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SKB response to NEA questionnaire on principles and good practice for safety cases

This document presents SKB's responses to the questionnaire on principles and good practice for safety cases. The answers are provided as part of the International Peer Review undertaken by OECD/ NEA as requested by the Swedish Government of SKB's reporting on post-closure safety in the licence application for a spent nuclear fuel repository.

The answers provided are to the questions specified in the OECD/NEA document **NEAJRWM/PEER(2011)1** dated 26 April 2011. The original questions are included in the text below. SKB responses are given in italics.

I. Managing the overall programme

I.1 Programme constraints

A number of factors constrain the way in which the planning and implementation of a repository proceeds. These include programme constraints that apply at all stages of a waste-management programme, as well as practical constraints that apply at a particular stage of development.

Which of the following constraints apply to the current project and where are they described in the project documentation?

a) Various strategic decisions determined at national level (e.g. to pursue, in addition to the domestic option, the possibility of international disposal options, to reprocess or dispose of spent fuel directly, to investigate one or more host rock options, to examine more than one design option, and to implement the repository in stages, beginning with an initial "demonstration repository" for a portion of the waste to be disposed, etc.).

In the 1970s the question of management of the radioactive waste came to the fore in the political debate. The result of this political involvement was a statutory requirement passed in 1977 – the Stipulations Act, which stated that the spent fuel should either be reprocessed or emplaced in an "absolutely safe" final repository. In 1984 the Stipulations Act was superseded by the Nuclear Activities Act.

In response to the Stipulations Act, the nuclear power producers assigned their company SKBF (now SKB) the task of working out a proposal for how to take care of the spent fuel. The first proposals, presented 1977 and 1978, were based on the two alternatives offered by the Stipulations Act: final disposal after reprocessing, and final disposal without reprocessing. The report "Final storage of spent nuclear fuel – KBS-3" was presented in May 1983 and was based on direct disposal of spent fuel. Reprocessing has since then not been considered a suitable option in Sweden. The concept presented in that report, the present KBS-3 method, has since then been further developed and now has the design described in the licence application.

Since the early 1980s alternative strategies and methods have been studied, evaluated and compared to the KBS-3 method. SKB's conclusion from the comparisons made is that the KBS-3 method is the favoured option. See SKB P-10-47.

Swedish law requires that final disposal of spent nuclear fuel is made within the boundaries of Sweden. Suitable host rock formations can in Sweden be found in crystalline bedrock and several such sites with different geological conditions were investigated in 1970s and 1980s. The principle of voluntary participation of potential host communities for the final repository was introduced in 1992. Feasibility (desk top) studies were made in 8 municipalities followed by comprehensive site investigations of the Forsmark site in Östhammar municipality and the Laxemar site in Oskarhsamn Municipality. Forsmark was selected in 2009 as it provided better prospects for achieving long-term safety. See SKB R-11-07.

A summary of major strategic decisions of the Swedish radioactive waste management programme can be found in the latest RD&D programme, SKB TR-10-63 sect 1.3.

b) Legal requirements (e.g., roles of relevant organisations, transparency laws, and requirements for providing a degree of retrievability in design).

The legal framework is adequately described in the Terms of Reference for the International Peer Review. Some more details on technical requirements are provided in the SR-Site main report sect 1.4 and Appendix A.

There are no requirements on retrievability in Swedish legislation. Even if there is no intention of retrieval of deposited canisters after closure, it would be resource-consuming but not impossible to retrieve canisters deposited using KBS-3.

c) Time constraints on repository implementation, which may be affected, for example, by the capacity available for interim storage.

Operation of the final repository is planned to commence in 2025. The interim storage facility (Clab) currently has a licence to store 8,000 tonnes of spent fuel. According to today's forecasts this amount will be reached 2023. Hence, SKB needs to use the possibility to increase the licensed storage capacity to 10,000 tonnes which would be reached approximately 2030. See TR-10-63 sect 3.3.

d) The licensing framework requiring a safety case to be made at defined points within the planning and development programme.

This is adequately described in the Terms of Reference for the International Peer Review, the section on a stepwise licensing process.

e) The regulatory framework, e.g., assessment endpoints and timeframes.

The time scale of a safety assessment for a final repository for spent nuclear fuel should be one million years after closure, see further SR-Site main report Section 2.4. A detailed risk analysis is required for the first thousand years after closure. Also, for the period up to approximately one hundred thousand years, the reporting is required to be based on a quantitative risk analysis.

The general aspects of the regulatory framework are described in the Terms of Reference for the International Peer Review and in SR-Site main report sect 1.4 and Appendix A.

f) Constraints resulting from the implementer's strategy to implement the programme (e.g. the necessity to come to a design decision).

General constraints are described in the Repository production report, TR-10-12, secs 3.1.1 and 3.1.2.

SKB considers that the development of the KBS-3 system has reached a sufficient level to submit a licence application to start construction of the final repository. The reference design described in the application is feasible and can be implemented. A repository constructed at Forsmark would satisfy the safety requirements. The stepwise and iterative approach described in the response to I.1.g) implies that details of the design might change before the facility is put into operation in 2025.

g) Adoption of a stepwise approach to repository planning and implementation.

Stepwise development is part of the basic approach to development and implementation of the repository. Technology development and repository design is carried out in steps based on successive selection of alternatives and increase in the level of detail. The steps are conceptual design, system design, detailed designed followed by implementation, see TR-10-63 sect 9.2 and 9.3. Successive adaptation of the repository design to local geological conditions will be performed using the Observational method, see TR-10-63 sect 8.4.

The design of the KBS-3 system is based on a set of successive safety assessments where the current (reference) design at the time of each assessment has been evaluated and feedback provided to further design developments. A structure has been developed where a set of design premises have been defined which the repository design has to meet in order to satisfy the requirements on long term safety. Revisions of design premises and hence of design may be made based on the outcome of future safety assessments that are planned during the construction and operation of the final repository. The iterative process and the relation between design premises, the design and the safety assessments are described in the ***Repository production report*** *(TR-10-12).*

I.2 Management strategy

According to NEA (1999, 2004a), a management strategy coordinates the various activities required for repository planning, implementation and closure, including siting and design, safety assessment, site and waste form characterisation and R&D. The management strategy keeps work focused on programme goals, allocates resources to particular activities, and ensures that these activities are correctly carried out and co-ordinated.

