the quantitatively evaluated cases, and the confidence that the SKI believes can be assigned to these models and analyses, should have been more clearly stated.

  - The similarities and differences between the SITE-94 methodology and that adopted by other organisations (outside Sweden) could usefully have been discussed in the project documentation.

- *SITE-94 conclusions*:

  - The conclusions are quite open about the lack of completeness of SITE-94, and identify areas where more work is required.

  - It is difficult to assess the relative importance of different technical areas on the basis of the SITE-94 results. Thus, little guidance can currently be given as to an appropriate allocation of R&D resources.

  - It should have been more clearly acknowledged that conclusions on "outstanding safety issues" are derived not only from SITE-94 analyses, but also from the SKI's general experience.

Overall, SITE-94 represents an impressive achievement. The SKI has not only increased its level of competence to perform technical reviews, but has also made significant contributions to the current state of practice in performance-assessment methodology, in the assimilation of site-specific data in a performance assessment and in the understanding of mechanisms that might compromise canister integrity. With some further improvement, the SITE-94 methodology should provide a valuable tool for regulatory review and comment. The application of the methodology to data from surface-based investigations at the Äspö research facility has provided a good initial test of the SITE-94 methodology and the identification and propagation of uncertainties in the structural model is particularly commendable. The review team supports the planned testing of the SITE-94 results using data gathered during the excavation phase at Äspö, which will further develop SKI's competence in site evaluation.

The review team recommends that, in its future work, the SKI focuses on measures to evaluate and present confidence in their findings and, more broadly, on measures that will facilitate a dialogue between the regulator and the implementer. The latter include the consideration of the likelihoods of scenarios with potentially high consequences and the consideration of "internal" scenarios based on deviations from the Design Basis.

1. Introduction

As a regulatory authority with a responsibility to review and supervise the activities of the nuclear industry in Sweden, the SKI is continually enhancing its competence in a range of technical areas, including the assessment of the final disposal of spent fuel and nuclear waste. The recently completed SITE-94 project is the SKI's latest effort directed at building competence and capacity in the assessment of safety of a spent-fuel geologic repository.

SITE-94 is a research project focusing on (i) the development of a performance-assessment methodology, particularly for FEP analysis and scenario development, (ii) testing the methodology by applying it to site-specific data and (iii) improving the understanding of mechanisms that might compromise canister integrity. Formally, SITE-94 analyses the performance of a hypothetical repository based on the KBS-3 concept and located at the site of the Swedish Hard Rock Laboratory at Äspö. The site data utilised are specific to Äspö and represent the results of surface-based investigations (the Äspö pre-investigation phase) carried out by the SKB between late 1986 and October 1990.

An earlier SKI project, Project-90[1], was completed in 1992 and peer reviewed by an international team assembled under the aegis of the NEA[2]. The SKI took into account the comments and recommendations of the NEA reviewers in planning the SITE-94 project. The contents and results of SITE-94 have been presented to technical audiences in the course of the project and, at its close, an international seminar was held in Sweden. On that occasion, the SKI also announced its intention to arrange for a peer review of the SITE-94 work through the NEA.

The present report summarises the outcome of the NEA review. The NEA peer review team, referred to as the International Review Team (IRT) in the rest of this report, was made up of experts of international standing in fields relevant to site evaluation and safety assessment (see Appendix 4 for résumés). The experts were drawn from waste-management organisations, national regulatory bodies, scientific consultancies and from the NEA itself.

The terms of reference for the review are reproduced in Appendix 5. The IRT was given a broad mandate, but was asked to focus on the technical and scientific methodology and on the conclusions. The terms of reference of the review state that SITE-94 is not a complete safety assessment, although the ambition was to document the project in a format that follows the SKI's general advice concerning the content of a safety assessment. In performing its review, the IRT recognises that SITE-94 is not an attempt to make a safety case (that is the responsibility of the SKB) but rather it aims to provide the SKI staff with experience in site-specific performance assessment and to identify important safety issues. The SKI staff will use the tools developed during SITE-94 and

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[1] Project-90, SKI Report 91:23,Vols. I and II, Swedish Nuclear Power Inspectorate, Stockholm, 1991.

[2] "SKI Project-90, a review carried out by an OECD/NEA Team of Experts", OECD Nuclear Energy Agency, Paris, 1992.

the experience gained in the review for evaluation of the SKB's research program and, eventually, for the evaluation of any safety case that the SKB may submit.

The comments provided hereafter are based on the principal SITE-94 documentation[3], supplemented by information obtained at the international seminar (April 4, 1997, Stockholm, Sweden) and at a meeting between the IRT and the SKI (June 16-20, 1997, Stockholm, Sweden). This report presents the main points of the review. It is not intended to be comprehensive, since more detailed points were presented, prior to the meeting between the IRT and the SKI, in the form of preliminary written comments and questions to the SKI. Furthermore, comments were made, and additional questions asked, during the meeting itself. The structure of the present report is guided by the terms of reference provided by the SKI. In particular:

- the SITE-94 methodology, including definition of the Design Basis, the analysis of Features, Events and Processes (FEPs), the development of scenarios and the assignment of likelihoods to scenarios, is discussed in Section 2;
- the application of the SITE-94 methodology, the demands that the methodology imposes on resources of an organisation, the analysis of uncertainties and the use of assessment models are examined in Section 3;
- the achievements of SITE-94 regarding canister analysis are reviewed in Section 4;
- the SITE-94 documentation, including its openness, comprehensiveness, readability and transparency, is assessed in Section 5;
- the SITE-94 conclusions, including their justification by the analyses and the extent to which they can be used to guide future work, are reviewed in Section 6.

Specific points are further elaborated in Appendices 1-3. The overall judgement from the review is given in Section 7.

2. The SITE-94 Methodology

The starting point of the methodology developed in SITE-94 is the definition of a Design Basis. Although the Design Basis for SITE-94 is principally derived from the KBS-3 design, there are some significant deviations from this concept. Examples of these deviations are: neglect of the concept that waste deposition holes are to be located at a "respect distance" from major fault zones and that those deposition holes that intersect water-conducting features can be rejected. The IRT finds that the lack of a well-argued definition and comprehensive description of the Design Basis is an omission in SITE-94 (Appendix 1). In particular, the rationale for deviations from the KBS-3 concept should have been carefully recorded in order to provide a context in which to view the calculational results. More importantly, the general issue of how to include possible deviations from Design Basis in the development of scenarios and in consequence analysis deserves further attention (see below).

