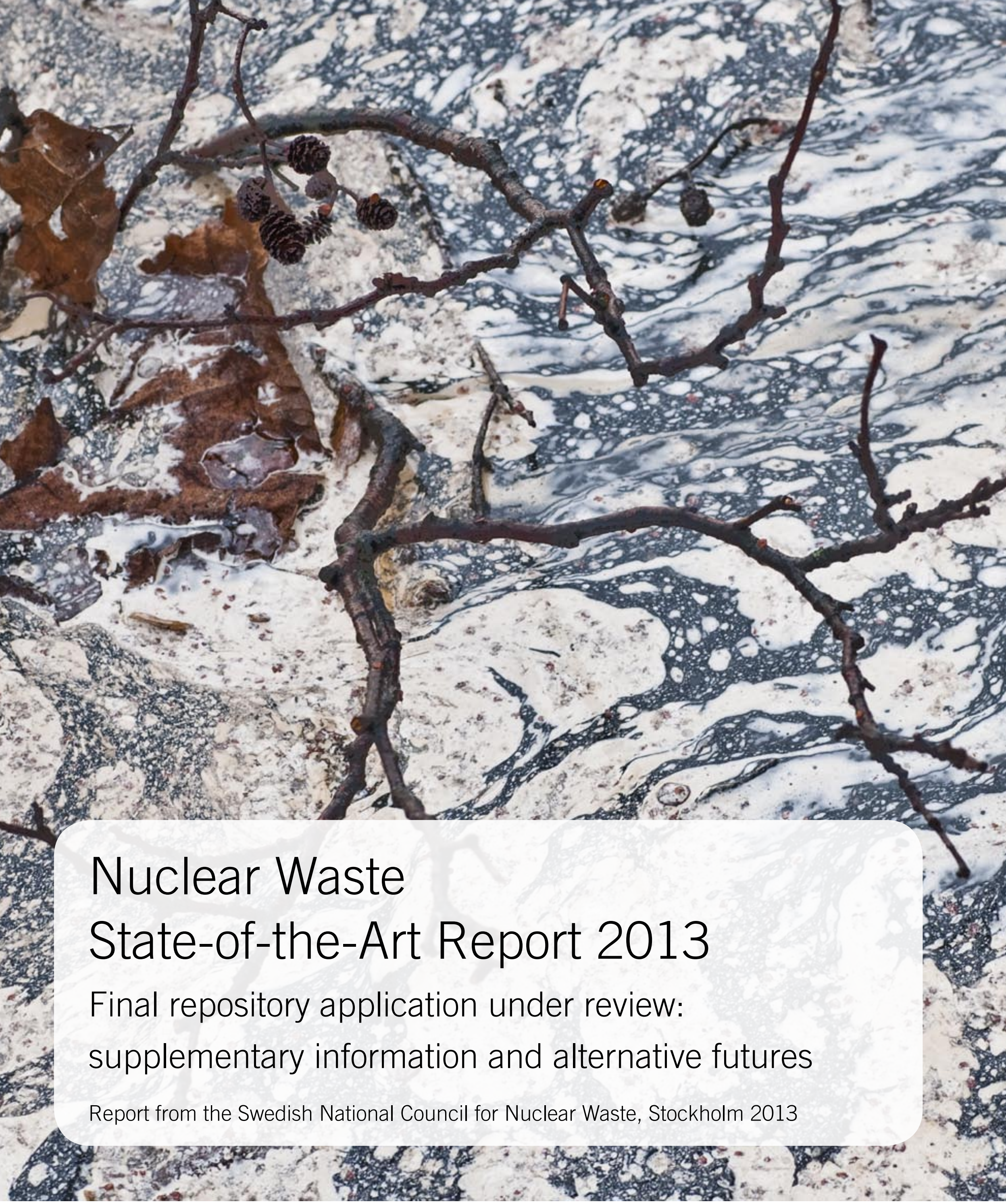

Nuclear Waste
State-of-the-Art Report 2013

Final repository application under review: supplementary information and alternative futures

Report from the Swedish National Council for Nuclear Waste, Stockholm 2013

KÄRNAVFALLSRÅDET
Swedish National Council for Nuclear Waste

SWEDISH GOVERNMENT INQUIRIES

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The Swedish National Council for Nuclear Waste

Stockholm 2013

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To the minister and head of the Ministry of the Environment

The Swedish National Council for Nuclear Waste is an independent scientific committee whose mission is to advise the Government on nuclear waste and decommissioning of nuclear facilities.

In the month of February every year, the Swedish National Council for Nuclear Waste publishes its independent assessment of the current state of the art in the nuclear waste field. The assessment is presented in the form of a state-of-the-art report. The purpose of the report is to describe important issues and clarify the Swedish National Council for Nuclear Waste's viewpoints on these issues. The Swedish National Council for Nuclear Waste hereby submits to the Government this year's state-of-the-art report (the thirteenth in this series) entitled *"Nuclear Waste State-of-the-Art Report 2013. Final repository application under review: supplementary information and alternative futures"* (SOU 2013:11).

The present report is endorsed by all members and experts in the Swedish National Council for Nuclear Waste.

English versions of the reports on the state-of-the-art in the nuclear waste field for 1998, 2001, 2004, 2007, 2010, 2011 and 2012 are also available.

Stockholm, 19 February 2013

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Abbreviations

Appendix AG	Activity and general rules of consideration (appendix to *SKB's application*)
Appendix CM	CM: Choice of method – evaluation of strategies and systems for disposal of spent nuclear fuel
Clab	Central interim storage facility for spent nuclear fuel
RD&D opinions	Statements of opinion on SKB's latest programme for research, development and demonstration of methods for the management and disposal of nuclear waste
GIF	Generation IV International Forum
KASAM	Predecessor of the present-day Swedish National Council for Nuclear Waste
KBS-3	The final disposal method developed by SKB is called KBS-3. KBS stands for Kärnbränslesäkerhet (Nuclear Fuel Safety) and the number 3 indicates that the method incorporates three barriers: the copper canister, the bentonite clay and the crystalline bedrock.
LWR	Light water reactor: a reactor cooled and moderated by ordinary (light) water.
SotAR	State-of-the-Art report
NWTRB	Nuclear Waste Technical Review Board
SKB	Svensk Kärnbränslehantering AB
SOU	Statens Offentliga Utredningar (Swedish Government Official Reports)
SSM	Swedish Radiation Safety Authority

1 Introduction

The most important task undertaken by the Swedish National Council for Nuclear Waste during 2012 was to review the Swedish Nuclear Fuel and Waste Management Co's (Svensk Kärnbränslehantering AB, SKB) licence application under the Environmental Code for an integrated system for final disposal of spent nuclear fuel, which was submitted to the Land and Environment Court at Nacka District Court. At the same time, SKB also submitted an application under the Nuclear Activities Act to the Swedish Radiation Safety Authority (SSM).

Both SSM and the Land and Environment Court have then asked for viewpoints regarding the need for supplementary information from a large number of referral bodies: public authorities, universities and non governmental organizations.

The Swedish National Council for Nuclear Waste was asked by the Land and Environment Court to express viewpoints on whether the application was complete enough for consideration by the court. Questions regarding SKB's application and the need for supplementary information have been identified by the Council's members and experts from the perspective of their different areas of competence. The results were collected in the Council's review statement with viewpoints on the need for supplementary information and submitted to Nacka District Court on 31 October 2012.

Meanwhile, the research situation has changed as regards alternative methods for managing spent nuclear fuel. A fundamental question when it comes to choice of method is whether the spent nuclear fuel is a burden or a resource for future generations.

In order to shed light on this question, the Council arranged an international scientific seminar on 8–9 November 2012 entitled *The Future of Nuclear Waste – Burden or Benefit?* The purpose of the seminar was, in the light of new technological developments, to look into different alternatives for the management of nuclear waste and spent nuclear fuel, with reference to SKB's proposal to use the KBS-3 method in its application.

In this year's state-of-the-art report, the Swedish National Council for Nuclear Waste focuses on the following areas from the perspective of the Council's activities during the past year:

Consideration of SKB's application – the need for supplementary information

The first part of the report provides an overview of the following areas:

- The chapter *The Council's viewpoints on the need for supplementary information in SKB's application* describes the questions to which the Council has devoted particular attention in its viewpoints on the need for supplementary information, which were submitted to the Land and Environment Court at Nacka District Court.
- The chapter *Overview of referral bodies' viewpoints on the need for supplementary information in SKB's application* summarizes the opinions that other referral bodies submitted to SSM and the Land and Environment Court.

Importance of technology for nuclear waste disposal

The second part of the report sheds light on the importance of technology development for nuclear waste disposal. The chapter *To recycle or not to recycle – that is the question...* discusses whether the spent nuclear fuel should be regarded as waste or as a resource based on SKB's application, the Council's previous policy positions and the conclusions from the Council's seminar in November 2012.

1.1 Review of SKB's application – the need for supplementary information

The Council's review of SKB's application

On 31 October 2012, the Swedish National Council for Nuclear Waste submitted its statement of opinion to the Land and Environment Court at Nacka District Court regarding SKB's licence application for a final repository for spent nuclear fuel. The statement of opinion identifies to what extent SKB should supplement the application documents.

The Council has reviewed the application from a broad scientific perspective based on the areas of competence of the different members. The review is based on the work done by the Council in conjunction with previous years' state-of-the-art reports and reviews of SKB's RD&D programmes[1]. The aim has been to investigate whether the application comprises an adequate basis for the judgements to be made by concerned municipalities, the Land and Environment Court, the Swedish Radiation Safety Authority and the Government.

In the Council's opinion, the application should be supplemented with information and data on some 70 different points before it can be considered to be complete. The supplementary information concerns, for example, the geosphere at the envisaged final repository, the safety functions of the copper canister and the bentonite buffer, backfilling of the deposition tunnels, and the possibility of verifying whether the safety assessment's requirements are met throughout the repository after final closure.

It is the Council's considered opinion that the environmental impact statement should be supplemented with information on a number of points. This includes information on radiological risks, an account of alternative methods, impact on nature and water operations, and the risks of intrusion and psychosocial effects. The Council further considers that SKB should prepare a plan of action for preservation of information and knowledge describing how SKB intends to preserve information about the final repository during the pre-closure period and how knowledge about the repository can be passed on to future generations.

[1] Programme for research, development and demonstration of methods for the management and disposal of nuclear waste.

Chapter 2 elaborates on some of the fundamental positions underlying the Council's statement of opinion. The Council's statement of opinion to the Land and Environment Court at Nacka District Court is included in its entirety as an appendix to this report.