Are the following technical and managerial principles applied in the programme and, if so, where are they described in the documentation of the safety case? If other principles are adopted, where are those documented?

a) Establishment of a safety culture (i.e. a "consistent and pervading approach to safety") among all those engaged in aspects of repository planning and implementation, including the development of the safety case.

According to SKB's policy, the guiding principles are: safety, efficiency and responsiveness. Hence, safety is a guiding principle that is implemented in the entire organisation. Requirements on safety are implemented in the management system. Reviews are made on a regular basis, in accordance with the management system, of how the safety culture within the company works in practice and corrective measures are identified and implemented if required.

b) Establishment, implementation and maintenance of a quality management system and quality control procedures.

SKB has developed and implemented a quality management system that is certified according to ISO 9001 and ISO 14001. The implementation and maintenance of this system is checked by regular third party reviews. The certificates were recently renewed. In addition, internal reviews are performed on a regular basis both on a company basis and also of specific projects, e.g. the SR-Site Project.

Additional quality procedures have been developed and implemented for the Spent Fuel Project to meet the needs of the project. Further information can be found in the SR-Site main report sect 2.9.

c) Arrangements for ensuring that the implementing organisation has suitably qualified and experienced personnel covering the range of disciplines relevant to the safety case, and a system for training and further education/development of staff.

Provisions for ensuring that SKB has suitably qualified and experienced personnel for the tasks related to nuclear safety are included in SKB's management system. The system meets the requirements made by SSM's regulations for nuclear activities. The system includes training and development of staff through a variety of activities. SKB has reviewed and documented the credentials of the experts engaged in the SR-Site project as part of the *quality management system, see section 2.9.4 of the SR-Site main report. The competence of external experts and consulting firms are checked as part of the procurement process.*

d) Establishment of clear roles for, and effective lines of communication between, those within the implementing organisation and its supporting organisations – particularly between safety case developers, safety assessors, research scientists, designers/engineers and operations staff.

The safety case (licence application) has been developed by the Spent Fuel Project. The project has been divided into a number of subprojects with clear division of responsibilities between the subproject managers. The project and its subprojects have engaged staff with appropriate competence from various parts of SKB's organisation and, where needed, external experts. Coordination has mainly been made through management team meetings with participation of the Project Director and the subproject managers. In addition there have been special coordination groups to resolve certain issues of joint interest for several subprojects. The responsibilities of all employees and key consultants have been documented in project plans, subproject plans or individual descriptions of responsibilities. The organisation and the management system are described in the licence application, appendix VP (in Swedish only).

e) Establishment of clear and effective lines of communication between the implementing and regulatory organisations and other oversight bodies.

Based on Government decisions there have been regular consultation meetings between SKB and the regulator SSM (before 2008 SKI and SSI) on site investigations and safety assessments. During the period 2002-2010 there has been approximately 40 consultation meeting on different topics. In addition SKI and SSI organised expert groups (INSITE and OVERSITE) which followed and reviewed the work undertaken by SKB and based on their findings provided advice to SSM. These meetings have provided for efficient communication between SKB and the regulatory organisations. In SKB's opinion, SSM at these meetings have provided sufficient information on what is expected of the licence application. This is described in the licence application, appendix VP (in Swedish only).

f) Establishment of procedures and policies for interaction with other stakeholders.

SKB has conducted extensive consultations in accordance with Chap. 6 of the Environmental Code. The consultations regarding the final repository and the encapsulation facility for spent nuclear fuel were initiated in 2002 and concluded in May 2010. This has provided interaction with the local population, the elected decision-makers in the municipality, the local and national NGOs and the authorities involved on the local, regional and national level. In total there have been approximately 60 consultation meetings of this kind.

In addition the municipalities of Oskarshamn and Östhammar have set up review groups that have interacted with SKB during the process.

This is described in the licence application, appendix VP (in Swedish only).

g) Establishment of means for effective integration of knowledge and information within the safety case.

Integration of knowledge and information is based on information management systems and meetings between different subprojects and expertise in different areas. With respect to information management, SKB has set up a document management system and have databases for data (e.g. site data, nuclear and thermodynamic data), models, and reports (library references) that are available to project members. Project meetings and special coordination meetings are held and documented. The minutes from meetings are distributed to the relevant members of the project.

Another important contributor to integration of knowledge and information is the system for review of reports produced by the Spent Fuel Project. In addition to providing a check of facts and improvement of the quality of the reports it also provides a means of information exchange between author(s) and reviewers (who often represent other scientific disciplines or subprojects).

h) Arrangements for periodic updating and use of the safety case and safety assessment to guide repository development, operation (e.g. waste acceptance), and closure.

The development of the KBS-3 system is based on successive safety assessments and feedback from these assessments. In addition SKB every third year presents results and plans for research, development and demonstration activities (RD&D programme). The review of these programmes by various government bodies, municipalities, stakeholders and SSM has provided input to the safety case over the years.

In 2006 SKB presented the safety assessment SR-Can which was subsequently reviewed by SKI and SSI. Feedback from SR-Can and the subsequent review has been implemented in the current assessment SR-Site. An important development is the ***Production reports***[1] *where it is explained how requirements on long term safety are implemented in design, construction and operation of the repository. The basic principles are described in the Repository production report (TR-10-12).*

The Swedish regulations require an updated safety report prior to start of construction of the repository, prior to the start of trial operation and prior to start of routine operation. These reports should be examined and approved by SSM. In addition, an overall assessment of the repository operations is required every 10 years (Periodic Safety Review).

i) Arrangements for independent peer review of the safety case and supporting work.

The management system for the Spent Fuel Project includes steering documents for review of documents (reports) produced by the project. These basically follow the guidelines on primary safety review in SSM's regulation on nuclear facilities. In accordance with these guidelines a comprehensive review by internal and external experts of the licence application and its supporting documents has been carried out.