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[3] SITE 94, Deep Repository Performance Assessment Project, SKI Report 96:36, Vols. 1&2; SKI Report 97:5 (Summary), Swedish Nuclear Power Inspectorate, Stockholm, 1996.

Having established a Design Basis, the next step in the SITE-94 methodology is the analysis of FEPs and the development of scenarios. Regarding FEP analysis, it is considered that the SITE-94 project represents an internationally significant contribution. In particular, the Process Influence Diagram (PID) and Assessment Model Flowchart (AMF) are useful tools for representing the inter-relationships and information flows between the various FEPs and the models that represent them. System understanding is laid open to scrutiny (for example by external reviewers) in the form of the PID, and the mapping of the PID onto the AMF indicates whether, and how, FEPs and influences are considered in the models. The methodology thus has the potential to generate performance assessments that are:

(i) Traceable, in that the motivation behind individual calculational cases can, in principle, be traced back, via the AMF and PID, to decisions regarding, for example, various classes of uncertainty. The AMF and PID should provide a long-term record of the detailed background to SKI performance assessments. Such a record avoids duplication of effort later in the programme and is particularly valuable to a small organisation, such as the SKI, where expertise resides with a limited number of staff members.

(ii) Transparent to technical examination, since the results obtained can be clearly linked to the arguments and assumptions made.

The scenarios identified in SITE-94 are limited to those generated by considering the effects of FEPs that are external to the Process System (EFEPs). This approach is logical, but incomplete, since it neglects deviations from the Design Basis on which the Process System is founded. Such deviations can never be excluded, and will be most prominent in the early stages of repository planning, when uncertainties are greatest. It would therefore be useful, particularly at the current early stage, to define a further set of "internal" scenario classes by considering deviations from the Design Basis. Such "internal" scenarios could provide a useful basis for a dialogue between the regulator and the implementer on the design principles and modifications that might be implemented, on safety requirements relating to specific components of the system and on the extent to which alternative technological possibilities should be considered. The IRT is satisfied that the importance of "internal" scenarios is recognised by the SKI and is taken into account in the SKI's recently proposed premises for regulations[4].

It was noted in the NEA review of Project-90 that the SKI had stopped short of creating scenarios and assigning likelihoods; the reviewers felt this "omission circumvented some of the most fundamental issues in scenario development". In SITE-94, the scenarios considered are described as means of illustrating possible future system behaviour and of defining how such behaviour might arise. The SKI considered that it was inappropriate to assign likelihoods to these scenarios. The conceptual difficulty inherent in assigning a likelihood to a specific scenario (mentioned in SITE-94) can,

[4] "Premises for regulations concerning Safety in connection with the Final Disposal of Spent Nuclear Fuel, etc.," SKI Memorandum 97017 of March 26, 1997.

however, be overcome by assigning likelihood to scenario classes, rather than to specific scenarios. The benefit to be obtained through the assignment of likelihood is that it facilitates dialogue with the SKB, as well as regulatory decision making by the SKI, regarding possible future system states with high potential consequences. It may be that the likelihood of such states can be shown to be acceptably low. If this is not possible, however, then the calculated consequences must be reduced, either through improvements in the analysis (e.g. through a reduction in conservatism, while maintaining a sufficient level of confidence in the analysis; see Appendix 2) or through design and siting measures.

An example of such a state, identified in SITE-94, is that where oxygenated glacial melt water penetrates to repository depth for limited periods, favouring the release of some redox-sensitive, solubility-limited radionuclides. It is also suggested in SITE-94 that the effects of glaciation on groundwater flow can cause the plume of radionuclides released from the repository to be flushed rapidly out of the host rock and into the biosphere, although this possible effect is examined in less detail. In view of its high predicted consequences, a review of the full body of evidence for, and models of, deep penetration of oxygenated melt waters is warranted, in order to establish whether this should be regarded as an unrealistic ("what-if") scenario or a scenario with a non-negligible likelihood of occurrence. The IRT notes that the SKI has plans to perform such a review.

In the absence of well-argued likelihoods of future system states -- expressed, for example, as either probabilities or possibilities --, the way in which decisions will be made regarding the need for improved analysis and/or design and siting measures is not entirely clear. The assignment of importance levels in the PIDs (as quantitative incorporation of expert judgement into the assessment) is only a first step, and there is further benefit to be obtained by ranking importance levels - i.e., evaluating likelihoods - in other aspects of the assessment. It is noted that some implicit judgements regarding the likelihood of the states represented by the calculational cases are, in fact, made within SITE-94; for example, in the exclusion from quantitative analysis of cases with simultaneously pessimistic near- and far-field hydrogeological and geochemical parameters. From discussions with the SKI staff, and the premises for the proposed regulations, it is clear that the SKI is now considering grouping high-consequence scenarios in different likelihood classes. This is a welcome development with respect to the position stated in SITE-94.

Overall, the IRT considers that, with some further refinement, the SITE-94 methodology will provide the SKI with a valuable tool to assist in its role as a regulator. Specific suggestions for the refinement of the methodology are described in Appendix 2 and are related to (i) the level of detail at which some FEPs are represented in the PID and a better definition of protocols for the assignment of importance levels; (ii) the recording of decisions in the AMF regarding the selection of calculational cases and the measures that have been adopted to build confidence in various models; (iii) the more general development of protocols for arriving at confidence statements in specific parts of the performance assessment and also in the overall findings of a performance assessment; (iv)

the incorporation of sensitivity analyses within the methodology; and (v) the further consideration, by the SKI, of the relative merits of deterministic and probabilistic approaches within performance assessment.