Viewpoints from other referral bodies

SKB's application has engaged numerous referral bodies. Viewpoints have been submitted to SSM and the Land and Environment Court regarding the need for supplementary information. These viewpoints have been concerned with both the structure of the application and individual technical issues. A rough compilation of the issues touched upon in the statements of opinion is presented in Chapter 3 of this report under the headings: Accessibility of background material; Decision processes, responsibility and ownership; Scientific quality; The engineered barriers: canister, buffer and backfill; Financing; Intrusion and physical protection; Preservation of knowledge; Choice of method; Site selection; Clink; Environmental impact statement (EIS); Monitoring; Licence conditions; and Reflections.

1.2 Importance of technology for nuclear waste disposal

Technical development in the nuclear power field (e.g. the fourth generation of reactors) can create possibilities for the spent nuclear fuel to be reused and thereby reduce the long-term risks posed by spent nuclear fuel from our nuclear power reactors. But the continued use of nuclear power often confronts us with thorny societal, political and ethical problems.

The chapter *To recycle or not to recycle – that is the question...* addresses the fundamental question of whether the spent fuel should be regarded as waste or as a resource. Both options must be thoroughly examined, but SKB's application treats the resource option very cursorily in comparison with the waste option. The Council therefore finds that there is a need for a more in-depth examination of the resource option and presents an analysis of this option in the chapter.

The Swedish National Council for Nuclear Waste has given attention to the question of alternative methods (such as deep boreholes) for many years and arranged, in November 2012, an international seminar to shed light on the technical possibilities of recycling the spent nuclear fuel using new reactor technologies. The seminar contributed to greater knowledge of the various factors that bear upon the assessment of the recycling alternative – such as different technical future scenarios, uranium supplies, climate change, other countries' experience and the international regulatory framework. The recycling alternative was dealt with not only from a technical and natural science perspective, but also from a social science and ethical perspective.

In its statement of opinion to the Land and Environment Court, the Council brings up some of the ethical principles that could guide spent nuclear fuel management, for example a principle concerning the freedom of choice of future generations: the autonomy principle. In some ways it may be difficult to satisfy this principle while at the same time satisfying the safety and responsibility principle. In the chapter in question, the Council elaborates on the autonomy principle and how treating the spent nuclear fuel as a resource could satisfy – or conflict with – this principle.

Finally, some social science issues are identified and we discuss how a responsible decision can be made on the management of the spent nuclear fuel in spite of incomplete knowledge and ethical uncertainty.

2 The Council's viewpoints on the need for supplementary information in SKB's application

2.1 Introduction

On 31 October 2012, the Swedish National Council for Nuclear Waste submitted its viewpoints to the Land and Environment Court at Nacka District Court regarding SKB's licence application to build a final repository for spent nuclear fuel. The viewpoints concern the extent to which the application documents need to be supplemented.

It is the Council's considered opinion that SKB's licence application for a final repository does not, in its present form, contain all the information and data needed in order for it to be properly considered in a meaningful way. In the Council's opinion, the application should be supplemented on some 70 different points. The statement of opinion is included in its entirety as an appendix to this report.

The Swedish National Council for Nuclear Waste identifies the following areas as being in particular need of supplementary information:

- Readability and searchability in the background material. This includes e.g. the structure of the application and references to appendices and background reports.
- Description of aspects of the geosphere at the envisaged final repository. This includes e.g. knowledge of the rock stresses at the planned repository depth in Forsmark and the need for monitoring of rock movements during the construction and operation of the repository. SKB should also investigate exploitable mineral resources in the Forsmark area.

- The functions of the engineered barriers. Additional information should be provided on the safety functions of the copper canister and the bentonite buffer and the backfilling of the deposition tunnels through both additional studies and experiments concerning the strength of the canister and the barrier function of the buffer. The Council calls for a more thorough account of how the functions of the engineered barriers are affected over a very long time, i.e. the transition from the initial state to target state.
- The interaction between the main processes "safety assessment" and "construction" should be investigated and supplementary information provided by an analysis of the roles and relationships between the three elements "design premises", "initial state" and "safety assessment", as well as by proposing a measurement programme for verifying that all design premises are fulfilled in the repository before final closure.
- The environmental impact statement should be supplemented with information on a number of points. These include radiological risks, alternative methods, impact on nature and water operations, and the risks of intrusion and psychosocial effects.
- The Council further considers that SKB should prepare a plan of action for preservation of information and knowledge describing how SKB intends to preserve information about the final repository during the pre-closure period and how knowledge about the repository can be passed on to future generations.

The Swedish National Council for Nuclear Waste possesses broad interdisciplinary competence and many different areas are dealt with in the Council's statement of opinion on the need for supplementary information that was submitted to the Land and Environment Court.

The following chapter particularly deals with three areas previously given attention by the Council:

Chapter 2.2 *The application as a basis for decisions in a democratic context* sheds light on how the application for a final repository for spent nuclear fuel, as well as the background material presented in support of the application, fill an important democratic function.

Chapter 2.3. *State of the engineered barriers in the final repository* describes the premises on which the Council's viewpoints on the copper canister, the buffer and the backfill (the engineered barriers) are based. The challenges in guaranteeing the function of these barriers are also described.

Chapter 2.4. *Interaction between construction and safety assessment* describes how the Council views the challenges faced by SKB in satisfying the requirement on long-term safety.

2.2 The application as a basis for decisions in a democratic context

Application for final disposal of spent nuclear fuel

The Swedish Nuclear Fuel and Waste Management Co (Svensk Kärnbränslehantering AB, SKB) has applied for a licence under the Environmental Code to dispose of spent nuclear fuel according to the KBS-3 method. The application concerns an integrated system for final disposal of the spent nuclear fuel[1] , which means that the application covers:

- a) an *encapsulation plant in Oskarshamn*, i.e. a facility where the spent fuel is encapsulated in copper canisters with inserts of nodular iron before final disposal in Forsmark,
- b) *the final repository* in Östhammar.

The shipments of the encapsulated Östhammar spent nuclear fuel between the encapsulation plant in Oskarshamn and the final repository in Östhammar will also be taken into account when the application is considered.[2]

The purpose of the system for which a licence is being applied is "to dispose of the spent nuclear fuel in order to protect human health and the environment from the harmful effects of ionizing radiation from the spent nuclear fuel, now and in the future".[3] The final repository in Östhammar is the measure intended to achieve this purpose, according to SKB.

[1] Cf. Chap. 21 Sec. 3 of the Environmental Code; The section defines the premises for handling cases and matters that have the same applicants and moreover are related to each other, known as cumulation of cases and matters.
[2] Cf. Chap. 16 Sec. 7 of the Environmental Code.
[3] See the application's top document, page 4.

Three laws govern the licensing process

It isn't enough for SKB to apply for a licence under the Environmental Code alone. Swedish law requires that SKB also apply for a licence under the Nuclear Activities Act[4], since management and final disposal of spent nuclear fuel is a nuclear activity.

The Radiation Protection Act must also be taken into account in this context. The purpose of the Radiation Protection Act is to protect humans, animals and the environment from the harmful effects of radiation. But a special licence is not required under the Radiation Protection Act in this context. Here a licence under the Nuclear Activities Act is sufficient. If a licence has been issued under the Nuclear Activities Act, the Swedish Radiation Safety Authority issues whatever conditions may be needed for the licence with regard to radiation protection.

Accordingly, there are three laws that govern the licensing process for final disposal of the spent nuclear fuel:

- The Environmental Code (1998:808),
- The Act (1984:3) on Nuclear Activities (Nuclear Activities Act)
- The Radiation Protection Act (1988:220).

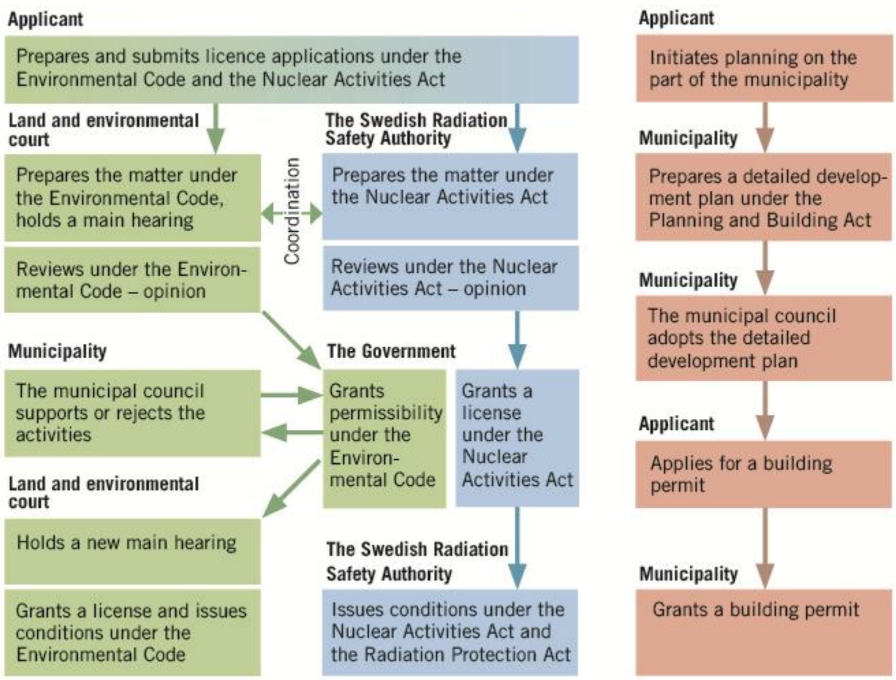
These three laws shall be applied in parallel. When it comes to consideration of the application, it is also a question of parallel processes. As noted, two separate licences are required to pursue the activity.

Each licence gains its legal force from its respective law. By "legal force" is meant that each licence applies separately, independently of other licences.[5] At the same time, the licence holder must of course abide by all licence conditions and other provisions of the licences. However, difficulties may arise for the licensee if the conditions issued under the different licences should for some reason conflict with each other.

All in all, it is a rather complicated procedure, which is described in simplified terms in the figure below:

[4] Act (1984:3) on Nuclear Activities.
[5] Cf. Chap. 24 Sec. 1 paragraph 1 of the Environmental Code.

Figure 1 **Process for licensing under the Environmental Code and the Nuclear Activities Act**



Several decision-making bodies are involved

As evident from the figure above, several decision-making bodies are involved in the review of SKB's Application under the Environmental Code:

- *The Land and Environment Court* submits its statement of opinion to the Government,
- *The municipal council* in each municipality submits a statement of opinion to the Government, which must occur before the Government rules on the permissibility of the activity,
- *The Government* then considers the permissibility of the activity for the integrated system for final disposal,

- *The Land and Environment Court* issues a licence and conditions for the activity, provided that the Government has judged the activity to be permissible.

In parallel with the licensing process under the Environmental Code, the Government considers the application for a licence under the Nuclear Activities Act.