The Spent Fuel Project set up the SIte Evaluation and design Review Group (SIERG) for external review of the project. The review group acted as advisors to the Spent Fuel Project management. The review work was mainly focused on reviewing main reports from the technical activities but SIERG also gave guidance to essential programme issues in terms of whether all aspects have been included that have to be penetrated. The members of SIERG are listed in the Preface of the SR-Site main report. See also SR-Site main report sect 2.9.5.

j) Establishment of a strategy for recording, managing and archiving of knowledge and information over the whole project timeframe, so that programme decisions can be placed in a broad, historical context.

SKB has developed and implemented a system for recording, managing and archiving of knowledge and information. The system comprises databases for management of documents, models and data. The system meets requirements in SSM's regulations.

The RD&D programmes provide regular (every three years) documentation of results, status and plans for the Swedish radioactive waste program. The licence application provides a comprehensive documentation of the scientific basis and plans for construction of the final repository for spent nuclear fuel. When the licence has been granted and construction begins, regular reporting to SSM is required according to the regulations (comprehensive

[1] The six **Production report** are among the several principal references to the SR-Site main report. See Section 2.5.12 of the main report for a complete list and nomenclature for referencing these in terms of short-names in bold, used also in this document.

reports annually). In addition, an overall assessment of the repository activity is required every 10 years. Hence, a comprehensive documentation of programme development so far is developed and will be regularly updated which can provide a framework for future decisions.

II. Principles, guidelines and procedures for developing a safe and robust system

Robust systems are, according to NEA (2004a), characterised by a lack of complex, poorly understood or difficult to characterise features and phenomena, by ease of quality control and an absence of, or relative insensitivity to, detrimental phenomena arising either internally within the repository and host rock, or externally in the form of geological and climatic phenomena. They are also characterised by a lack of uncertainties with the potential to compromise safety. Various principles, guidelines and criteria can be identified that aim to ensure robustness by minimising unfavourable phenomena and uncertainties and/or the effects of uncertainty on the evaluation of safety.

Box 1: (NEA 1999) describes two categories of robustness:

> *Engineered robustness:* Intentional design provisions that provide additional assurance of disposal system performance and safety, in order either to compensate for known phenomena and uncertainties or to guard against the possible consequences of unexpected phenomena, are said to provide "engineered robustness" (e.g. conditioning the waste in highly durable matrices, over-dimensioning of certain engineered barriers).
>
> *Intrinsic robustness:* Intentional siting provisions that avoid or reduce the effects of potentially detrimental phenomena and sources of uncertainty are said to provide "intrinsic robustness" (e.g., the selection of a site away from natural resources such as oil, gas, minerals etc.).

Were national or internal principles in place regarding the following topics? If so, which of the following were applied, and where is implementation of these described?

a) Inclusion of reserves of safety in the system concept.

The system concept is based on the principles described in the response to question II.1.b) below. The system is robust and the safety assessment shows that the calculated risk for a final repository at Forsmark is below the regulatory risk criterion with a margin (an order of magnitude), even in a million year time perspective and with a number of pessimistic assumptions.

b) Adoption of multiple safety provisions, such as the multi-barrier concept or the concept of multiple safety functions, in order to avoid over-dependence on any single safety provision, safety function, or barrier.

The KBS-3 concept is based on a set of safety principles. These are

- *The final repository will be located deep down in a long-term stable geological environment to isolate the waste from man and the environment. This reduces the risk that the repository will be impacted by possible societal changes or long-term climatic changes.*
- *The final repository will be located on at a site where the host rock can be assumed to be of little economic interest for future generations, reducing the risk of human intrusion.*
- *The spent nuclear fuel will be surrounded by multiple safety barriers – engineered and natural.*
- *The primary safety function of the barriers will be to contain the fuel in the canister.*
- *If the containment should be breached, the secondary safety function of the barriers will be to retard any release from the repository.*
- *Engineered barriers will consist of naturally occurring materials that are stable in the long-term in the repository environment.*
- *The repository will be designed so that the radiation from the spent fuel does not have significant detrimental effects on the properties of the engineered barriers or rock.*
- *The repository will be designed so that high temperatures, which could have significant detrimental effects on the properties of the barriers, are avoided.*

- *The barriers will be passive, i.e. function without human intervention and without active input of materials or energy.*

Together with other aspects – such as the premises defined by Sweden's geological environment and the requirement that the final repository's facilities must be technically feasible to build and operate safely – these principles have led to the choice of the KBS-3 method for final disposal of spent nuclear fuel.

These safety principles are summarised in the licence application.

c) Adoption of a flexible strategy for design development and improvement (e.g. "design-as-you-go")
in order to ensure safe and efficient use of the host rock and repository capacity.

The Observational Method will be applied to adapt the layout of the repository to the host rock. This is described in the ***Underground openings construction report****.*

d) Principles relating to optimisation and Best Available Technology (see e.g. NEA 2010).

SKB has developed the KBS-3 method because it enables the spent fuel to be kept isolated from the biosphere in an effective manner for such long periods of time that SSM's requirements on safety and radiation protection are met. SKB concludes that the design as described in the license application to be optimal and is best available technique. The supporting analyses are presented in the SR-Site main report sec 14.3 with a summary of conclusions in sec 15.3.5. A broader discussion on optimisation and best available technique is provided in Appendix AH (The activity and general rules of consideration, in Swedish only) to the license application.

e) Engineering principles other than those identified in Box 1 above to promote robustness (e.g. the backfilling of access routes, measures to guard against future inadvertent human intrusion, the use of institutional surveillance etc).

The design of the repository system is governed by a set of design requirements. The design requirements are structured in a requirements management database, see TR-10-63 sect 1.5. The high level requirements on the KBS-3 system are described in the ***Repository production report*** *(TR-10-12) sect 3.1.2 and 3.3-3.9. Detailed requirements on the barriers are described in the* ***Production reports****.*

f) Other engineering principles for the design, construction and operation of the repository.

See answer to question II.1.e) above.

Were national or internal guidelines in place regarding the following topics? If so, which of the following were applied, and where is implementation of these described?

a) Guidelines related to the characteristics of a site (e.g. a site that is geologically stable and structurally understandable and/or characterisable with respect to processes and events – including geological events and possible inadvertent human intrusion).

The national guidelines on siting included in the Swedish legislation are of a general nature, see R-11-07 sect 2. Their implementation in the siting process is described in the site selection report, R-11-07. General guidelines are also provided by the safety principles for KBS-3, see II.1.b).

b) Guidelines related to the design basis for the repository (e.g. a minimum depth for the repository; a site may be sought that is larger than the minimum necessary; the possibility for retrievability and monitoring may be incorporated in the design).