3. Application of the Methodology

The application of the SITE-94 methodology has provided the SKI with experience in site evaluation and in the use of real site data that will be valuable in the review of the SKB's arguments and analyses, even though the current application of the methodology is somewhat incomplete. The application of the methodology is, for example, restricted to the FEPs that are assigned the highest (a numerical score of 10) importance levels and only the consequences of the Reference Case and Central Scenario are evaluated quantitatively. The databases underlying the PID and AMF are incomplete and are currently inadequate to allow the tracing of the basis for decisions regarding, for example, model selection.

The application of the methodology is also somewhat unbalanced. There are potentially important, level-10 FEPs that were not incorporated in the analysis, such as the generation and migration of gas and colloids and the long-term behaviour of the bentonite. On the other hand, other processes, such as the possible penetration of oxygenated glacial melt waters to repository depth, are considered in some detail, even though their likelihood (not explicitly considered in SITE-94) may be somewhat lower. The omission from the analysis of potentially important FEPs, and the consequent lack of balance, is acknowledged in SITE-94. The existence, however, of a *de facto* clearing house for deciding on the high-importance FEPs to be incorporated in the analysis should also be acknowledged and, like other clearing houses, the basis for the decisions of this clearing house should be recorded. In this respect, traceability is not fully demonstrated in SITE-94.

In spite of the incompleteness of application of the methodology, it has proven to be highly demanding in terms of financial and manpower resources. The practicality, and usefulness, of applying the methodology in full (inclusions of FEPs with lower importance levels) needs to be further examined. In particular, the IRT concurs with the SKI that the implication must be avoided that the SKB should apply this methodology (or an equivalent one) to examine all facets of the PID. On the other hand, it is clear that the implementing organisation will have to provide reasonable explanation for omitting items from the PID that, for example, have an importance level of 5 or higher. Such explanations may develop from the implementing organisation's long-term safety strategy, which is likely to include concepts such as "robustness" (i.e. an emphasis on detrimental FEPs and on a sub-set of impact-reducing FEPs where uncertainties are either low or well characterised). Indeed, a safety strategy is expected to be an integral part of any implementer's submission. The SKI, as a regulator, is not required to formulate a strategy for making/presenting a safety case. On the other hand, in order to make recommendations to the SKB and to judge the adequacy of the SKB's submissions, the SKI could use its methodology to explore arguments which are likely to be employed in

formulating a safety strategy.

Data for the application of the SITE-94 methodology are taken from the SKB's surface-based investigations (the pre-investigation phase) at the Swedish Hard Rock Laboratory at Äspö. As acknowledged in SITE-94, the data-collection strategy was not orientated towards the characterisation of an actual repository site for performance assessment and the data are, therefore, both biased and, in some respects, incomplete. Nevertheless, the data provide a reasonable test of the methodology, in that the type of geological information taken from the SKB surface-based investigations of Äspö is similar to (or, if anything, rather more detailed than) the type of information that would be available to support site selection. This represents an advance with respect to Project-90, which was reliant on synthetic data. SITE-94 is thus consistent with the advice of the NEA review group for Project-90 to " ... develop their expertise further in the interpretation of real site data in the context of reviewing performance assessments". The IRT believes that the SKI's analysis of raw site data is technically sound and finds it commendable that, as a result of their experiences using raw data, the SKI is able to provide several recommendations to the SKB regarding the gathering and handling of data from future site investigations. Also commendable are the SKI's efforts to identify uncertainties in the structural and hydrogeological models, and to propagate these uncertainties throughout the analysis. This is a rare accomplishment, particularly in the case of structural models, as discussed recently in the second NEA GEOTRAP workshop[5].

The SKI's competence in site evaluation will be further enhanced by considering data from the underground exploration phase at Äspö. This exercise, which is currently planned by SKI, will guide the refinement of the SITE-94 methodology, may allow limited testing of some specific SITE-94 results, and will better equip the SKI to review the SKB's license applications subsequent to repository siting. More generally, the SKI should consider the extent to which various sources of data will be available at different phases of repository development and the implications that this has for the credit that can be taken for the different barriers in a performance assessment. For example, the credit that can ultimately be taken for the geological barrier will depend, to a large extent, on whether it is possible to "design-as-you-go", adapting the repository layout to geological features as they are detected.

The decision to analyse quantitatively the Central Scenario has lead the SKI to consider the impact of a sequence of climatic events on repository evolution. The SKI is to be commended in this decision, which has highlighted effects that have high potential consequences for repository safety, although, as mentioned in Section 2, it is important to review the evidence supporting these analyses in order to assess, through a dialogue with SKB, how these high potential consequences should be dealt with (e.g., through improved analyses or through design and siting measures).

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[5] "Synthesis of the Second GEOTRAP Workshop: Basis for Modelling the Effects of Spatial Variability on Radionuclide Migration", Paris, France, 9-11 June 1997, OECD Nuclear Energy Agency, Paris (in preparation).

The Reference Case and its variants and the Central Scenario are analysed using a suite of assessment models, some of which appear to be disproportionately simplistic and may need to be updated. As discussed in Appendix 3, models where an improvement seems warranted are (i) the pinhole near-field release model, (ii) the single-pathway geosphere model and (iii) the geosphere-biosphere interface, with 100% capture by a well. The assumptions of, and confidence in, the models could have been more clearly stated in the project documentation (see Section 5, below). Furthermore, the simplicity and, in some cases, the high degree of conservatism of these models should have been more strongly emphasised when discussing the results of the consequence analysis. In particular, the suggestion that calculated doses provide an indication of the number of failed canisters that would be admissible in a repository should have been avoided.

The NEA review group for Project-90 noted that the project lacked "... suitable treatment of biosphere and human-intrusion issues". Treatment of human intrusion remains absent in SITE-94 and the treatment of the biosphere remains simple. Given the irreducible uncertainties associated with biosphere modelling, a simple approach, such as that of SITE-94 may well be justified. SITE-94 would, however, have benefited from fuller discussion of the problems inherent in biosphere modelling. In particular, the differences in aims of biosphere models compared to other components of the model chain could have been addressed (i.e. biosphere modelling is more concerned with illustrating the radiological significance of geosphere releases than with the prediction of doses that will actually be received by individuals).