Municipal council plays important role in decision process

The review that takes place in the municipalities of Östhammar and Oskarshamn is crucial in determining whether the facility is to be permitted. In a statement of opinion to the Government, the municipal council in both municipalities must either approve or reject the part of the activity that affects that particular municipality. This must be done before the Government makes a decision under the Environmental Code on the permissibility of the activity.

When it comes to facilities for nuclear activities, the Government may only permit the activity if the municipal council in the municipality where the facility will be sited has approved it – the municipal veto. The final repository and the encapsulation plant are thus subject to the municipal veto. The main rule is that the Government may not permit the activity against the municipality's will.[6]

The municipal veto has, however, been provided with a "veto valve" when it comes to facilities for interim storage or final disposal of nuclear material or nuclear waste. The Government may permit the activity without the approval of the municipal council if it is of the utmost importance for the national interest that the activities be realized.[7]

However, in order for the activity to be permitted without the municipality's approval, no other more suitable site must be available for the activity. This refers not only to the suitability of the site from technical and economic perspectives, but also from ethical, social and environmental perspectives. The reasons given by the municipalities for their attitudes must also be taken into consideration. Thus, a site in a municipality that approves the siting may be considered more suitable than a site in a municipality that opposes an establishment, even if a siting in the latter municipality entails

[6] Cf. Chap. 17 Sec. 6 paragraph 1 of the Environmental Code.
[7] Cf. Chap. 17 Sec. 6 paragraph 4 of the Environmental Code.

less of an intrusion in the environment, lower costs, etc. In summary, the right of the Government to override the municipal veto must be used extremely restrictively.[8]

Thus, the municipal councils in Östhammar and Oskarshamn each play an important, perhaps crucial, role in the decision process.

Application fills an important democratic function

As the process according to the Environmental Code is designed, responsibility for a decision to build, or not to build, the proposed final repository ultimately rests with the Government. Municipal decision-makers also play an important role, as explained in the section above.

Against this background, the application and the background material presented along with the application fill an important democratic function. The background material presented in support of the application should shed light on the issue in a manner that can be understood by laymen[9]. Even though the licensing process requires complex analyses, the background material in the application must be clear and transparent, so it is easy to follow.

SKB's application should be explained from a broad perspective

It is urgent that the treatment of the application not lead to a limitation of perspective in the nuclear waste issue. The period of time for which the spent nuclear fuel must be isolated to render it harmless to human health and the environment is almost incomprehensibly long. The risk analysis for a final repository should cover at least a hundred thousand years (the length of a glacial cycle) in order to shed light on reasonably foreseeable external stresses on the final repository.

The assessment of the final repository's protective capability for the first thousand years after closure shall be based on quantitative analyses of the effects on human health and the environment. For the time following the first thousand years after repository closure, the assessment of the repository's protective capability shall be based on different possible scenarios.

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[8] See Gov. Bill 1997/98:45 II p. 221.

[9] A layman (or layperson) is a person without professional or specialized knowledge in a particular subject (Oxford dictionary).

Different methods for final disposal of the spent nuclear fuel should therefore be considered and alternatives to the KBS-3 method should be examined in the court.

The Swedish National Council for Nuclear Waste assumes that the process in the Land and Environment Court will include all circumstances of importance for the question of permissibility.[10] In the opinion of the Swedish National Council for Nuclear Waste, the review under the Environmental Code should naturally also consider the damage and detriment due to ionizing radiation that could result from failure of the barriers or the final repository in one or more respects, resulting in a radiological accident.

Nor are there any formal obstacles to prevent the Land and Environment Court from examining all questions related to nuclear safety and radiation protection.[11]

Application should be supplemented and clarified

In the opinion of the Swedish National Council for Nuclear Waste, the application does not satisfy reasonable requirements on clarity. The application has grown unnecessarily voluminous in a way that does not facilitate an understanding of the material presented. The material in the application is not transparent with respect to structure, readability and accessibility. The same issues and phenomena are mentioned in numerous different places in the application and under different headings.

Important information concerning the choice of alternatives or the safety of the facility have the character of general information on how the facility is envisaged to work. For more detailed information, the reader is referred to underlying documents in the safety analysis report. This information can be hard to find in the large body of material. Certain supplementary information necessary for an understanding of the facility's safety and radiation protecttion is lacking entirely in the application under the Environmental Code. The information is only found in the application under the Nuclear Activities Act. Accordingly, this information will not be available for consideration by the Land and Environment Court.

[10] See Gov. Bill 1997/98:45 Part 2 p. 235.
[11] See the Superior Environmental Court's judgement MÖD 2006:70 (M 3363-06).

These deficiencies in the application undermine the role of the application as a basis for making a decision under the Environmental Code.

All supporting material and all information referred to in the application under the Environmental Code should also be available in the application under the Environmental Code. The application under the Environmental Code should therefore be supplemented with all information regarding safety and radiation protection that is included in the application under the Nuclear Activities Act so that the review under the Environmental Code can address all questions regarding safety and radiation protection in a meaningful way. In the opinion of the Swedish National Council for Nuclear Waste, it is not satisfactory that the Land and Environment Court should have less adequate material than the Swedish Radiation Safety Authority when it comes to determining whether the final disposal facilities satisfy the requirements on safety and radiation protection based on the rules of consideration in Chap. 2 of the Environmental Code.

In the opinion of the Swedish National Council for Nuclear Waste, SKB should also improve the searchability of the application, with clear references to background reports. All references in the top document should be made directly accessible via a link system. This would substantially facilitate a fair and thorough review of the application and its appendices.

The application's top document plays an important role in this context. It may be the main document which the members of the municipal council will consult. The top document should therefore give a clearer picture of the responsibility of different actors in the process, which would be valuable when judging the application. This applies, for example, to the municipality's role in the process, the municipal veto and the veto valve. A description of the planned timetable for treatment of the application and the uncertainties and risks of delays inherent in the decision process, plus an analysis of the consequences of these uncertainties and risks, would make the material more complete.

2.3 State of the engineered barriers in the final repository

The long-term status of the engineered barriers (copper canister, bentonite buffer and backfill), and the continued functionality of the backfill, are important prerequisites in order for the final repository for high-level spent nuclear fuel to satisfy the requirements on long-term safety. The future course of events is dealt with in the safety assessment, which is the instrument SKB uses to describe possible scenarios for the evolution of the final repository and calculate the probabilities of different outcomes.

The starting point for the calculations in the safety assessment is the initial state, which is the situation immediately after deposition of fuel, canisters, buffer and backfill and subsequent closure of the repository.

There are a number of specified requirements on the engineered barriers that comprise premises in the safety assessment, but which are clearly not fulfilled at closure. These include the environment around the copper canister, which is in turn dependent on processes of water saturation of buffer and backfill, mineral alteration in the bentonite due to drying-out and uneven water supply, the kinetics of oxygen consumption in the buffer, etc.

The most important processes, from the initial state until the requirements on which the safety assessment is based are satisfied, have previously been described in Swedish National Council for Nuclear Waste's report *Nuclear Waste State-of-the-Art Report 2012 – long-term safety, accidents and global survey* (SOU 2012:7) in Chapter 3 "From initial state to target state in the final repository for spent nuclear fuel" and do not have to be repeated in detail.

In the Council's opinion, an analysis is lacking of the consequences if some of these requirements are not met for a very long time or ever. The transition to the target state that is expected to prevail for the rest of the pre-closure period is assumed to occur via a number of natural processes that can take a very long time, perhaps thousands of years. Since conditions in different parts of the repository vary, achievement of the target state will therefore exhibit great time variation. This means, for example, that the bentonite buffer will become water-saturated at different times in different deposition holes, and that the backfill in the deposition tunnels will not achieve its optimal function for a very long time and with great variation depending on where the tunnels are situated in relation to the presumed water inflow.

SKB's application should therefore be supplemented with a more thorough account of how the transition from the initial state to the target state will take place, in view of the uneven distribution of groundwater inflow from the rock and the buffer's water saturation, the temperature gradient in the deposition holes, the copper canister's original surface coating of oxides, oxygen consumption in the bentonite buffer, the buffer's mineral composition and impurities, the influence of different types of bacteria and the composition of the groundwater.

Water saturation of the buffer is thus a key process for preserving the canister's safety functions. By supplying pure and temperate water without corrosive substances, an impervious barrier against groundwater penetration can be created much faster and more effectively than in SKB's concept, and at roughly the same time in all deposition holes. This artificial watering should be followed by means of a specially designed monitoring programme where the process can be observed in detail.

There may be practical difficulties associated with early water saturation of the buffer. The swelling buffer must be handled by creating a sufficiently high counter-pressure in the deposition holes in order to preserve a high density. There are moreover knowledge gaps concerning what happens with a water-saturated buffer that is subsequently subjected to prolonged drying-out. It should, however, be an advantage that drying-out does not lead to the formation of salt deposits on the copper canister that could accelerate corrosion. SKB should therefore supplement its application by investigating and describing the long-term consequences of artificial water saturation of the buffer.

Copper canister

The copper canister is the most important barrier in the KBS-3 concept, since it contains the spent nuclear fuel and prevents radionuclides from escaping. There are three different causes of canister rupture and failure: corrosion, high isostatic pressure and shear movements in the surrounding rock. The canister's mechanical properties are greatly affected in the long run by creep (slow deformation of the copper metal under stress). It is the Council's considered opinion that SKB's application should be supplemented by an account of the current state of knowledge regarding creep in copper, especially in the weld metal, and how this process affects damage tolerance. SKB should also develop a validated creep model that shows how the integrity of the copper shell can be sustained under different loads.

Copper corrosion in oxygen-free water causes hydrogen evolution. In the final repository, high pressures are eventually expected to be exerted on the copper canister when the buffer becomes water-saturated. High pressures affect the formation and transport of hydrogen as well as hydrogen uptake in copper, which alters the material structure and degrades the mechanical properties of the canister. SKB's continued research programme on copper corrosion should therefore include the role of hydrogen in different corrosion mechanisms and how absorption of hydrogen in copper shell causes creep and changes in material structure.

The cast iron canister insert meets high demands on strength and damage tolerance under isostatic loading. However, if shear occurs along fractures in the rock, relatively small defects in the insert could initiate cracking of the cast iron, which imposes high demands on fabrication and non-destructive testing. Technical specifications on the ductility (ultimate elongation and fracture toughness) of the insert material should therefore be developed, along with requirements on the microstructure of the insert material. The methods for quality control of the cast iron insert and copper shell are described as preliminary, and their reliability has been judged by studies of man-made defects but should be extended to include natural defects as well.