*Guidelines for the design of the repository have been defined in terms of design premises. The higher level requirements are described in the **Repository production report**, TR-10-12, and more detailed requirements in the **Production reports**.*

According to these design premises the repository should be located at a depth in excess of 400 m. Monitoring of the repository site has already been started and will continue during repository operation. There are currently no plans for post-closure monitoring, see SR-Site main report 5.8.4.

c) Safety-related exclusion guidelines for a site and/or for zones within a site (e.g. exclusion zones around geological features with unfavourable properties, regional zones of weakness, etc).

*Design premises for the layout of the underground openings are described in the **Underground openings construction report**.*

d) Guidelines related to waste conditioning and packaging (e.g. prohibition of liquid waste forms, use of a stable passively safe waste matrix, use of long-lived containers).

*Requirements and specifications of the spent fuel to be disposed of are described in the **Spent Fuel report** and SR-site main report sec 5.3.1. Important restrictions on the spent fuel elements to be emplaced in a canister are maximum thermal decay power (1700 W), water content and criticality. See also response to question I.1a).*

e) Guidelines related to the safety of repository construction (e.g. requirements on exploration, drilling, mining and excavation methods to minimise the excavation damaged zone)

*Design premises for the layout and construction of the underground openings are described in the **Underground openings construction report**. There are restrictions on investigations boreholes and the excavation damaged zone.*

f) Guidelines related to the safety of repository operation (e.g. requirements to minimize the presence of certain materials, requirements on waste handling and operational safety, requirements on the locations and methods of emplacement for different waste types).

*Requirements on repository operation are described in the SR-Operation (in Swedish) and in the **Production reports**. Requirement on residual materials are described in the **Underground openings construction report**. Only low pH cement is allowed for construction and grouting.*

g) Guidelines related to the safety of repository closure (e.g. requirements on backfilling and sealing).

*These design premises are described in the **Closure production report**.*

Which of the following procedures were applied, and where is adherence to these procedures described?

a) Procedures for peer review (e.g. of decisions regarding siting and repository design, and of the safety case and safety assessment).

Procedures for peer review are described in the answer to I.2.i. The important decisions like the selection of site and submission of the license application have been reviewed and approved by SKB management and the SKB Board of Directors.

b) Quality assurance procedures for waste and site characterisation, waste immobilisation and container fabrication, repository construction and operation.

These are described in the ***Production reports****.*

c) Quality assurance procedures for waste acceptance.

These are described in the ***Spent fuel report****.*

d) Quality assurance procedures for safety case and safety assessment.

These are described in the SR-Site main report sect 2.9 and the response to I.2.b).

III. Assessing system safety and robustness

The means that are available to assess the safety and robustness of a disposal system are collectively termed the assessment capability. The assessment capability should be used to generate an assessment of adequate quality and reliability. According to NEA (1999), the assessment capability comprises:

- The identification and conceptualisation of safety-relevant features, events and processes (FEPs), their evolution over time and their possible interactions.
- The identification and development of appropriate assessment models and couplings amongst models, the compilation of the required data and model parameters in form of discrete values or sets of values, or probability density functions (PDFs), and the implementation of the models, normally in the form of computer codes.
- A critical reflection on the uncertainties in the understanding of the FEPs, models and the associated data.
- The uses of thorough quality management to assure a proper and reliable application of the assessment methodology, models, data and codes in a safety assessment.

III.1 The assessment methodology

Do the following apply to the assessment methodology used in the current safety case and, if so, where are they described?

a) Definition and characterisation of the initial state, including an assessment of the uncertainties in the initial state.

*This applies to the methodology. Chapter 5 of the SR-Site main report is dedicated to the initial state. The initial state is defined in section 5.1. The characterisation of the initial state is given in subsequent sections, heavily drawing on information from a number of references, in particular the six **Production reports**. Uncertainties are addressed in these sections, and the final assessment of data and data uncertainties related to the initial state is documented in the SR-Site **Data report**.*

b) Identification of the safety functions of the main system components.

This is a key part of the SR-Site methodology. A comprehensive set of safety functions relating primarily to the key barriers the canister, the buffer and the host rock have been defined. Also indicators allowing the quantification of barrier performance have been defined. In some cases it has been possible to define also criteria, indicating the limit between proper and improper functioning. Chapter 8 of the SR-Site main report is dedicated to safety functions.

c) A strategy for classifying and handling the different classes of uncertainty (e.g., scenario uncertainty, model uncertainty and parameter uncertainty).

This applies to the methodology. Both the classification and the handling of uncertainties are described in section 2.8 of the SR-Site main report.

d) Identification of a broad range of scenarios that encompass the possible evolutions of the disposal system.

This applies to the methodology. In the SR-Site main report, section 2.5.8 explains the *principles for scenario selection and the actual selection is reported in chapter 11. Note, however, that the scenario selection is not primarily aiming at encompassing the possible evolutions, but to identify safety critical states of the system. Whether or not these states can be expected to occur in reality, i.e. whether they belong to the possible evolutions, is addressed in the subsequent analyses of the scenarios.*

e) Identification of a range of scenarios (or cases) for quantitative evaluation in safety assessment;
this may be more limited than the range referred to in (d).

This applies to the methodology.

All selected scenarios are evaluated quantitatively <u>with respect to containment potential</u> in chapter 12 of the SR-Site main report, with the exception of i) FHA scenarios that are reported in section 14.2 and ii) scenarios where loss of containment is postulated.

*Scenarios where loss of containment cannot be ruled out according to the analyses in chapter 12 are evaluated quantitatively <u>with respect to retardation potential</u> (i.e. radionuclide transport and dose assessments) in chapter 13 of the SR-Site main report with details provided in the **Radionuclide transport report**. Additional selected scenarios in which loss of containment is postulated (what-if scenarios) are also evaluated quantitatively with respect to retardation in chapter 13, section 13.7 with details provided in the **Radionuclide transport report**. Radiological consequences of FHA scenarios are reported in section 14.2 of the SR-Site main report with details provided in the **FHA report**.*

f) Use and justification of stylised treatments for certain scenarios or FEPs (e.g. for human intrusion, for the biosphere) where there are uncertainties that are, in practice, impossible to quantify or reduce.