4. Canister Analysis

The IRT appreciates the achievements of the SITE-94 project regarding potential canister failure mechanisms, following the recommendations of the Project-90 review. Discussion is given of both mechanical integrity and chemical durability. In the case of chemical durability, quantitative evaluations are made of generalised copper corrosion and qualitative discussion is given of localised corrosion. The IRT believes that SITE-94 builds confidence in the corrosion resistance of the copper canister and will serve to focus future R&D work on particular corrosion mechanisms and environmental conditions that could compromise the otherwise very long predicted containment times, namely (i) microbially-induced corrosion and (ii) the persistence of oxidising conditions at the copper surface.

It is acknowledged that these achievements cannot be coupled directly to the SITE-94 performance-assessment calculations, in the absence of final specifications for design, manufacture and quality-assurance procedures for the reference full-scale canister. Rather, in the Design Basis, the SITE-94 assessment assumes that the canister has an undetected manufacturing defect through the copper. However, by incorporating this assumption in the Design Basis and by not considering any variants on this Design Basis, a considerable amount of conservatism is built into the analysis and the important role of the canister is considerably down-played (see also Appendix 1).

Overall, the SKI could have taken more credit in the SITE-94 conclusions for their studies of potential canister-corrosion mechanisms and their contribution to confidence in the long-term integrity of the canister. Although it is not the role of the SKI to finally resolve technical issues, SITE-94 conclusions regarding the intrinsic quality of this potentially highly effective barrier could have been more clearly emphasised.

5. The Documentation of SITE-94

The transparency and traceability of decisions made within the project relies not only on the existence of the PID and AMF and their associated databases, but also on the clarity with which arguments and assumptions are reported in the project documentation.

The SKI has addressed different audience levels with a full range of SITE-94 documentation. The two main volumes are well-written and are also well condensed in the summary report[6]. The documentation is commendably open with respect to stating the limitations of, and omissions within, the SITE-94 project and, in general, strikes an appropriate balance between comprehensiveness and readability. Transparency is, however, only partially achieved. In particular, the assumptions and simplifications made in the models that are applied to the quantitatively evaluated cases, and the confidence that the SKI believes can be assigned to these models, should have been more clearly stated.

The following are specific areas in which improvements could be made:

- It would have improved the transparency of the documentation if key terms (for example, "fracture zone", "major features", "minor fractures") had been more clearly defined.

- There is a lack of balance in the level of detail in the description of some aspects of the project. Some models, for example, are presented together with their governing equations and boundary conditions, whereas others are described only qualitatively.

- Arguments as to why the SKI have confidence in the assessment models could have been more fully presented. These would include, for example, underlying well-founded physical/chemical principles, testing against experimental results over a range of spatial/temporal scales and a judgement of the limits of applicability of the models. These arguments could also appear in the database associated with the AMF (see Appendix 2).

- A statement of confidence in each of the assessment models, based on the arguments discussed above, could usefully have been included in the documentation. Such statements of confidence build discipline on the part of the performance assessor, in

[6] SITE 94, Deep Repository Performance Assessment Project, SKI Report 97:5 (Summary), Swedish Nuclear Power Inspectorate, Stockholm, 1996.

that the assessor must consider carefully why the output of the model should be believed. This, in turn, leads to a more credible analysis.

- There is a lack of transparency in the description of some models, in that the key assumptions are not clearly stated (e.g. the concept of the CCL parameter in CALIBRE). Transparency in individual model descriptions would, in some cases, be enhanced through the use of simplified sketches (e.g. the concept of geosphere transport occurring through a single, hypothetical tube connecting the repository to the biosphere well).

- A simplified sketch of the full model system would also enhance transparency, drawing attention to key assumptions.

- The sources of basic data should be more clearly referenced in the main volumes (e.g. dose-conversion factors and thermodynamic data).

The similarities and differences between the SITE-94 methodology and that adopted by other organisations (outside Sweden) could usefully have been discussed in the project documentation. This could have included, as recommended in the NEA review of Project-90, a discussion of " ... the relative merits and coupling of deterministic and probabilistic performance-assessment approaches" and the reasons for adopting a deterministic PA methodology in SITE-94. International projects, such as those organised by the NEA and IAEA are also relevant.

6. SITE-94 Conclusions

In the SITE-94 conclusions, the SKI is quite open about the lack of completeness of SITE-94, and identifies areas where more work is required. The sources of ambiguity that the NEA review group for Project-90 identified have been resolved. In particular, the review group for Project-90 recommended distinguishing " ... conclusions about current information from recommendations for future assessment or characterisation activities". This has been achieved in SITE-94 by separating the conclusions (which largely deal with "outstanding safety issues" - i.e., technical areas where further understanding is required) from a chapter dedicated to "implications for safety assessments of the studied repository concept".

In the course of the June meeting between the IRT and the SKI, it became clear to the IRT that the conclusions of SITE 94 on important "outstanding safety issues" are based not only on the somewhat limited analyses performed within the SITE-94 project, but also on the SKI's general experience (e.g. the experience gained in reviewing the SKB's RD&D programme). It is felt that this should be more clearly acknowledged in the SITE-94 documentation. For example, while it is clear that the bentonite buffer is of great significance to the safety of the disposal system, it is not clear from any of the discussion on buffer degradation (save the mention of the term "cementation") that a significant possibility of buffer degradation has been argued. In fact, it is stated that the

buffer cases are hypothetical. In the conclusions, however, buffer degradation has been converted into an important "outstanding safety issue" in which the understanding is "not fully adequate".

As discussed in Section 3, there is a lack of balance in the high-importance FEPs that are selected for incorporation in the SITE-94 analyses. Furthermore, due both to the lack of a procedure for sensitivity analysis within the methodology and to the simplicity of some of the consequence-analysis models, it is not possible judge the importance, in terms of overall impact, of the FEPs that are selected. Thus, it is difficult to assess the relative importance of different technical areas on the basis of the SITE-94 results and little guidance can currently be given as to an appropriate allocation of R&D resources.

On the specific issue of the mechanical stability of potential repository host rocks, the IRT concurs with the SKI that further development of the currently available models would be valuable. The IRT suggests, however, that, in view of their potential importance in the opening up of new transport pathways from the near field to the water-conducting features of the far field, an enhancement in the current level of understanding of the coalescence and propagation of excavation-induced fractures should take priority over the development of fully coupled T-H-M and T-H-M-C models.