Buffer and backfill

The material in buffer and backfill consists of bentonite clay that has been compacted to blocks and pellets under high pressure. In order to ensure optimal properties of the barriers (the target state), the bentonite must be water-saturated, which may take a very long time. In the deposition holes, the canister will generate heat for hundreds of years, which affects the environment around the canister and gives rise to undesirable drying-out and alterations in the bentonite's mineral structure. Prolonged drying-out of the bentonite blocks in the buffer and backfill could degrade their strength, so that blocks that are subjected to high loads become unstable and collapse. At worst, the result could be that the canisters no longer stand completely vertically in the deposition holes and new transport pathways for water are created in the backfill. The risk of erosion also increases.

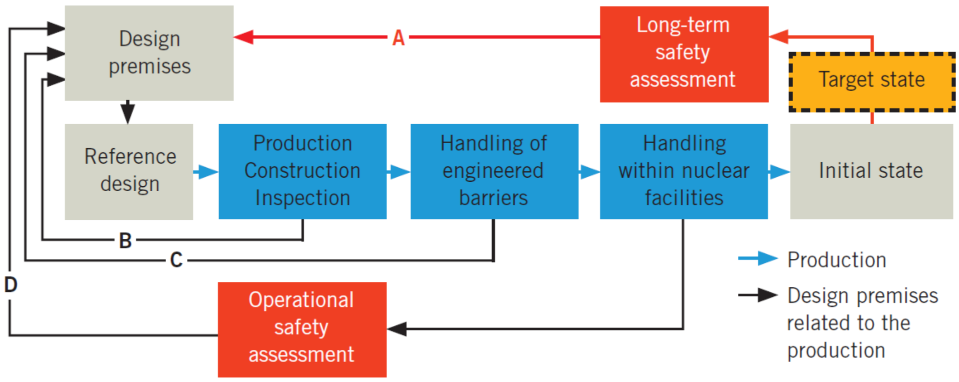
The bentonite in the backfill has a lower content of swelling mineral (montmorillonite), and prolonged drying-out could degrade the vibration tolerance of the blocks when blasting is done in adjacent tunnels. An extra grinding to activate the surfaces of the clay minerals prior to compaction could improve the stability of the bentonite blocks, and the pellet fraction could be substantially reduced by shaping the contour of the blocks next to the roof and walls of the deposition tunnels for an optimal fit. This would also reduce the risk of bentonite erosion.

2.4 Interaction between construction and safety assessment

The preceding section about the engineered barriers shows that important requirements from the safety assessment are not met in the initial state, and not until long after closure. This lack of agreement between safety assessment and initial state is manifested again in the standards and procedures which SKB intends to use to guide the interaction between construction and safety assessment. This means that if it is found that the safety assessment correctly shows that a repository in Forsmark could provide long-term safety, the next question must be considered: How is it possible to build and operate a facility over a period of more than half a century so that we can be sure that it will satisfy all the safety assessment's requirements after closure?

Interaction between construction and safety assessment is the key to long-term safety in the final repository. A lack of clarity in this interaction creates considerable uncertainty regarding SKB's ability to realize such a final repository. It is the Council's considered opinion that the present design of this interaction cannot guarantee that construction will lead to reasonable long-term safety in the final repository and that the application must therefore be supplemented by a) a system analysis that demonstrates forms of interaction where the construction process guarantees that all the requirements of the safety assessment are met, and b) a proposal for a measurement programme for monitoring conditions in backfilled or closed parts of the repository.

Figure 2 **Reproduction of Figure 3-1 in Appendix SR to the application. "Target state" (yellow box) has been added to the original figure in the application**



A. Design basis cases
B. Possibilities to control and inspect the design parameters
C. Occuring loads
D. Design basis events

The arrow marked "A" indicates how the results of the safety assessment ("Assessment of post-closure safety") are interpreted and translated to specific requirements on the different engineered barriers ("Design premises"). Taken together, these requirements constitute a building code for the final repository. Based on the design premises and conditions on the building site in Forsmark, the facility is designed ("Reference design"). The blue boxes refer to different aspects of the construction and operating processes. These processes result in the initial state, which according to SKB's definition in the application's top document consists of "Properties of the spent nuclear fuel and the engineered barriers when they are finally put in place in the final repository and are not handled further in the final repository". The circle is closed by a safety assessment of the initial state. The concept of "target state" was touched upon in the preceding section on engineered barriers, and Figure 2 shows its place in the interaction between construction and safety assessment. Events during the construction and operating phases may require changes in the building code (the arrows marked "B", "C", "D") , but most important for long-term safety are the measures in the loop Safety Assessment – Design Premises – Initial State.

Uncertainty regarding SKB's ability to realize a reasonably safe final repository arises when the schematic illustration in Figure 2 is to be applied due to the fact that the important requirements from the safety assessment cannot be met until long after repository closure. An analysis of the problems is provided in Chapter 2 of last year's Nuclear Waste State-of-the-Art Report (SOU 2012:7)[12]. Two aspects of this analysis that are relevant to the realization of the final repository are discussed here.

All design premises cannot be fulfilled in the initial state

A reasonable conclusion from Figure 2 is that all design premises should be fulfilled in the initial state, and that it should be possible to verify this. The initial state is what is produced by the construction process, and in an industrial project it is expected that the product will fulfil the design requirements before it is turned over to the market, or in this case to eternity. This turns out to be a hasty conclusion in the case of the final repository, however.

The review in the 2012 state-of-the-art report shows that at least two important design premises, one for the buffer and one for deposition holes, relate to the target state and are thus in principle impossible to verify before repository closure. Thus, the initial state does not reflect the design premises, but should instead, according to the application, be verified against the reference design. This means that the design premises have to be reinterpreted and adapted to be included in the reference design, which defines verifiable requirements on the initial state. The application does not offer any procedures for such reinterpretations, but instead refers to "judgements". The question is how the safety assessment should treat the initial state – can the assessment assume that all design premises are fulfilled, or is this only true of the measurable design premises? The need for reinterpretations based on judgements thus creates great uncertainty regarding the status of the design premises in the construction process and has consequences for the definition and use of the concept "initial state".

[12] Swedish National Council for Nuclear Waste (2012). *Nuclear Waste State-of-the-Art Report 2012 – long-term safety, accidents and global survey.* SOU 2012:7.

Initial state not clearly defined

The initial state plays a central role in the interaction between construction and safety assessment, since this is where the fulfilment of the safety assessment's requirements can be directly verified by measurements. In an ordinary industrial project, two verifications are made between promised and actual, physical performance: the first in the form of the industry's verification against its own design, and the second in the form of the market's judgement of the product, which in this case is the initial state. But there is no market verification in the final repository project. It has been replaced by a verification via the safety assessment, which is largely performed by the industry itself. Verification of the initial state is thus the only opportunity for society to physically verify that SKB lives up to its promises. It is therefore extremely important that the initial state be clearly defined, and that its properties can be measured and verified against all design premises.

The preceding discussion shows that great uncertainty prevails concerning the relationship between design premises and initial state, and a perusal of the application also shows that the initial state is unclearly defined. The application's top document has another definition of initial state than the one used in the important appendix about the safety assessment. This appendix also notes that "There is no obvious definition of the time of the initial state".[13] According to the application, the initial state will exist over a period of several decades, since SKB intends to backfill and plug deposition tunnels as the deposition holes are filled with canisters and buffer. Since the design premises may be changed during the construction period, this means that different parts of the initial state will be related to different design premises. SKB has no measurement programme to follow e.g. water saturation of the buffer in plugged tunnels. Such a measurement programme would make it possible to define the initial state at a unique time for the whole repository and thereby eliminate many of the questions surrounding the concept of initial state.

[13] Appendix SR-Site, page 143 (English edition).

3 Overview of referral bodies' viewpoints on the need for supplementary information in SKB's application

This chapter provides an overview and identifies the aspects that have been commented on by the referral bodies in their statements of opinion (referral responses) to the Swedish Radiation Safety Authority and the Land and Environment Court at Nacka District Court. The compilation does not necessarily reflect the Swedish National Council for Nuclear Waste's view of the identified areas and is not complete, but merely a brief summary of selected issues that recur in the referral bodies' reponses.

For more specific viewpoints, the reader is referred to the referral bodies' responses, which are posted on the websites of the Swedish Radiation Safety Authority and the Land and Environment Court at Nacka District Court.

3.1 Background

On 16 march 2011, the Swedish Nuclear Fuel and Waste Management Co (SKB) submitted its application for a licence to build a final repository for spent nuclear fuel in Forsmark in Östhammar Municipality to the Swedish Radiation Safety Authority (SSM) and the Land and Environment Court at Nacka District Court. At the same time, SKB submitted supplementary material to its application from 2006 for a licence to erect an encapsulation plant adjacent to Clab, the central interim storage facility for spent nuclear fuel in Oskarshamn. SKB calls these integrated facilities Clink.

As a regulatory authority, SSM bears responsibility for ensuring that the requirements of the Act (1984:3) on Nuclear Activities (Nuclear Activities Act) and the Radiation Protection Act (1998:220) are satisfied, along with the provisions of SSM's regulations and ordinances. The final objective of SSM's review of the application is to determine whether the final repository system proposed by SKB satisfies relevant radiation safety requirements and to prepare a statement of opinion recommending a decision and possible licence conditions to the Government, along with comments to the Land and Environment Court. To permit review under the Nuclear Activities Act, the authority has demanded supplementary information from SKB.[1] SSM's demand for supplementary information from SKB to facilitate the authority's review under the Nuclear Activities Act is not dealt with further in this compilation, and SSM's viewpoints to the Land and Environment Court are described briefly.

The Land and Environment Court is supposed to consider all emissions/releases and disturbances the applied-for activity can give rise to according to the Environmental Code (1998:808) and stipulate the conditions that are needed. It may be a question of conditions for the construction of the final repository and the operation and monitoring of the repository. The conditions may, for example, concern measures to limit noise, vibrations, emissions to water and air, haulage and disposal of rock spoil and transportation of the spent nuclear fuel to the final repository, but also measures for physical protection of the facility and other measures with a bearing on safety.[2]

As a part of the licensing process, SSM and the Land and Environment Court have sent the applications for consideration and commentary to public authorities, decision-makers and organizations to obtain their opinion on whether the applications are complete. Most of the referral bodies have been following the final repository project for some time. Some have participated in SKB's consultations under the Environmental Code, and many have also

[1] Dnr SSM2011-2426-16, Dnr SSM2011-2426-57, Dnr SSM2011-2426-58, Dnr SSM2011-2426-59, Dnr SSM2011-2426-60, Dnr SSM2011-2426-63Dnr SSM2011-2426-68.
[2] Licensing under the Environmental Code is also subject to the Nuclear Activities Act and the Radiation Protection Act.

been consulted as referral bodies in connection with the review of SKB's RD&D programme[3]. Other actors are new in the process.

According to SSM's website, 26 referral bodies submitted responses to SSM regarding the need for supplements to the final repository application and 20 referral bodies submitted replies to SSM regarding supplements to the Clink-application.