*This applies to the methodology. There is a discussion of this issue in section 2.8.2 of the SR-Site main report. Stylised treatments are applied to i) intrusion scenarios as documented in section 14.2 of the SR-Site main report with details provided in the **FHA report** and ii) some aspects of the biosphere, namely concerning population, eating and drinking habits that are all treated pessimistically, as documented in section 13.2 of the SR-Site main report with details provided in the **Biosphere synthesis report** and references therein.*

g) Identification of the most important features and processes on which the safety functions rely at any particular stage.

In general, and at any stage, the upholding of a particular safety function relies on i) appropriately achieved relevant aspects of the initial state and ii) on the limited (accumulated) extent of processes that may influence the safety function adversely.

A FEP chart, figure 8-4 of the SR-Site main report, gives an overview of initial state factors and processes of relevance for the key safety functions.

In the analysis of a comprehensive reference evolution, the status of all safety functions are evaluated at the end of each of a number of time frames, see further chapter 10 of the SR-Site main report. The analyses carried out for each time frame address the relevant features and processes on which each safety function relies.

h) Emphasis and analysis in the safety case of the most important features and processes in order to assess the robustness of the disposal concept.

This is achieved through the method for scenario selection that is centred around the safety functions and where all features and processes of relevance to the safety function under scrutiny in a particular scenario are systematically evaluated. (As mentioned in the response to question III d, section 2.5.8 of the SR-Site main report explains the principles for scenario selection and the actual selection is reported in chapter 11.)

i) Identification of the most important safety-relevant parameters (e.g. through sensitivity and uncertainty analyses).

Sensitivity and uncertainty analyses are carried out in several parts of the assessment. A summary of findings relating to uncertain factors affecting the calculated risk is provided in section 13.10 of the SR-Site main report, with references to sections where key uncertainty and sensitivity analyses were carried out. A summary table is also provided in section 13.10, including references to subsequent sections in the main report where plans for reducing the identified uncertainties are discussed. The table also states whether the factors in question are treated pessimistically, probabilistically or otherwise.

j) Creation of "frozen" versions of the underlying database in order to make its assessment during review and evolution during subsequent updates traceable.

This applies to the methodology. All data used in the assessment are stored in accordance with procedures established in the SR-Site quality assurance plan, cited in section 2.9 of the SR-Site main report. Also, a specified version of the site descriptive model for the Forsmark site, documented in the ***SDM Forsmark*** *report and summarised in chapter 4 of the SR-Site main report, and specified versions of the repository design and repository layout, given in the six* ***Production reports*** *and summarised in chapter 5 of the SR-Site main report, are used in the assessment. Finally, all data to be used for quantification of repository evolution and for radionuclide transport and dose calculations are assessed and selected according to the structured procedure for selecting data as described in the* ***Data report****. A final check that the data finally given in the* ***Data report*** *is actually used in the modelling reported, was carried out in accordance with the QA plan.*

k) Checks for overall and internal consistency of assumptions, models, and supporting data.

This is largely obtained through the integrated approach taken when studying the reference evolution. Results and uncertainties identified in a specific part of the reference evolution are propagated to subsequent parts of the analysis of the evolution or to the later scenario analyses. This is achieved by reporting, after each subsection of the reference evolution, under the heading "Identified uncertainties and their handling in the subsequent analysis".

A final check that the data finally given in the ***Data report*** *is actually used in the modelling reported, was carried out in accordance with the QA plan.*

l) Formulation of conceptual models that are based on sound science and engineering, and that are supported by evidence.

Regarding the site, the assessment is based on a site specific model. The model is based on data from comprehensive site investigation, followed by scientific interpretation, modelling and peer reviewing. The model is described in the ***SDM Forsmark*** *report and summarised in chapter 4 of the SR-Site main report.*

All identified processes of relevance for long-term safety are handled according to a pre-established procedure, requiring the documentation of existing theoretical and experimental knowledge and the formulation of a model (if modelling is required) that is consistent with this knowledge. The processes are documented in three ***Process reports*** *that have been subjected to peer reviewing and the requirements on process documentation are described in chapter 7 of the SR-Site main report.*

m) Consideration of alternative conceptual models.

An integral part of the confidence and uncertainty assessment in developing the Site Descriptive model, ***SDM Forsmark****, is to consider different conceptual models, see e.g. section 11.9.3 of SDM Forsmark. Alternatives judged to potentially impact safety, e.g. different models for the correlation between fracture size and transmissivity, have been propagated through the analyses, in accordance with the established procedures of e.g. the Data report, and their impact on risk has been assessed (see e.g. chapter 13 of the SR-Site main report). See further response to question III.1 l) above.*

Also, for each process of relevance for long-term safety, uncertainties in mechanistic understanding are addressed according to the template for describing processes mentioned in the response to question III.1 l) above. Here, consideration of alternative conceptual models is mentioned as part of the instruction.

n) Identification of whether assumptions, models, simplifications, and parameter values are realistic, reasonable, conservative or otherwise, and an analysis of how collectively these choices affect the results of the safety assessment.

This information is summarised in section 13.10 of the SR-Site main report, see further the response to question III.1 h) above.

o) Consideration of alternative performance indicators (e.g. relating to engineered barrier performance; relating to water flows and radionuclide fluxes) to complement dose and risk estimates.

A comprehensive set of safety function indicators relating to barrier performance have been formulated and used in the evaluation of long-term safety, see further response to question III.1 b) above. These refer primarily to the physical state of the barriers rather than to radionuclide fluxes or concentrations.

Regarding alternatives to dose and risk on a system level, four alternative indicators have been applied: release of activity from the geosphere, radiotoxicity flux from the geosphere, concentrations of radionuclides in ecosystems and natural geosphere fluxes of radionuclides. This is described in section 2.6.3 of the SR-Site main report and applied as described primarily in section 13.5.8.

Also, the relative importance as regards retention properties of the waste form, the canister, the buffer and the host rock are examined in a number of dedicated cases where retention properties of one or several of the components are systematically disregarded (although this was done with the normal dose indicator).