7. Overall Judgement

Overall, the view of the IRT is that the SITE-94 Project represents an impressive achievement, particularly given the limited staff and financial resources available to the SKI. In particular, in performing the SITE-94 project, the SKI has not only increased its level of competence to perform technical reviews, but has also made significant contributions to the current state of practice in performance-assessment methodology, in the assimilation of site-specific data in a performance assessment, and in the understanding of mechanisms that might compromise canister integrity. Some models used in SITE-94 appear to be disproportionately simplistic and need to be appropriately updated. It is, however, understood that it was an explicit decision by the SKI to focus resources in SITE-94 on the development and application of a performance-assessment methodology, rather than on model development. The updating of models is indeed a current area of activity of the SKI, following the completion of the SITE-94 project.

With some improvement, the SITE-94 methodology should provide a valuable tool for regulatory review and comment. Furthermore, the methodology may provide a useful basis for the development of quality-assurance procedures in the various aspects of repository development. The SKI, as a regulator, is not required to formulate a strategy for making/presenting a safety case. On the other hand, in order to make recommendations to the SKB and to judge the adequacy of the SKB's submissions, the SKI could use its methodology to explore arguments which are likely to be employed in formulating such a safety strategy

This review has provided a number of suggestions for improving the SITE-94

methodology. Refinements of the SITE-94 methodology are also likely to follow from its application to the presently available data obtained from underground investigations at Äspö. Broadly, it is recommended that the SKI focuses on measures that will facilitate a dialogue between the regulator and the implementer. This could include:

- *Consideration of the likelihoods of scenarios with potentially high consequences.* If a high likelihood is assigned, then the dialogue should focus on measures to reduce either the calculated consequences or the likelihood of occurrence. This could be achieved either through improvements in the analysis or through siting measures. Furthermore, alternative technological possibilities could be considered.

- *The consideration of "internal" scenarios based on deviations from the Design Basis.* Identification of "internal" scenarios with high consequences could again provide a basis for a dialogue on design modifications or QA requirements that might reduce either the consequences or the likelihood of occurrence.

In addition, the SKI should consider measures to evaluate and present confidence in their findings; if the findings of a performance assessment are to be acceptable to its intended audience, a suitably structured confidence statement in its findings, backed up by various types of supporting evidence, is necessary.

The application to data from surface-based investigations at the Äspö research facility has provided a good initial test of the SITE-94 methodology. The SKI's achievements in the identification of uncertainties in the structural and hydrogeological models, and the propagation of these uncertainties throughout the analysis, represent a rare accomplishment, particularly in the case of structural models. In principle the SKI methodology can be applied to analyse data from underground testing, and can therefore be updated to the next phase of repository development. It is recommended that the SKI considers the extent to which various sources of data will be available at different phases of repository development and the implications that this has for the credit that can be taken for the different barriers in a performance assessment.

Finally, it is appreciated that many of the comments made in the NEA review of Project-90 were taken into account in carrying out the SITE-94 study, although the SKI still needs to clarify its views on how to evaluate and take into account the likelihoods of scenarios.

APPENDIX 1

Comments on the Definition of the Design Basis

The Design Basis for SITE-94 is principally derived from the KBS-3 design, but with some significant deviations from this concept. For example, unlike the KBS-3 canister, the reference canister design includes an inner steel vessel for mechanical strength.

Although mentioned several times in SKI reports 96:36 and 97:5, there appears to be no well-argued definition and comprehensive description of the term "Design Basis" in SITE-94. The repository design is fully described in 96:36 (Chapters 3-8), but, according to 97:5, p.5, the Design Basis also includes ".. certain potential properties or states of the system..." and, in particular:

- an allowance for early canister failure, whereby ".. the single canister considered is assumed to have an undetected manufacturing defect ... through the copper ..."

- an assumption of "immediate" resaturation of the bentonite buffer.

Other "potential properties or states of the system" included in the Design Basis appear not to be listed systematically in the principal SITE-94 documentation. From discussions between the IRT and the SKI, these include:

- no rejection of unfavourable deposition holes - if a deposition hole were found to be intersected by a water-conducting feature, this could, in reality, be rejected as a location for waste emplacement,

- no credit for respect distances - major fault zones are, in reality, likely to be detected during repository tunnel construction and the repository design adapted such that a credit could be taken for a minimum respect distance between such zones and the deposition holes.

Potential deviations from the Design Basis, including effects associated with the transient phase (resaturation and the thermal pulse), the effects of poor QA on the waste and EBS, etc., are excluded from SITE-94 on the grounds that:

- much development work still lies ahead, particularly in the areas of canister design and encapsulation and repository construction methods;

- SITE-94 is not intended to assist in the development of safe disposal solutions (p.2 in 96:36) - such issues should primarily be treated in the SKB RD&D programme;

These points are certainly true. On the other hand, questions can be asked as to how much conservatism should be build into a performance-assessment analysis at an early

stage and what is meant by Design Basis. A clear link between the definition of the Design Basis and current design principles, and an identification of possible deviations from the Design Basis and their likelihood, (even if these are not analysed quantitatively) would be desirable. A well-argued Design Basis establishes the context in which to view the results of the performance assessment. Furthermore, as discussed in Section 2, deviations from the Design Basis could be used to generate "internal" scenarios. These would provide a useful basis for dialogue between the regulator and the implementer on future design principles that might be implemented, on safety requirements relating to specific components of the system and on the extent and limit to which alternative technological possibilities should, or can, be considered.

APPENDIX 2

Possible Refinements of the SITE-94 Methodology

The IRT considers that, with some further refinement, the SITE-94 methodology will provide the SKI with a valuable tool to assist in its role as a regulator. The following are some specific suggestions for the refinement of the methodology:

(i) The level of detail at which some FEPs are represented in the PID and the definition of protocols for the assignment of importance levels.