According to the Land and Environment Court at Nacka District Court, statements of opinion were received from 20 referral bodies, 8 of whom only submitted comments to the Land and Environment Court.

Referral responses received by SSM and the Land and Environment Court consisted of commentaries from regulatory authorities (14)[4], county administrative boards and municipalities (6)[5], universities (6)[6], non governmental organizations (NGOs) (8)[7] and one private individual[8]. The referral bodies' viewpoints will be presented in the above order.

3.1.1 OECD/NEA's International Peer Review

As a support in the review of SKB's application for a licence to construct a final repository for spent nuclear fuel, the Swedish Government engaged the OECD/NEA[9] to conduct an independent peer review of the application. The purpose of the review was

[3] The RD&D programme is an account of SKB's research, development and demonstration of methods for management of nuclear waste.
[4] National Board of Housing, Building and Planning, Swedish Energy Agency, Swedish Agency for Marine and Water Management (HaV), Swedish National Council for Nuclear Waste, Swedish Environmental Protection Agency, National Heritage Board, National Archives, Swedish Maritime Administration, Swedish Geotechnical Institute (SGI), Swedish Radiation Safety Authority, Geological Survey of Sweden (SGU), Swedish Board for Accreditation and Conformity Assessment (Swedac) and Transport Administration.
[5] County Administrative Board in Kalmar County, County Administrative Board in Uppsala County, Oskarshamn Municipality, Oskarshamn Municipality's local planning committee, Östhammar Municipality and Östhammar Municipality's local planning committee.
[6] Chalmers University of Technology (CTH), Karlstad University, Karolinska Institute, Royal Institute of Technology (KTH), Lund University, Uppsala University.
[7] European Committee on Radiation Risk (ECCR), Environmentalists for Nuclear Power (MFK), Swedish Environmental Movement's Nuclear Waste Secretariat (Milkas), Swedish Society for Nature Conservation in Kalmar County, Swedish Society for Nature Conservation and Swedish NGO Office for Nuclear Waste Review (MKG), Opinion Group for Safe Final Disposal (Oss), Swedish Renewable Energies Association (SERO).
[8] Torbjörn Åkermark.
[9] The Nuclear Energy Agency (NEA) is an independent agency in the area of nuclear energy within the OECD (Organisation for Economic Co-operation and Development), based in Paris, France.

to provide a complementary view of radiological safety in the final repository. Following is a brief summary of the International Review Team's (IRT) conclusions.

The IRT arrived at the conclusion that SKB's safety assessment, SR-Site, is, from an international perspective, sufficient and credible for the first step in the licensing process. But the IRT also notes that improvements are necessary in several areas for the purpose of enhancing confidence in the results of the safety assessment. The areas dealt with in the report are: Geosphere, Buffer and Backfill, Copper Canister, Fuel and Cladding, Biosphere, Practical Implementation, Performance Assessment, Performance Confirmation and Societal Aspects.

The IRT notes that the deterministically modelled deformation zones (those that extend over more than 1,000 m) are subject to uncertainties. The IRT therefore considers that further studies should be conducted to improve knowledge of the deformation zones with a trace length up to 3,000 m.

The IRT points out that the most important geochemical parameters of the host rock groundwater from a safety viewpoint are salinity, sulphide concentration and O_2 content. Sulphide can cause corrosion of the copper containers. Copper corrosion due to O_2 in the groundwater could have an even greater effect on the containers, especially in deposition holes affected by bentonite erosion if oxygenated water is able to reach the deposition holes.

The IRT recommends more detailed studies and that a monitoring programme be installed to keep track of hydromechanical conditions that can arise in the final repository. Regarding the copper canister, the IRT notes that the discussion of copper corrosion due to hydrogen evolution is important and must be resolved.

Regarding buffer and backfill, the IRT considers that they fulfil the intended safety function in a relevant and complete manner, but that SKB does not have a complete understanding of the buffer erosion processes. The IRT therefore recommends continued studies of: the effect of Ca and mixed Ca/Na systems on swelling and colloid formation; erosion in fractures or slots; self-healing effects by the clogging of fractures/slots by accessory minerals; and effects of flow and water velocity on erosion.

The IRT also made observations on the handling of requirements regarding BAT (best available technology), made recommendations regarding competence assurance, pre- and post-closure information preservation, and stakeholder involvement in the continued process.

3.2 Accessibility of material

The application material is very extensive and based on a system of main reports, appendices and references to research reports. Several referral bodies note that the application documents are difficult to overview and that they have therefore not been able to familiarize themselves with all the material for reasons of time and cost.

The Swedish National Council for Nuclear Waste writes in its statement that SKB should improve the searchability of the application material, particularly from the top document to appendices and with clearer references to background reports.

The National Archives is one of the referral bodies that points out that the contents have been difficult to read and comprehend. The authority says that a database with search function and better indexation would greatly improve searchability.

Östhammar Municipality notes that SKB has to deliver clear and comprehensible material to facilitate the process. Furthermore, the municipality considers it extremely important that SSM should also have a high level of ambition when it comes to the accessibility of the material on which the authority's judgements have been based.

3.3 Decision processes, responsibility and ownership

The need for a clearer description of the licensing process has been emphasized by several referral bodies. The question of responsibility during the different phases of the project and opportunities for participation have been discussed.

The Swedish National Council for Nuclear Waste points out that the application needs to be supplemented with a clearer description of responsibility for the final repository, in particular post-closure responsibility. The legal situation for the applicant, the licensee and the state should also be clarified in the application.

In its comments, Östhammar Municipality also makes note of the special role of the municipality in the continued process. The municipality demands to be allowed insight and an active role in the process, including as a reviewing body, even after (if) the

Government has granted permissibility. The municipality believes that ownership must be clarified. It should be made clear who bears responsibility for the final repository at every given point in time. It's important if anything serious happens that requires a response.

The difference in content in the material submitted to SSM and the Land and Environment Court has been noted by the Swedish National Council for Nuclear Waste, the Swedish Society for Nature Conservation and the Swedish NGO Office for Nuclear Waste Review (MKG), as well as the Opinion Group for Safe Final Disposal (Oss). All the material presented in the licensing process under the Nuclear Activities Act is not included in the material for consideration by the Land and Environment Court. The material for consideration under the Environmental Code is not considered to be complete with regard to safety assessments and underlying materials. The referral bodies demand that all the material submitted for licensing review under the Nuclear Activities Act should also be included in the material for licensing review under the Environmental Code.

The Swedish Society for Nature Conservation in Kalmar is of the opinion that the entire final repository concept should be examined in one licensing process. They are also of the opinion that activities such as transport between Clink in Simpevarp and the final repository in Forsmark should be examined at the same time as the facilities.

3.4 Scientific quality

The question of scientific review of the material presented in the applications has been brought up by several of the referral bodies.

The statement of opinion from the Swedish Board for Accreditation and Conformity Assessment (Swedac) notes that SKB's laboratory is only accredited for sampling of environmental water. Swedac says that Appendix VP to the application gives the impression that the laboratory's accreditation is much more comprehensive in terms of the analyses and tests that may need to be done to assure quality and safety.

In their statements of opinion, Lund University, the Swedish Society for Nature Conservation and MKG claim that the applicant has committed too soon to a main alternative and devoted too little time and effort to studying alternative repository solutions.

In its statement of opinion, the European Committee on Radiation Risk (ECRR) writes that SKB has based its risk calculations on the ICRP's (International Commission for Radiation Protection) risk model. The organization considers that SKB should calculate radiological risks using the ECRR's risk model as well.

The Swedish Society for Nature Conservation and MKG note that the applicant has failed to make large parts of the scientific material publicly available, making it impossible to verify the scientific quality of the applicant's work. Similarly, Oss says that all relevant scientific studies should be finished, analyzed, reported and incorporated in the application material before the application is considered.

3.5 The engineered barriers: canister, buffer, backfill

The safety analysis reports SR-Drift and SR-Site are central parts of the application, intended to show that the final repository meets the requirements on radiation safety.

The role of the engineered barriers in meeting the requirements of the safety assessment, in particular the strength of the copper canister and the role of bentonite as a buffer in the event of radioactive releases have been noted by the referral bodies.

Below is a summary of the referral bodies' viewpoints on buffer, backfill, copper canister and the interaction between these barriers.

3.5.1 Buffer and backfill

It is the Council's considered opinion that SKB's application should be supplemented with a more thorough account of how the transition of bentonite from its initial state to its target state will occur, in view of the uneven distribution of groundwater inflow from the rock and the buffer's water saturation. By "target state" is meant a hypothetical state between the initial state and the post-closure safety assessment. The target state is characterized by the fact that the requirements on the engineered barriers are satisfied with respect to long-term safety.[10]

It is the Council's considered opinion that SKB should investigate how the interaction between buffer, rock and canister – as well as between buffer and backfill – will function under conditions with a very uneven water supply. Other aspects which SKB should investigate are how the long-term strength of the bentonite blocks in the deposition holes will be affected by a diminishing water content due to drying-out, and how the chemical and physical properties of the bentonite will be affected by the high temperature in the deposition holes.

The Swedish Radiation Safety Authority believes that the long-term barrier function needs to be described with respect to buffer and backfill aspects. This applies in particular to the following aspects[11]:

- Supplementary information on the bevelled rim of the deposition holes, including a detailed description of the geometry of the bevel, its backfilling and its impact on final buffer density.
- Supplementary information on piping and erosion of buffer and backfill.
- Supplementary information on fabrication and installation of buffer rings and blocks. A detailed account of the need for supplementary information is given in Appendix 6 in the authority's demand for supplementary information from SKB.

The Swedish Geotechnical Institute (SGI) is of the opinion that the question of uncertainty resulting from the long time perspective has not been investigated sufficiently. SGI also requests supplementary information regarding the buffer. The questions concern buffer erosion as described in SR-Site due to calcium and low salinity, homogenization of the buffer material and whether bentonite is affected by heat from the nuclear fuel. SGI would like supplementary information on how much radiation the bentonite

[10] The concept was presented in the Swedish National Council for Nuclear Waste's Nuclear Waste State-of-the-Art Report SOU 2012:7.
[11] Appendix 4 to SSM's "Yttrande över Svensk Kärnbränslehantering AB:s ansökan enligt miljöbalken", "Kompletteringsbehov inom granskningsområde *slutförvarsanläggningen*". A detailed account of the need for supplementary information is given in Appendix 6 to the authority's statement to SKB regarding the need for supplementary information.

can absorb, and whether a chemical reaction can occur between bentonite and iron-bearing water from corroding bolts.

Another question raised by SGI concerns copper supplies. SKB should investigate whether copper supplies can be secured and how an increase in the price of copper could affect the final repository, and whether it is possible to eliminate the use of copper.