III.2 Identification of safety functions and FEPs

To what extent are the safety functions and FEPs considered based on the following? Where is this documented?

a) Scientific knowledge (e.g., of processes) and technical experience (e.g. of materials behaviour), as supported by literature (including literature related to anthropogenic and natural analogues, and theoretical and experimental evidence from inside and outside the radioactive waste field).

*This is included in the assessment basis. The information of this type is summarised in the documentation of processes of relevance for long-term safety found in the three **Process reports**. The format and requirements on process documentation is summarised in chapter 7 of the SR-Site main report.*

b) Structured approaches to repository design and description (e.g. by using "Interaction Matrices" or "Process Influence Diagrams" to represent processes and interactions between different elements of the system).

Several such tools, e.g. assessment model flow charts, process tables and a FEP diagram are used in the assessment basis. See chapter 7 and section 8.5 of the SR-Site main report.

*The repository design, of relevance to safety, is focused on designing the underground openings and adapting their layout to the site conditions such that the repository will confirm to the design premises as described in Chapter 5 of the main report and in more detail in the **Underground openings construction report.** The design premises, in turn, are essentially derived from the safety functions identified in earlier safety assessments.*

c) Measures to ensure comprehensiveness of the FEPs considered and the relationships between FEPs and the fulfilment of safety functions (e.g. by comparison with international databases).

*Comparison with international databases was done as an early part of the FEP processing for SR-Site, as described in chapter 3 of the SR-Site main report with details provided in the SR-Site **FEP report**.*

The relationships between FEPs and the fulfilment of safety functions can in fact be regarded as the purpose of all modelling efforts in the assessment. Comprehensiveness is achieved through a structured assessment of a reference evolution, chapter 10 of the SR-Site main report, followed by the analysis of an exhaustive set of safety relevant scenarios, selected according to procedures described in chapter 11. An overview of relationships between FEPs and safety functions is provided by the FEP chart in section 8.5 of the SR-Site main report.

d) A reasoned definition of the time-scales over which safety assessments and the supporting modelling are carried out, and over which the safety functions need to be fulfilled.

Such a reasoned definition, establishing one million years as the overall timescale of the assessment, is provided in section 2.4 of the SR-Site main report.

III.3 Development of assessment models and databases

To what extent are the assessment models and parameter values that support the current safety case based on the following? Where is this documented?

a) Expert elicitation and expert judgement.

*Expert judgements permeate the SR-Site assessment as discussed in section 2.9.4 of the SR-Site main report. They thus form an important part of the basis for both the formulation of assessment models and the selection of parameter values. The handling of processes, including, if relevant, the formulation of mathematical models, is discussed in chapter 7 of the main report and implemented in the three **Process reports**. The procedure for establishing input data to the assessment is discussed in chapter 9 of the main report and implemented in the **Data report**.*

Formal expert elicitations were not used as a basis for SR-Site, see section 2.8.5.

b) Scientific and technical literature (theoretical and experimental evidence from inside and outside the radioactive waste management field).

*This is used for both models and data. Regarding processes and models, see further Chapter 7 of the main report which explains the format and requirements on documentation of processes, applied in the three **Process reports**. Regarding data, the corresponding information is given in chapter 9 of the main report and in the **Data report**.*

c) Small-scale experiments (e.g. on the properties and behaviour of repository

materials).

See response to question III.3b above.

d) Studies of relevant (similar) natural systems and natural analogues.

See response to question III.3b above. (A dedicated heading in the template for process documentation requires the documentation of this type of information.)An integrated discussion of support from natural analogues for the safety case is provided in section 14.6 of the SR-Site main report.

e) Underground rock laboratory (URL) studies.

*See response to question III.3b above. In particular, in addition to providing enhanced understanding of underground physical and chemical processes, several dedicated tests and experiments at the Äspö HRL have confirmed the technical feasibility of EBS installation and the actual achievability of the initial state - as is further elaborated in the **Production reports.***

f) Large-scale site-specific field studies (e.g. pumping tests, tracer

tests).

*As further described in **SDM Forsmark**, the Forsmark site is characterised by an extensive surface based, site characterisation effort including surface and airborne mapping and geophysics, 25 core-drilled boreholes ranging in depth* *down to c. 1,000 m and having a total borehole length of c. 17,800 m and 38 percussion-drilled boreholes and more than 100 monitoring boreholes in the Quaternary cover, so-called soil wells. An extensive testing programme was followed in each bore hole. In particular the applied hydraulic testing tool, the "Posiva Flow Log", can be seen as a single hole pumping test. Confidence in the site description primarily rests on the relative wealth of data from the target volume and the consistency between independent data from different disciplines. In addition, a larger scale pumping test ("interference tests") in borehole HFM14 was performed in 2006, see section 8.3.4 of* ***SDM Forsmark.*** *Also, two multiple well and seven single well tracer tests have been carried out, see section 10.7 of* ***SDM Forsmark.*** *The evaluation and interpretation of these tests essentially confirmed the interpretation made before the tests.*

See also response to question III.3b above.

g) Process models for extrapolation to repository conditions and

scales.

Selection and justification for how to model a specific process in the safety assessment is part of the procedure followed in the ***Process reports.*** *For each process assessed there is a concluding section on "Handling in the Safety Assessment SR-Site". Regarding field data from the site investigations they are assessed in* ***SDM Forsmark*** *into Site descriptive models. This often includes upscaling detailed field data, such as core samples or hydraulic tests into models describing the rock properties over the repository scale. Furthermore, the final selection of data to be used in SR-Site is made in the* ***Data report****, which, among other things, considers the adequacy of the upscaling made.*

For example, the main groundwater flow code used for assessment calculations in SR-Site, ConnectFlow, was also the main code used for assessing the field data from the site investigations; i.e., we first calibrated the hydrogeological discrete fracture network model on the multitude of borehole test data, we then performed confirmatory testing of the resulting groundwater flow model using independent data such as hydrogeochemistry data and data from hydraulic interference tests See further Chapter 8 of ***SDM Forsmark*** *and section 6.6 of the* ***Data report****.*

Another example, described in detail in Chapter 6 of ***SDM Forsmark*** *and in the* ***Data report*** *section 6.2, is thermal conductivity data obtained from core samples are upscaled to represent proper averages when assessing the thermal evolution in the deposition hole scale. Among other things, this upscaling considers the correlation between rock type and thermal conductivity, the correlation between thermal conductivity and geophysical data and the spatial structure of the geophysical core logs in order to produce a geostatistical description of the thermal conductivity.*

III.4 Ensuring proper application of the assessment methodology, models, data and codes

Have the following been applied to ensure proper application of the assessment methodology, models, data and codes that support the safety case. If so, where is this described?

a) Quality assurance procedures for the safety assessment.