Depending on its intended purpose, a judgement has to be made as to the level of detail at which FEPs are represented in the PID. The level of detail is, in some cases, reduced by the grouping together of several lower-level FEPs as a single, higher-level FEP. Within SITE-94, the principal purpose of the PID is to provide a structured and comprehensive record of the SKI's system understanding. The IRT feels that, for this purpose, some FEPs are not represented at an appropriate level of detail. It is acknowledged that the level of detail must not be so high that the PID becomes unmanageable, but it must be sufficient that key FEPs and interactions are preserved. The level of detail of the PID should, for example, reflect the container failure modes rather than to group the modes together as "failure of the copper canister".

An integral part of the construction of the PID is the assignment of importance levels to the influences between FEPs. Currently, according to the protocols that guide these decisions, importance levels should be based on local considerations. Examples exist in the PID, however, where a purely local definition of importance level is not achieved. Indeed, it may not be practical to achieve such a local definition (if considerations are strictly local, then all importance levels might prove to be high). The IRT suggests that a clarification and tightening of the protocols is warranted.

(ii) The recording of decisions in the AMF regarding the selection of calculational cases and the measures that have been adopted to build confidence in the various models

Calculational cases for consequence analysis are constructed from variants delivered by the various Clearing Houses and recorded in the AMF. The variants reflect the different sources of uncertainty. The assembly of the variants into calculational cases, though fully and transparently documented in SITE-94, is not an explicit part of the SITE-94 methodology. The IRT observes that, although not referred to as such in SITE-94, there exists, in effect, a Clearing House that assembles variants into calculational cases. By acknowledging the existence of this Clearing House within the AMF, the link between the AMF and consequence analysis could be explicitly built into the methodology, with decisions regarding the selection of calculational cases recorded in the AMF database.

The AMF facilitates the tracing of the impact of decisions on a final performance assessment. The capture of all decisions, and the basis for these decisions, in the database underlying the AMF could, potentially, provide a full audit of the performance-assessment rationale. In this database, it would be valuable to have information, not only on the decisions themselves, but also on the background for these decisions. Specifically, this would include the measures that have been adopted to build confidence in the various aspects of the assessment. Information regarding model assumptions, supporting evidence, "validation" efforts and a judgement of the limits of applicability of the models would be useful (it was noted by the IRT that all hydrogeological models used in SITE-94 were based on Darcy's law, without discussion of its validity in the media and flow regimes to which the models were applied).

(iii) The more general development of protocols for arriving at confidence statements in specific parts of the performance assessment and also in the overall findings of a performance assessment.

If the findings of a performance assessment are to be acceptable to its intended audience, a confidence statement in its findings, backed up by various types of supporting evidence, is necessary. SITE-94, however, lacks such a confidence statement. The IRT recommend that the SKI develops protocols for arriving at confidence statements in specific parts of their performance assessments, as well as in overall performance-assessment findings. These are areas where progress could be made in an international context.

(iv) The incorporation of sensitivity analysis within the methodology.

The SITE-94 methodology appears to be adequate for identifying and ranking relevant safety issues and R&D priorities, but only at a very high and somewhat generic level (e.g., the need to perform research on corrosion of copper containers). Most of the detailed-level importance ranking is done subjectively during the formulation of the Process Influence Diagram (PID) and in the Clearing Houses (expert groups responsible for processing information in a particular field) at the very beginning of the analysis. The importance ranking is, however, intended to be local, and not to represent a judgement of the overall importance of an interaction to repository safety. The IRT suggests that some form of overall sensitivity or importance analysis needs to be incorporated in the methodology. One possibility would be to include one or more lower-importance influences, as well as the highest-level influences, in the consequence analysis, in order to test their global impact.

(v) The further consideration of the relative merits of deterministic and probabilistic analyses within performance assessment.

In SITE-94, a deterministic approach to consequence analysis is adopted throughout. In order to keep the number of calculational cases manageable, cases represented by similar combinations of parameters are merged in a procedure that is somewhat subjective. There may be some merit in adopting a probabilistic approach to

analysis in parallel to deterministic calculations, particularly where the uncertainties can be well characterised. In that case, a probabilistic approach provides a structured procedure for exploring combinations of variants.

APPENDIX 3

Comments on the Assessment Models

The detailed 3-D modelling and visualisation of Äspö geological structure and the examination of alternative structural models, as well as alternative conceptual models for groundwater flow, are commendable. On the other hand, whereas considerable effort is expended in modelling geological structure and groundwater flow as realistically as possible, other models are considerably less detailed and/or more conservative, e.g.:

- The pinhole near-field release model, in neglecting the transport resistance of the failed container, is highly conservative.

- The geosphere-transport model, in representing all transport paths between the repository and the biosphere as a single one-dimensional channel with uniform properties along its length, is highly simplified compared to the models of flow and it is unclear whether this simplification leads to bias that is conservative or non-conservative. The variability between pathways is represented through a dispersion term. Whereas this approach may be justified for a simple, generic geosphere, the considerable variability between pathways indicated by the SITE-94 data means that the transport model may well have been taken beyond its range of applicability (the transport equations are only strictly applicable where the dispersion term is small). This also means that there is a substantial loss of information at the interface between groundwater flow modelling and geosphere transport modelling.

- The coupling between the geosphere-transport model and the biosphere model, in assuming that all radionuclides that are transported through the geosphere are captured by a single well, is highly conservative. The improbability of 100% capture of the plume by the well seems obvious when examining the complexity of the fracture network model of the site. The loss of information (on the distribution of radionuclide discharge locations) at the geosphere/biosphere interface is an unfortunate limitation of the analysis (and is acknowledged in the SITE-94 report).

APPENDIX 4

The NEA Peer Review Team

Budhi Sagar (CNWRA, USA) - Chairman

Budhi Sagar has B.Sc. and M.Sc. degrees in Civil Engineering and a Ph.D. degree in Hydrology with over thirty years of professional experience that includes teaching, research, and consulting. His research interests span computational methods, stochastic analyses, and probabilistic system assessments. He is the author of several computer codes dealing with flow, heat transfer, and mass transport in fractured geologic media. He has written or collaborated on over 100 technical papers and reports.