Östhammar Municipality also takes up the problem that the so-called "target state" must be achieved in order for the repository's engineered barriers to work as expected during the long-term evolution of the repository. According to the municipality, the target state in the long-term evolution of the repository is characterized by the fact that the density of the water-saturated buffer lies in the range 1,950–2,050 (kg)/m^2 and that all oxygen has been consumed. The municipality believes that SSM should assess the consequences of the uneven evolution of the repository from initial state to target state for different canister positions. This can affect corrosion of the copper canister, risks of cementation of buffer and erosion of buffer and backfill. The municipality also points out that safety and buffer performance, no matter how long time it takes for the backfill to be saturated with water, are adversely affected by the assumed long timeframe for backfilling.

The so-called "target state" required for the bentonite buffer to function as a barrier in the final repository is also discussed by the Swedish Society for Nature Conservation and MKG in their joint statement. The organizations note that knowledge is lacking of how the clay will behave in the Forsmark rock, especially during the first 1,000 years. The bodies also find that experimental results are lacking from both laboratory experiments in a repository-like environment and from the actual rock in Forsmark. They say that an adequate description must show how the clay swells given an uneven supply of water in time and space. The description should also show how the clay is affected by heat, radiation, the copper canisters and the copper that is liberated during copper corrosion. The organizations demand that the applicant present supporting material showing that the bentonite buffer in the rock in Forsmark will achieve the target state.

Milkas comments that the properties and behaviour of the bentonite as a buffer have not been fully studied. Oss also calls for a presentation of supporting material that shows convincingly what conditions must be fulfilled in order for the long-term functions of the clay buffer to be optimized. Oss demands that the application be supplemented with a definition of the target state, and adequate supporting material verifying that this state can be achieved on the site in question.

3.5.2 The copper canister

Several referral bodies (the Swedish National Council for Nuclear Waste, SGI, SSM, Östhammar Municipality, KTH, Lund University, Uppsala University, ECRR, the Swedish Society for Nature Conservation and MKG, and Torbjörn Åkermark) point out the need for clarification of the strength of the copper canister and presentation of studies of embrittlement of the copper canister.

Possible corrosion of the copper canister in oxygen-free water and stress corrosion cracking are problems that have previously been brought up by regulatory authorities, independent researchers and interest organizations.[12]

It is the Council's considered opinion that the application should be supplemented by an account of the canister's safety functions that covers the consequences of creep (transport of copper atoms in the shell) and corrosion of welded joints. Formation and transport of hydrogen from copper corrosion in an oxygen-free environment under high external pressure in the final repository should be investigated. A description of the cast iron insert's damage tolerance and the reliability of nondestructive testing for detecting small defects should be included. It is the Council's considered opinion that SKB should supplement its application with a comparison of corrosion tests in a laboratory environment and tests under repository-like conditions.

SSM writes in its statement that the authority has already requested supplementary information on the ability of the canister to contain the fuel.[13] The supplementary information is considered

[12] The problem of copper corrosion in pure oxygen-free water was the subject of an international seminar arranged by the Swedish National Council for Nuclear Waste (together with SSM and SKB) in November 2009. A joint conclusion was that more research is needed, and since then SSM has funded a number of new projects in the area at KTH and Studsvik Nuclear AB and also engaged an international expert (professor Digby Macdonald) to perform thermodynamic calculations. SKB has also initiated and funded new projects at KTH as well as an ongoing project at Uppsala University.

[13] A detailed account of the need for supplementary information is given in Appendix 7 of the Swedish Radiation Safety Authority's statement to SKB: Strålsäkerhetsmyndigheten, Begäran om komplettering av ansökan om slutförvaring av använt kärnbränsle och kärnavfall- SR drift kapsel. 2012-09-17. SSM 2011-2426-65.

important for assessing the risk of canister failure according to the corrosion scenario as well as canister failure according to the load scenario for isostatic pressure. SSM also believes there is a need for supplementary information and calls for further research into the long-term degradation of the copper canister. Information is needed regarding the factors and processes that lead to canister failure, and the consequences of canister failure must be described.

In the subarea *canister matters* in SSM's statement of opinion, the authority has identified the need for the following supplementary information:

- Presentation of limit values or acceptance criteria for the integrity of the barriers or for mechanical stresses in the barriers.
- Supplementary information regarding safety classification of barriers and systems as well as a quality assurance process.
- Supplementary information regarding quality assurance measures planned in conjunction with transloading, transport and deposition of canisters.

Östhammar Municipality would like a supplementary account of the processes that cause canister corrosion and would like SKB to supplement the application with a description of how the bentonite is affected by different copper corrosion products. The municipality believes that the application must be supplemented with an overview of all the corrosion process that could take place in in repository, such as sulphide corrosion, corrosion in water that is free of dissolved oxygen, radiation-induced corrosion and microbial corrosion.

KTH does not believe that SKB has given sufficient consideration to a number of copper corrosion processes. KTH points out that parts of SR-Site need to be updated, since new scientific studies have been published in this area. For example, results are available from new experimental studies concerned with radiation-induced corrosion. Effects of radiation on atmospheric corrosion during the handling of the canister should also be commented on. In its commentary, KTH identifies three important corrosion processes that SKB should take into consideration and study further:

1. Corrosion problems in the gas phase should be taken into account and studied, including experimentally.

2. The problem of salt enrichment and associated corrosion problems must be examined by full-scale tests (regarding salt enrichment) and laboratory experiments (regarding corrosion).
3. The risk of copper corrosion in the planned repository caused by stray currents from power cables[14] should be evaluated by experiments.

Uppsala University comments that the risk of corrosion of the copper canisters must be investigated further and over a longer period of time. The university points out that the different corrosion risks are described separately, whereas it is most likely that different types of corrosion will occur simultaneously. According to the university, the scientific evidence in support of copper corrosion by sulphide ions appears to be much less convincing that that supporting corrosion by oxygen. In its statement of opinion, the university emphasizes the importance of taking a joint approach to the various types of copper corrosion, since it is likely that they will occur simultaneously and thereby interact. According to the university, this warrants further investigations to determine whether "combined" corrosion could lead to e.g. more rapid pitting.

The university also takes up the issue of how other parameters affect copper corrosion and identifies the need for further study of stress corrosion cracking and stray current corrosion, which can occur due to mechanical loads on the canister and via electrical fields, and notes that extensive corrosion of the nodular iron will most likely affect the copper canister and should be further investigated.

The Swedish Society for Nature Conservation and MKG give thorough treatment to the question of the engineered barriers, and much of their statement deals with the strength of the canister. In an appendix to their statement, the organizations identify a number of areas where results are lacking from critical experiments under relevant conditions.[15]

The organizations demand that the applicant present evidence based on corrosion experiments in an oxygen-free repository environ-

[14] The envisaged final repository in Forsmark is situated near the power transmission cables between Sweden and Finland, Fenno-Scan 1 and 2.
[15] Appendix 2 to the Swedish Society for Nature Conservation's and MKG's statement of opinion. Underlag för kompletteringskrav rörande barriärproblematik. Synpunkter på SKB:s ansökan för slutförvar av kärnkraftsavfall och tillhörande säkerhetsanalys SR-Site. Dr. Olle Grinder, PM Technology AB May 2012.

ment. According to the organizations, the following aspects should be studied further and supplementary information be provided in the application: corrosion of copper caused by hygroscopic salt precipitation on the copper surfaces, elevated salinity in the deposition holes, dissolution of copper in the groundwater and precipitation in the bentonite, radiolysis and risk of corrosion due to stray currents.

According to the organizations, SKB has not dealt with either atmospheric corrosion during the period when the bentonite is not water-saturated or the interaction between different corrosion mechanisms. SKB has also devoted too little or no attention to the following embrittlement mechanisms for copper: sulphur embrittlement, creep ductility, hydrogen embrittlement and hydrogen sickness, and stress corrosion cracking.

In his statement, Torbjörn Åkermark takes up the risk of stress corrosion cracking. Åkermark also points out that radiolysis (caused by radiation from the spent fuel) has a much greater effect than SKB has assumed in its application.

3.5.3 Interaction between the engineered barriers and the multi-barrier principle

According to several referral bodies (the Swedish National Council for Nuclear Waste, Karlstad University, Milkas, the Swedish Society for Nature Conservation and MKG, and Torbjörn Åkermark), the potential interaction between the bentonite and the strength of the copper canister is not adequately described in the application. Furthermore, it is not clear how the individual barriers influence each other and that there may be more interacting corrosion processes (embrittlement mechanisms) than assumed by the applicant in their safety assessment.

Chalmers University of Technology points out the lack of a reference to the original philosophy behind "the multi-barrier principle," i.e. the final repository concept formulated in the AKA Committee report in 1976. A discussion is needed of what it entails and how the systems perspective is handled in the safety assessment.

3.6 Financing of spent nuclear fuel management

One question that has been brought up by several referral bodies has to do with the activity operator's financial responsibility for safe management of the spent fuel. According to the Nuclear Activities Act, the holder of a licence for nuclear activities is responsible for taking all necessary measures for the management and final disposal of all nuclear waste arising in the activities.

It is the Council's considered opinion that this question is important in order to guarantee safe disposal during the long time perspective of the project and should be investigated in the application.

The Swedish Environmental Protection Agency is of the opinion that it must be clarified in the application whether guarantees are needed for other costs than those covered by the financing system. Guarantees must also be provided for measures warranted for environmental reasons and not just for safety reasons.

This question has also been brought up by the Swedish Society for Nature Conservation and MKG.

3.7 Intrusion and physical protection

It is the Council's considered opinion that the application should describe physical protection and risks as a consequence of intentional human actions.

SSM also considers that the description of physical protection should be supplemented in the application for both the final repository and Clink.

The Swedish Society for Nature Conservation and MKG think that the application should be supplemented with scenarios for intentional post-closure human intrusion and that the applicant should describe what barriers can be devised to prevent such intentional intrusion as far as possible.

Oss says that the risk of intentional intrusion is one of the basic problems with the selected method and must be further elucidated.

3.8 Preservation of knowledge

The Swedish National Council for Nuclear Waste observed in its statement that it is not clear how SKB intends to preserve and administer information about the final repository.

In its statement, the National Archives criticizes the account of knowledge preservation and finds that SKB has failed to explain how they intend to comply with Section 6, paragraph 1 of the Radiation Protection Act (1998:220) regarding preservation of information for the future. The authority finds the account to be insufficient and says that SKB should already have started planning how this information is to be managed and subsequently updated and revised continuously. The authority points out that such documentation efforts should not be postponed until the actual closure of the final repository. The Clink application also lacks an account of how information is to be preserved.

Östhammar Municipality demands a clearer treatment of information preservation and that SKB return at given intervals during the entire operating period and prior to closure with an external environment and future analysis focused on information presservation and monitoring.