QA procedures have been applied according to a dedicated QA plan for the SR-Site safety assessment project. The plan and the QA procedures are described in section 2.9 of the SR-Site main report.

b) Peer-review of the safety assessment methodology, models, data and codes.

All important parts of the assessment have undergone peer review in accordance with the QA requirements. Normally, this is done as peer reviews of the reports describing the methodology (i.e. the main report), the models (part of the reporting on modelling activities) and data (i e the ***Data report*** *and its underlying references).*

c) Verification of the assessment codes (e.g. through comparison with analytical solutions and with results from other codes).

This has been done as described in the various modelling reports and summarised in the ***Model summary report****. For example, the radionuclide transport codes for the near field and the far field have been compared to analytical solutions where possible.*

d) Examination of the performance of the assessment codes and supporting models when applied to similar problems (e.g. the use of groundwater flow models to simulate behaviour observed in field tests).

The main groundwater flow code used, ConnectFlow, was also the main code used for assessing the field data from the site investigations;, i.e., we first calibrated the hydrogeological discrete fracture network model on the multitude of borehole test data, we then performed confirmatory testing of the resulting groundwater flow model using independent data such as hydrogeochemistry data and data from hydraulic interference tests. In SR-Site, we used the same groundwater flow model for the hydraulic analyses. Concerning transport of radionuclides, parameters for use in the modelling were derived from data from the site investigations. Both laboratory data (e.g., from batch sorption measurements) and field data (e.g., from tracer tests) were obtained from the site investigations.

e) Comparison of the assessment data and parameter values with information from other sources (e.g. alternative data in the literature, data used in other safety assessments, data held in international databases).

In general, all relevant data sources have been considered when establishing data for the assessment, according to the procedure described in chapter 9 of the SR-Site main report and fully documented in the ***Data report*** *and its underlying references.*

f) Checks to determine compliance with any requirements for statistical convergence of model results.

All key probabilistic results have been checked for appropriate convergence of their calculation endpoints, in general the mean values. This applies e.g. to the radionuclide transport calculations, see further the ***Radionuclide transport report****, and the assessments of canister failures due to earthquake induced secondary shear movements in the stochastically generated DFN fracture network, see the report entitled "Full perimeter intersection criteria. Definitions and implementations in SR-Site", TR-10-21. In the assessment of canister failures due to corrosion, analytical solution methods are applied to a probabilistic problem thereby ensuring a correct mean value, see further the report entitled "Corrosion calculations report for the safety assessment SR-Site", TR-10-66.*

g) An analysis of the results from the safety assessment to demonstrate that they are in accordance with the general understanding of the behaviour of the disposal system that has been modelled (e.g. through expert judgement and possibly by the use of more simplified models of the most important safety related processes).

Generally, the reasonableness of the results is compared to the expected behaviour of the system. This applies e.g. to the results of hydrogeochemical and hydrogeological modelling as documented where these modelling efforts are described.

Simplified models have been applied as a complement to e.g.

- *the radionuclide transport calculations, see section 13.5.20 of the SR-Site main report and further the* ***Radionuclide transport report****;*
- *the calculations of likelihoods of deposition positions being intersected by large fractures included in the stochastic DFN fracture network, see the report entitled "Full perimeter intersection criteria. Definitions and implementations in SR-Site", TR-10-21.*

III.5 Assessment results

For each scenario evaluated in the current safety case which of the following apply? Where c), d) or e) apply, what if any arguments are made to counter these unfavourable conclusions? Where are these arguments documented?

a) Assessed consequences are below (or within) acceptance guidelines across the range of model and parameter uncertainty.

This applies to all scenarios where containment failures cannot be ruled out, i.e. the corrosion scenario and the shear load scenario, see further e.g. section 15.3.3 of the SR-Site main report.

b) Assessed consequences at or above acceptance limits have been identified, but the likelihood of such a scenario is argued to be low.

Consequences above acceptance limits have been calculated only for "what if" scenarios used to illustrate the relative importance of barriers etc. These scenarios address postulated barrier failures and cannot be assigned probabilities.

c) Assessed consequences at or above acceptance limits have been identified, but the consequences are not related to the evolution of the repository itself but, rather, to significant externally-imposed FEPs (such as large meteorite impact or nuclear war). In such cases, releases from the repository may not dominate the overall consequences to human health, and some might be regarded as force majeure.

No consequences have been calculated for this type of situations. Rather they are excluded from further assessment based on either very low probability or other dominating overall consequence, or both. See further section 6.1 of the SR-Site main report regarding meteorite impact and section 14.2 of the main report regarding nuclear war and other FHA activities.

d) Assessed consequences at or above acceptance limits have been identified; the likelihood of such a scenario is not known at present.

No such scenarios have been identified.

e) Assessed consequences at or above acceptance limits have been identified and the likelihood of such consequences is judged to be significant.

No such scenarios have been identified.

IV. Implementation, planning and feasibility

Does the safety case include information relating to aspects of repository implementation, planning and engineering feasibility? Which of the following topics are addressed, and where is this described?

a) Identification and selection of materials for repository components (e.g. waste containers, buffers, backfills and seals).

*This is included in five of the six **Production reports**:*

- *Design, Production and Initial State of the Canister, TR-10-14*
- *Design, Production and Initial State of the Buffer, TR-10-15*
- *Design, Production and Initial State of the Backfill and Plug in Deposition Tunnels, TR-10-16*
- *Design, Production and Initial State of the Closure, TR-10-17*
- *Design, Construction and Initial State of the Underground Openings, TR-10-18*

*(The sixth production report relates to the spent fuel.) Information of relevance for long-term safety in the **Production reports** is summarised in chapter 5 of the SR-Site main report.*

In case the design premises restrict the use of a substance (e.g. ordinary cement), this is considered in the material selection and procedures for ensuring conformity with the design premises are presented.

b) Supply, quality assurance and characterisation of engineered barrier materials.