In his current position as the Technical Director of the Center for Nuclear Waste Regulatory Analyses (CNWRA), Dr. Sagar's responsibilities are to manage all ongoing technical activities at the CNWRA. He is the primary technical representative with the US Nuclear Regulatory Commission, the sponsor of CNWRA. Dr. Sagar provides overall direction for conducting technical assistance work and research activities of the CNWRA, assures efficient manpower utilisation, controls budgets and schedules, and assures quality of work. He assists the CNWRA President in the conduct of overall administrative and operations activities.

He was a member of the international peer review of the Post-closure Performance Assessment of AECL's Environmental Impact Statement of the Disposal of Canada's Nuclear Fuel Waste.

Lucy Bailey (UK Nirex Ltd., United Kingdom)

Lucy Bailey holds MA and MPhil degrees in Physics from the Cambridge University, UK. She has seven years' post-university experience in radioactive waste disposal post-closure safety assessment, and in particular in constructing mathematical models to represent complex systems. She is a Chartered Physicist and a Corporate member of the Institute of Physics (CPhys MInstP).

From 1990 to 1995, she worked for RM Consultants Ltd. (Abingdon, UK) on the development of several safety assessment codes (network groundwater flow, repository source term, time-dependent geosphere network) and on their integration into VANDAL, the HMIP probabilistic safety assessment code. She was also responsible for establishing suitable models for the hydrogeology of Sellafield, including a palaeohydrogeology study, to be used in the full HMIP PSA simulation.

She joined UK Nirex Ltd in July 1995. As the Model Development Manager, she is currently responsible for the co-ordination and management of the development of the Nirex safety assessment modelling programme, ensuring all features, events and processes relevant to the post-closure safety of a deep geological radioactive waste repository are correctly represented within mathematical models.

Christian Devillers (IPSN, France)

Christian Devillers is an engineer from the "Ecole Centrale de Paris". He worked 16 years in reactor physics and shielding at the french Atomic Energy Commission, developing radiation transport codes and participating in the design of experimental power and propulsion reactors.

He joined the Institute for Protection and Nuclear Safety (IPSN) in 1977 where he successively headed the teams in charge of assessing the safety of nuclear sites, of evaluating potential exposures due to severe accident at PWR's and of assessing the safety of nuclear fuel cycle facilities, including near surface disposal facilites. He has also been involved in the safety of radioactive material transportation as chairman of the French Transport Safety Commission. Nominated in 1990 as head of the Safety Assessment Department at IPSN, he is now Director for Waste Management Safety and a member of the Standing Group of Experts which provides advice to the regulator on the safety of radioactive waste disposal facilities.

He has contributed to the establishment of site selection criteria and to the development of the safety assessment methodology for deep geological repositories.

Lawrence Johnson (AECL, Canada)

Lawrence Johnson was born and educated in Canada. He obtained a B.Sc. in Chemistry from the University of Lethbridge in 1977. He joined the Atomic Energy of Canada Limited (AECL) in 1978, working on the dissolution behaviour of spent fuel and vitrified high-level waste. In 1985, he was appointed Manager of Fuel Waste Technology Branch, responsible for all aspects of research and development for engineered barriers for disposal of nuclear fuel waste for the Canadian Nuclear Fuel Waste Management Program. In the performance assessment area, he has been chairman of the Vault Model Working Group for 10 years, responsible for the development of a source term model for spent fuel, corrosion models for nuclear fuel waste containers, transport models for clay-based buffer and backfill barriers, and integration of near-field models.

He is senior author of two comprehensive performance assessment studies of engineered barriers, one detailing borehole emplacement of spent fuel in Ti containers and the other on in-room emplacement of Cu containers. The two studies have played a central role in the Canadian government review of AECL's Environmental Impact Statement under the Environmental Assessment and Review Process. He is the author of over 50 journal papers and reports on spent fuel dissolution and near-field performance assessment and has been a consultant to several national radioactive waste management programs.

Philippe Lalieux (OECD/NEA) - Secretariat

Philippe Lalieux is a geologist and geophysicist with ten years' professional experience in the field of radioactive waste disposal. He graduated from the University of Brussels (Belgium) in 1983 with a B.Sc. in Geological Sciences and obtained a Masters Degree (M.Sc.) in Geophysical Sciences from the same university in 1984. From 1986 to 1994 he was a staff member of the Belgian Agency for the Radioactive Waste and Enriched Fissile Material (ONDRAF/NIRAS). His responsibilities included the management and supervision of geoscientific characterisation of

potential sites for deep and near-surface disposal, and natural analogue studies. He was also in charge of the co-ordination and defence of a Safety Assessment and Feasibility Interim Report (SAFIR).

He joined the OECD/Nuclear Energy Agency Secretariat in 1995. He has been in charge, within the Radiation Protection and Waste Management Division, of the Agency's programmes on deep disposal site characterisation and evaluation. In particular he is responsible for the Technical Secretariat of the Co-ordinating Group on Site Evaluation and Design of Experiments for Radioactive Waste Disposal (SEDE). His current activities also entail involvement in the NEA performance-assessment related activities, notably through the launching of the GEOTRAP Project on radionuclide transport. He was a Secretariat member of the joint NEA/IAEA international peer review of the 1996 Performance Assessment of the US Waste Isolation Pilot Plant (WIPP).

Claudio Pescatore (OECD/NEA) - Secretariat

Claudio Pescatore holds a Ph.D. in nuclear engineering from the University of Illinois, Urbana-Champaign (USA). He has 18 years' experience in the field of nuclear waste covering low-level waste, high-level waste and spent-fuel storage and disposal.

He joined the Brookhaven National Laboratory in 1982 and was directly involved in the study of high-level waste and spent-fuel disposal concepts in basalt, salt, and tuff formations: reliability and modelling studies of waste package materials during storage and disposal, analyses of gaseous and aqueous pathways for radionuclide migration, peer reviews of environmental impact assessments studies and site characterisation plans. In 1989 he was nominated Group leader for Radioactive Waste Performance Assessment. He was also adjoint Professor of Marine Environmental Sciences at the University of New York at Stony Brook.