3.9 Choice of method

The different methods for managing the spent fuel are described in SKB's application in the appendix "Choice of Method" (CM).

Reuse

It is the Council's considered opinion that SKB should give greater attention to the consequences for the nuclear fuel programme of the possible development and operation of new types of nuclear power reactors. One question that can be asked is what it means for a planned final repository that reactors in the future might use as fuel what is currently regarded as waste.

Uppsala University is of the opinion that potential reuse of the high-level waste in future Generation IV reactors must be regarded as an alternative to the present final repository concept. It is believed that these reactors will in the near future be able to extract more energy from the spent fuel while also greatly reducing the time it takes for the residual products to decay to a harmless level – from 100,000 years to 1,000 years.

Uppsala University also points out, like the Swedish National Council for Nuclear Waste, that in light of the Environmental Code's requirement regarding conservation of raw materials and energy and recycling where possible, SKB should explain more clearly the option of reusing the fuel in the fourth generation of reactors (Generation IV). The University considers the application to be deficient in this respect, and says that the alternative cannot be judged from the perspective of either the Environmental Code's requirement on resource utilization or safety requirements.

Deep Boreholes

Deep Boreholes is a disposal method entailing that the spent nuclear fuel is deposited at a depth of 3–5 kilometres in the bedrock. In the EIS and in Appendix MV (CM) to the final repository application, SKB compared deposition in a KBS-3 repository with disposal in deep boreholes.

Lund University finds that this comparison is based on obsolete analyses of Deep Boreholes. The Swedish National Council for Nuclear Waste, SSM, Karlstad University, Lund University, Milkas, the Swedish Society for Nature Conservation and MKG, and Oss also point out that evaluations and comparisons must be based on the latest developments in technology and knowledge. The method must therefore be further investigated.

SSM, Karlstad University and the Swedish Society for Nature Conservation and MKG would like to see an in-depth discussion and evaluation of barriers for both Deep Boreholes and the KBS-3 method. This assessment should be focused on the interdependency between the barrier functions, as well as their robustness.

Dry Rock Deposit (DRD)

The Dry Rock Deposit (DRD) concept involves a dry repository located above the groundwater table. Milkas and SERO think the DRD method should be further investigated, since they believe it offers the possibility of inspecting and reusing the waste.

SKB rejects the DRD method in its application on the grounds that it does not meet the requirement of the Nuclear Activities Act on safety without monitoring, control and maintenance.[16] According to SKB, the waste will eventually become the responsibility of future generations. Milkas judges this criticism to be misdirected and says that the DRD method is not a kind of monitored storage.

Miscellaneous

The Swedish Society for Nature Conservation and MKG want SKB to describe the possibilities of final disposal of spent nuclear fuel in clay formations and perform an assessment of whether this is possible in the Sweden.

According to the Environmental Code, the best available technology (BAT) should be used to prevent, hinder or counteract damage or detriment to human health or the environment.[17] Milkas finds it impossible to single out any technology as best in SKB's application, since SKB has not evaluated other methods.

3.10 Site selection

Milkas, the Swedish Society for Nature Conservation and MKG, and Oss point out that predetermined criteria and requirements with respect to the rock and groundwater on the sought-after site did not exist before SKB began its feasibility studies. According to these organizations, the main focus has been on the artificial barriers, while the properties of the rock and the groundwater have been toned down.

Several statements demanding supplementary information – for example from the Swedish National Council for Nuclear Waste, SSM and Östhammar Municipality – would like the account in the EIS to be clarified so that it provides a better description of how the safety issues have been handled during the site selection process.

[16] Appendix P-10-25 MV (CM), p. 12.
[17] Chap. 2 Sec. 3 of the Environmental Code.

Forsmark as a final repository site

The Swedish Society for Nature Conservation and MKG emphasize the importance of selecting the most suitable site and question SKB's choice of Forsmark. Milkas does not think that the choice of Forsmark is based on considerations of long-term safety, but that the site was chosen because it was assumed that the local population would accept a final repository in the municipality.

Östhammar Municipality would like SKB to explain why the original selection pool of potential sites for site investigation only included sites close to nuclear facilities.

The suitability of locating the repository near a nuclear power plant is questioned by the Swedish National Council for Nuclear Waste, the Swedish Society for Nature Conservation and MKG, Oss and SERO. All call for an account of how a reactor accident with radioactive releases would affect the operation of a nearby final repository.

The environment and geology in Forsmark

The site for which SKB has applied for a licence to build a final repository has very high natural values, which will probably be affected. Oss therefore questions whether the site can be considered suitable and how the purpose can be achieved with minimal intrusion and detriment to human health and the environment.

The geology in the Forsmark area also raises some questions among the referral bodies. High rock stresses have been measured at repository depth. Oss questions the suitability of building a final repository under these conditions, with high stresses that could lead to spalling of the rock. The manner in which SKB has measured the rock stresses, as well as the quality of the measurement results, is questioned by the Swedish National Council for Nuclear Waste. SGI considers several claims concerning rock stresses to be without evidence. SKB also needs to explain how it is possible to reinforce the rock under the prevailing conditions.

It is also the Council's considered opinion that SKB should shed further light on the claim that there are no future exploitable mineral resources in the Forsmark area.

The Geological Survey of Sweden (SGU) recommends further investigations to explore "pockmarks" (i.e. craters in the seabed caused when gas or liquid erupts and streams through the sediments) in order to ascertain whether thermogenic gas is the cause of these craters.

SKB plans to build the final repository in a so-called tectonic lens. According to Milkas, this lens was created by movements in the bedrock, and they think SKB should investigate whether these movements could be reactivated following a glaciation. Milkas also thinks the durability of the lens should be investigated if a final repository is to be built in the lens. Milkas says that there is much more tectonic activity in the area than is evident from SKB's application documents.

The geohydrology of the area is also dealt with in several statements of opinion. SGU recommends a survey of glaciofluvial material and sedimentary rock to obtain a better understanding of the hydrogeological processes as well as future changes in e.g. surface geology, stratigraphy and thickness of different quaternary deposits in the area.

The fact that the rock in Forsmark is very dry at repository depth could mean that it will take a long time for the bentonite buffer to become saturated. The Swedish Society for Nature Conservation and MKG state that the possible consequences of incomplete or uneven saturation of the buffer should be investigated. The County Administrative Board in Uppsala County and the Swedish National Council for Nuclear Waste would like SKB to study the possible advantages of artificial water saturation of the bentonite buffer.

Taking climate change into consideration

SGI calls for a risk analysis and an account of preventive measures in the face of sea level rise during the construction and operating phases of the facility. The institute would like an account of how the planning premises will be continuously revised in view of the uncertainties that exist today regarding continuously rising sea levels during the coming centuries.

Laxemar as an alternative site

An environmental impact statement should include a report on alternative sites.[18] Laxemar is presented as an alternative to Forsmark in SKB's application. Both Laxemar and Forsmark are located on the coast, and the Swedish Society for Nature Conservation and MKG would like SKB to describe an inland alternative.

SKB chose to apply for a licence to build a final repository in Forsmark because the results of the site investigation showed that substantially more canisters may be damaged if a repository is built in Laxemar. On this basis, the Swedish Society for Nature Conservation in Kalmar and Oss question whether SKB's presentation of Laxemar as an alternative to Forsmark is appropriate. In their opinion, if a final repository in Laxemar cannot be built in a safe manner, then it cannot be regarded as an alternative site to Forsmark.

3.11 Clink

At the same time as SKB submitted its application for a licence to build a final repository for spent nuclear fuel in Forsmark in Östhammar Municipality, they also submitted an application to the Land and Environment Court and material to SSM to supplement the application from 2006 for a licence to construct an encapsulation plant adjacent to Clab, the central interim storage facility for spent nuclear fuel, In Oskarshamn. SKB calls these integrated facilities Clink.

In its statement of opinion to the Land and Environment Court, the Swedish National Council for Nuclear Waste has refrained from commenting on whether they consider the Clink application to be complete.

Quality of application for Clink

SSM makes the judgement that the material is not sufficiently complete and that there is a need for clarifications and supplementary information, as well as deficiencies in the traceability and

[18] Chap. 6, Sec. 7 of the Environmental Code.

clarity of the application.[19] SSM's overall comment on all the reviewed material is that it is often unclear whether the conclusions that are drawn are supported by any analyses and whether these analyses are documented. Moreover, references are lacking in the text.

Furthermore, SSM says that SKB in several cases makes reference to outdated documents, standards, rules, laws and regulations. The Swedish Defence Research Agency (FOI) notes that references concerning requirements and design premises are only made to ICRP 26 and 60 and not to the much more recent ICRP 103, and as a result there is no discussion at all concerning *dose constraints*.

Sea level rise

SGI requests a risk analysis and an account of possible preventive measures in conjunction with sea level rise during the construction and operating phases of Clink.

Cooling water

Oskarshamn Municipality notes the absence of a petition under the Environmental Code for use and management of cooling water for Clink. The cooling water is to be diverted via the nuclear power plant's cooling system. The municipality would also like to know how the matter will be handled after the nuclear power plant has been taken out of service.

[19] SSM has submitted a statement of opinion to the Land and Environment Court regarding SKB's Clink application. The statement is very detailed and describes many points where SKB should supplement the application. (Begäran om komplettering avseende uppförande och drift av inkapslingsanläggningen (Clink), Diarienr: SSM2011-1483). The Swedish National Council for Nuclear Waste's compilation consists of only a small selection of the many viewpoints offered by SSM. For the complete body of material, see SSM's statement of opinion.

Extinguishing water

Oskarshamn Municipality would like a description of the contents of the extinguishing water and how it will be disposed of in the event of a fire in Clink.

Seismic activity

Uppsala University points out that it is of great importance that seismic activity in the area be monitored continuously.

Accidents

Uppsala University finds that a description is needed of protection in the event of accidents, for example a dropped fuel assembly.

Site selection

SSM is of the opinion that the description of the facility site is not complete. They would like a systematic inventory of all the external factors and conditions that can affect safety. What is needed is a summary of, and references to, underlying studies and analyses that show how safety can be affected and how this has been taken into account in the design or execution of the facility, or in other ways.

The Swedish Society for Nature Conservation in Kalmar thinks that SKB should supplement its application with a description of an alternative solution where the encapsulation plant is not located adjacent to a nuclear power plant. This is by reason of the events in Fukushima, which clearly show the unsuitability of locating important facilities near nuclear power plants in the event a serious nuclear power accident should occur. MKG's demand for supplementary information is that the applicant make a study of the possible consequences of a major nuclear power accident at the Oskarshamn Nuclear Power Plant for the possibility of building and operating the encapsulation plant.

SSM notes that the application lacks a description of how potential events at local industrial plants, such as a nuclear power plant and a hydrogen plant, could affect safety at the encapsulation plant.