See response to question IV a).

c) Methods for engineered barrier component manufacture (e.g. waste containers, buffer and backfill blocks, repository seal components).

See response to question IV a).

d) Trials and demonstrations of engineering feasibility (e.g. covering excavation and tunnelling to required tolerances; waste packaging, handling, and emplacement; engineered barrier emplacement).

See response to question IV a). Such trials and demonstrations have usually been made in the laboratory or at the Äspö HRL for the various EBS parts and for the underground construction. However, all these tests have not been made at full scale.

e) Approaches to quality compliance checking and testing of manufactured

components.

*See response to question IV a) and the **Repository production report**, TR-10-12 sect 5.*

f) Plans for quality compliance checking and monitoring of installed components

See response to question IV a).

g) Plans for waste and engineered barrier emplacement, including methods, sequences and timings.

See response to question IV a).

V. Arguing the case to proceed to the next development stage

A safety case that concludes that there is sufficient confidence to justify a positive decision to proceed to the next stage of planning or implementation must provide adequate support for this conclusion.

The focus of the safety case has generally been on argumentation that the consequences (or risks) have been thoroughly assessed and are acceptable vis-à-vis the acceptance guidelines. Other complementary lines of argument are, however, also required in order to show, for example, that an appropriate site-selection process has been followed, that systematic approaches have been applied in disposal concept and repository design, that the waste and the site have been well characterised and are sufficiently well understood, and that a programme of work is in place to manage remaining uncertainties. In recent years increasing attention is being given to issues associated with implementation, feasibility, uncertainty management.

Which of the following are explicitly cited as complementary evidence or lines of argument to support the final conclusions or recommendations of the safety case? Where are such arguments documented?

a) That appropriate management systems are in place to proceed to the next step in the repository development programme in a safe and secure manner.

The plans for implementation of the quality management system are described in the ***Repository production report****, sect 5. The plan for management of the construction of the repository, technology development and future research is described in an appendix to the licence application "Operation, management and control – construction of the final repository" (VU, in Swedish).*

b) That the relevant principles, guidelines and procedures have been adhered to in order to achieve a safe and robust system.

In the licence application it is argued that the proposed repository system complies with applicable legal requirements and guidelines and specifically that it meets the requirements on safety. Section 15.3 of the SR-Site main report presents a demonstration of compliance with requirements on long-term safety, robustness, optimisation and best available technique.

c) That there is sufficient confidence in the understanding of the site and the disposal concept, and that a strategy is in place for addressing and managing uncertainties[2].

Sufficient confidence in the site and the disposal concept is argued in section 15.3.6 of the SR-Site main report. Feedback to design development, to detailed site investigations and to further R&D is provided in section 15.5 – 15.7 of the main report.

The stepwise approach to repository planning and implementation described in response to question I.1.g) provides the basic strategy for addressing and managing uncertainties, both with regard to design of the engineered barriers and adaptation of the repository to the host rock. The strategy for adaption of the repository to the host rock is described in the

Underground openings construction report *and in SR-Operations (in Swedish).*

d) That there is sufficient confidence in the assessment capability and the assessment basis, and in plans for research and development work to manage and reduce uncertainties.

This is argued in section 15.3.6 of the SR-Site main report.

e) That plans for implementation of the disposal concept are feasible and have been, or will be, tested, demonstrated and verified.

The licence application argues that the plans are feasible and that SKB has the competence and experience required to implement the disposal concept. Essential parts of the repository system have been tested at the Canister Laboratory and the Äspö Hard Rock Laboratory. Relevant results are presented in the ***Production reports*** *to substantiate that the initial state can be achieved in practice. Plans for continued development are described in the RD&D programme, TR-10-63 secs 8-15.*

f) That explicit connections have been identified between safety and the roles (safety functions) of the various barriers within the multi-barrier concept.

The methodology followed in the SR-Site assessment is focussed on safety functions of the safety bearing features of the system. Key results related to the allocation of safety are discussed in section 15.3.2 of the SR-Site main report.

g) That sufficient knowledge exists that provides confidence that the barriers will perform as intended and fulfil their functions.

This is argued in section 15.3.6 of the SR-Site main report.

h) That all identified safety-related issues that are important for the decision under consideration at the current development stage have been addressed.

This is argued in bullet point five of section 15.3.6 of the SR-Site main report.

i) That there are FEPs that would contribute to safety, but which have not been included in the quantitative safety assessment.

There are few examples of this in the SR-Site assessment. Rather, throughout the assessment, a number of included FEPs have been treated pessimistically.

j) That consideration has been given to all relevant data and information, together with their associated uncertainties.

This is achieved through the systematic approach taken in the ***Process*** *and* ***Data reports****, as described in chapters 7 and 9 of the SR-Site main report, respectively. It is also part of the reasoning in section 15.3.6.*

k) That all models and databases used have been adequately tested.

This is part of the quality assurance of models and data, addressed in bullet point five of section 15.3.6 of the SR-Site main report.

l) That a well-defined and rational assessment procedure has been used, and the effects of uncertainties on the conclusions of the assessment considered.

This is argued in bullet point five of section 15.3.6 of the SR-Site main report.

m) That the safety case and safety assessment have been fully disclosed and subjected to quality assurance and peer review.

Quality assurance and peer review is argued in section 15.3.6 of the SR-Site main report. The assessment has been fully disclosed through the documented peer review procedure.

n) The existence of independent evidence, obtained, for example, by comparing assessment results with independent studies performed for similar disposal concepts (in particular, the results of sensitivity analyses within these studies).

No particular comparisons to similar disposal concepts have been carried out within the SR-Site assessment.

o) Other evidence and lines of argument.

Support from natural analogues is addressed in section 14.6 of the SR-Site main report. The results of using safety indicators alternative to dose and risk are accounted for in section 15.3.3.

[2] According to both NEA (1999) and NEA (2004a), a key element of the safety case is the guidance that it provides for addressing uncertainties and remaining siting and design issues in the course of future programme stages. Uncertainties can be reduced by research investment, or else they can be avoided or their impact can be reduced through siting and design measures.