He joined the NEA/OECD Secretariat in 1992 in the Division of Radioactive Waste Management and Radiation Protection. He is presently the Acting-head of the Division. Within the NEA/OECD Secretariat he has been in charge of the Agency's Performance Assessment programmes, with additional contributions in the field of site characterisation. He has been at the centre of several recent international initiatives such as the ASARR and GEOTRAP projects, and the GEOVAL'94 symposium. He was a Secretariat member of the international peer reviews of SKI's Project-90, of the Post-closure Performance Assessment of AECL's Environmental Impact Statement of the Disposal of Canada's Nuclear Fuel Waste, and coordinated the joint NEA/IAEA international peer review of the 1996 Performance Assessment of the US Waste Isolation Pilot Plant (WIPP) as well as the present review of SITE-94.

Paul Smith (Safety Assessment Management Ltd., United Kingdom)

Paul Smith graduated in 1980 with a degree in Natural Sciences from Cambridge University, and proceeded to take a higher degree in Geophysics at Newcastle University and a PhD in Computational Fluid Dynamics at Manchester University.

Has 14 years experience in mathematical modelling and safety assessment. This has included over 8 years in work in Switzerland and the UK related to geological disposal of radioactive waste, with particular emphasis on geosphere modelling. He has co-ordinated a major technical

assessment project and participated in international working groups and projects.

He is a Consultant at Safety Assessment Management Limited, a small independent consultancy specialising in radioactive waste disposal assessment.

APPENDIX 5

Terms of Reference

In this appendix, a letter from the SKI requesting the NEA to organise a peer review of the SITE-94 Project is reproduced. The terms of reference provided by the letter have guided the IRT in performing their review and presenting their findings in this report.

Request by the Swedish Nuclear Power Inspectorate for an international review of the SKI Project SITE-94 to be organised by the OECD/NEA

Background

As a regulatory authority with a responsibility to review and supervise the activities of the nuclear industry, the Swedish Nuclear Power Inspectorate, SKI, needs to develop its competence in different areas including nuclear waste. SKI is therefore since many years engaged in research and development of safety assessment methodology for systems for final disposal of spent fuel and nuclear waste.

SKI has however no responsibility for the development of waste management and disposal systems as such. This responsibility rests with the waste producers, the nuclear power companies. To meet the requirements stated in nuclear legislation, the nuclear power companies have formed a jointly owned company, the Swedish Nuclear Fuel and Waste Management Co, SKB.

SKI is preparing for the future licensing procedures concerning an encapsulation facility for the spent fuel and a deep geological repository. Before SKB submits a license application for a deep repository, a siting process including feasibility studies in several municipalities and surface-based site investigations at two sites will take place. Also in these phases of the siting process SKI will be involved. To support the development of licensing procedures SKI will need to continue its competence building activities. One very important area is of course integrated performance assessment methodology.

The first step in the licensing procedure for the deep repository involves an application to conduct detailed underground investigations (shaft sinking etc) and to start the construction at one of the two studied sites. SKB's license application for the deep repository, which SKI will have to review, will thus include a post-closure safety assessment based on site data from surface-based site investigations (including boreholes).

The SITE-94 Performance Assessment Project

The Swedish Nuclear Power Inspectorate (SKI) has recently finished a major research project, SITE-94, the aim of which has been to build up SKI's competence and capacity in assessing the safety of disposal of spent fuel. In 1992 SKI asked NEA for a review of an earlier project, Project 90, also aiming at building up SKI's competence in performance assessment (PA) methodology. NEA undertook this task. The comments and recommendations in the NEA review were valuable to SKI and were considered in the planning of the SITE-94 project.

SITE-94 is an integrated post-closure PA project focused on development of PA methodology and evaluation of site specific data in the PA. The project was set up as an assessment of a hypothetical repository for spent nuclear fuel, and used field data from SKB's surface-based investigations (including borehole data) at the Äspö Hard Rock Laboratory site, in southeastern Sweden. The hypothetical repository is based on the KBS-3 concept as it was presented by SKB in their Research, Demonstration and Development programme 1992.

As described in detail in the SITE-94 main report (SKI Report 96:36), SITE-94 is research project aimed at developing particular aspects of PA methodology. It is not a complete safety assessment. The ambition has been to document the project in a format that follows SKI's general advice concerning the content of a safety assessment. However, although adequate for the purpose of SITE-94, the level of detail and depth of the analyses in some sections of the report do not reflect what SKI would expect in complete safety assessment. Care was taken to state clearly in the report where this is the case. This concerns, for example, treatment of backfills, seals, gas, colloids and biosphere. In several cases there were simply no information available due to the fact that SKB's disposal concept is not yet fully developed.

In applying the developed methods, the results were factored into calculations of radionuclide release and transport, but these do not represent a complete basis for evaluating the safety of the site. Instead they are used as a means to identify critical safety issues that deserve further R&D and need to be taken into account in a complete safety assessment.

It is important to view SITE-94 in the above context.

Peer Review

It would be valuable if the OECD/NEA could accept to review the outcome of the SITE-94 project, with focus on technical and scientific methodology and conclusions. SKI would be interested to have specific written and oral remarks on the PA methodology, models and data, treatment of uncertainty and on the scenario development. Comments on traceability, clarity and the structure of the presentation would also be of great value.

Advice on R&D priorities for SKI as a safety authority are velcome, but is seen as auxiliary to the review.

Materials for the Review

The review should in the first place focus on the final report of SITE-94 (SKI Report 96:36), which is intended as a stand-alone document. A summary report and referenced technical background reports will also be available. The SKI Report 96:36 is already available and could be sent to the NEA within a few days.

Time Schedule and Organization of the Review

The time schedule and practical arrangements should be agreed upon by the NEA and SKI. It is understood that, if the NEA accepts to perform a peer review, a special review team will be set up. This team would include four or five international experts and two experts from the NEA Secretariat. The choice of experts for the review is left to the NEA.

If the international experts are appointed soon there is a possibility to attend a seminar in Stockholm on the 4th of April at which the SITE-94 project will be presented by SKI representatives and experts that SKI has engaged in the project. In any event it is expected that the review team will pay at least one visit at SKI.

SKI is willing to bear reasonable costs of the review as identified with the NEA Secretariat.

The NEA review team should provide a written report with the team's conclusions and recommendations to the SKI before December 1997.

SKi

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