Blasting work

SSM assumes that SKB will, during the blasting work in connection with the construction of the encapsulation plant, adopt the necessary measures and controls to ensure that the existing Clab facility is not adversely affected. An account of these measures and controls should be given to the authority at a later stage, but before the start of construction.

Transportation

SSM notes the lack of a general description of how transport is envisaged to take place inside Clink, for example an area for terminal vehicles with peripheral equipment, handling of reverse transport from the final repository, etc.

3.12 Environmental impact statement (EIS)

The viewpoints contributed by the referral bodies regarding the need to supplement the environmental impact statement with additional information pertaining to both the structure of the document and the methodology, as well as the description of the different consequences of the activity.

Overall picture of the impact of the project on health and the environment

According to Chapter 6 of the Environmental Code, the purpose of the environmental impact statement is to "to enable an overall assessment to be made of this impact on human health and the environment." The Environmental Code contains requirements on what the EIS must contain. An acceptable EIS comprises a so-called "process prerequisite" for examination of a licence application by the land and environment court under the Environmental Code and is a prerequisite for the Government's examination under the Nuclear Activities Act.

The important role of the EIS in the examination under the Environmental Code is emphasized in the referral responses.

The Swedish National Council for Nuclear Waste and SSM are of the opinion that the EIS should be supplemented so that private citizens can easily obtain an overall picture of the project's impact on health and the environment. For example, the relationship between dose and risk of harmful effects should be quantified and the decline in the radiotoxicity of the waste with time should be described.

Methodology and scope

The Swedish Agency for Marine and Water Management (HaV) points out that sub-appendix P-10-32 "Metodik för miljökonsekvensbedömning" ("Methodology for environmental impact assessment") cites appropriate references, but that these references are not appended to the application. Instead they are described in general terms. HaV says that the absence of references and assessment criteria in the EIS makes it difficult to evaluate SKB's assessment.

The Swedish Environmental Protection Agency states that SKB should describe the limits of the applied-for activity in the actual application. It would facilitate the licensing process if SKB specified in greater detail in the application what facilities the final repository will consist of. The Swedish EPA says that it is difficult with the current material to determine whether the canister factory should be included in the licensing process. They believe that the application should be supplemented with information that makes it possible to determine whether the canister factory is connected with the other activities in such a way that it should be included in the application.

Structure

Certain viewpoints from the referral bodies (statements from Östhammar Municipality, the Swedish National Council for Nuclear Waste, the Swedish Society for Nature Conservation and MKG, and Oss) note that some of the information is found in SKB's own reports that are appended to the application. SKB refers to these reports in the application, e.g. the appendices on choice of method and site selection and the reports on water operations, which constitute appendices to the EIS.

The Swedish EPA says that referring to other reports makes it difficult for concerned persons and the general public to obtain an overall picture of the project's impact on health and the environment. It should be clarified whether SKB believes that sub-appendices to the EIS are a part of the assessment and whether SKB shares the conclusions drawn in the appendices.

The Swedish National Council for Nuclear Waste, the Swedish Society for Nature Conservation and MKG are of the opinion that documents such as SR-Site, the site selection appendix and the choice of method appendix should be linked to and appended to the environmental impact statement so that the connection between the environmental impact assessment, environmental safety and alternatives reports is clear.

Description of impact of possible nuclear accidents

HaV, the Swedish National Council for Nuclear Waste, SSM, Östhammar Municipality, the County Administrative Board in Kalmar County, the Swedish Society for Nature Conservation and MKG, and Oss express the opinion that the description of possible nuclear accidents in the application should be supplemented.

SSM believes that SKB should supplement the description of the relationship between dose and risk of harmful effects, the risk of disturbances and mishaps in connection with the construction and operation of the final repository, and the consequences of a possible accident. The authority also calls for an overview of SKB's obligations in the application.

HaV says that a clearer description is needed of environmental risks and different scenarios, including consequences for the aquatic environment of a possible accident in conjunction with the sea transport of spent nuclear fuel on the planned vessel (in addition to preventive measures and an estimation of probabilities).

Östhammar Municipality and the County Administrative Board in Kalmar County are of the opinion that the application should shed light on the consequences of a radiological accident, especially during the transport of nuclear waste, both by sea and overland, and what measures can be adopted.

Account of alternative methods

As is evident from the above, several referral bodies consider that the description of alternative methods should be expanded in the EIS, i.e. supplemented with the information on choice of method given in Appendix CM (for a compilation of viewpoints on Appendix CM, see 3.9 in this report).

It is the Council's considered opinion that the description of alternative methods should be supplemented in the application with information given in Appendix CM. At the same time, the description of the alternatives Deep Boreholes and Reprocessing should be updated with new research findings. The Council would like to see a comparative account of alternative methods for final disposal with respect to safety, radiation protection and environmental impact, and would like SKB to justify its support for the chosen method against the background of such an account.

SSM is of the opinion that an in-depth account is needed of how different methods for final disposal of the spent nuclear fuel can be expected to satisfy the requirements of the radiation safety legislation and the Environmental Code in relation to the applied-for activity.

Östhammar Municipality would like a more detailed report on alternative methods.

The County Administrative Board in Uppsala County is of the opinion that a clearer account of the state-of-the-art of new technology for alternative methods should be presented in the application.

Karlstad University, the Swedish Society for Nature Conservation and MKG believe that supplementary information is needed in the description of Deep Boreholes.

Karlstad University also states in a separate appendix to its statement that the alternatives report lacks references to recent research on Deep Boreholes and the need for supplementary information. The statements of the Swedish Society for Nature Conservation and MKG and Oss criticize the description of the choice of methods in the EIS, where the Deep Boreholes alternative should be elaborated on in both the EIS and Appendix CM (see further Chapter 3.9).

The no action alternative

According to the Environmental Code, the consequences if the applied-for activity is not implemented (the no action alternative) should be described. The statements of the referral bodies call for a more detailed account of the consequences of delays, or of denial of a licence.

SSM is of the opinion that SKB needs to supplement its account of the no action alternative with a description of the measures that need to be adopted in the short and long term for the continued radiologically safe management of the spent fuel in the event a licence is not granted for the final repository. SSM is of the opinion that SKB should supplement its application with a plan of action for the event that the capacity of Clab is not sufficient, for example as a result of the fact that the final repository system cannot be put into use as planned.

It is the Council's considered opinion that effects and consequences of delays in the process that could lead to a (time-limited) realization of the no action alternative should be described and assessed.

Oskarshamn Municipality points out that the no action alternative does not entail that nothing is done, but that something else may have to be done in the event the application is not approved. The no action alternative, as it is described by SKB, is, in the municipality's opinion, not an alternative in the sense of the Environmental Code. The municipality therefore believes that SKB should present the consequences of the no action alternative in the application. Östhammar Municipality would also like an account of what events could lead to the realization of the no action alternative.

In its statement of opinion, Oss says that further clarification is needed of the no action alternative. The application should be supplemented with a clarification of what is meant by the no action alternative and how it may evolve.

Description of alternative sites

According to the Environmental Code, alternative sites for the activity should be described in the EIS. In the case of the applied-for activity, alternative sites should be described for the final repository and the encapsulation plant.

SKB is applying for a licence to site the final repository in Forsmark and the encapsulation plant (Clink) in Oskarshamn.

As is evident in Chapter 3.10 of this report, several referral bodies think that the description of the choice of site given in the application should be developed. SSM is of the opinion that SKB should clarify the account of the site selection process in the EIS so that it describes more clearly how radiation safety issues have been handled during the site selection process. SSM also believes that SKB needs to supplement the EIS with an in-depth comparative evaluation of the location of an encapsulation plant at Simpevarp and Forsmark.

Östhammar Municipality thinks that the choice of site should be justified so that the municipality can evaluate whether SKB has fulfilled the requirement on site investigation. The municipality also needs supplementary information from SKB concerning how a balance has been struck between the three criteria: industrial aspects, societal aspects and bedrock aspects.

Supplements to the consultation report with viewpoints offered in the process

The consultations that SKB has held in accordance with the Environmental Code are described in an appendix to the application.[20]

SSM is of the opinion that SKB needs to supplement the consultation report with a description of how important viewpoints offered during the consultations have been addressed in the submitted EIS. Östhammar Municipality also requests supplementary information on what important questions have come up during the consultations, how they have been dealt with in the application and what questions have not been answered.

[20] Appendix P-10-34 Samrådsredogörelse (consultation report).

Description of environmental impact and consequences

The area around Forsmark is very special with its unique flora and fauna. There are very high natural values in the area, which is classified as being of national interest for nature conservation.[21]

Red-listed species

Saying that a species is red-listed means that it is included in ArtDatabanken's (the Swedish Species Information Centre) list of species at risk of extinction in Sweden. There are red-listed species where the final repository is planned to be located, in particular the pool frog and the fen orchid. The Swedish EPA wants SKB's application to be supplemented with information on all red-listed species that have been encountered and how they will be affected, as well as how measures to mitigate the impact on these species should be handled.

Species Protection Ordinance

The Species Protection Ordinance (SFS 2007:845) covers species that are protected under the EU's Birds Directive and Habitats Directive, as well as certain other wild species that are threatened in Sweden. In order to be allowed to carry out activities that may affect species that are protected under the Species Protection Ordinance, the operator must apply for an exemption. The area around Forsmark contains species that are protected under the Species Protection Ordinance, and SKB has submitted a separate application for an exemption to the County Administrative Board in Uppsala County. The Swedish Environmental Protection Agency and MKG point out in their statement that it will be difficult to determine the impact on red-listed species, since the exemption from the Species Protection Ordinance that SKB has applied for is not included in the licence application for a final repository. In the opinion of the Swedish EPA, the supporting material given by SKB to the County Administrative Board in Uppsala County relating to

[21] In Chap. 4 of the Environmental Code, the Riksdag has specified a number of areas in the country that are of national interest in their entirety in view of the natural and cultural values that exist there.

an exemption from the Species Protection Ordinance should be included in the final repository application.

Compensatory measures

In order to be able to operate a final repository, SKB needs to divert the groundwater flowing into the repository. It is assumed that this diversion will affect natural values, since the groundwater table may be lowered. Wet areas will become drier, and the plants and animals that are adapted to a wet environment will have difficulty surviving. SKB writes in its application that water may be infiltrated in order to prevent the impact on natural values of a groundwater lowering (drawdown). SKB also plans to create new water areas to compensate for the valuable existing water areas that will be filled in.

In its statement of opinion, the Swedish EPA points that that SKB states in its environmental impact statement that the national interest for nature conservation in Forsmark-Kallrigafjärden will be appreciably harmed by the groundwater diversion entailed by the final repository. SKB bases the expectation of appreciable harm on the fact that the damage is not reversible and that affected natural values comprise the basis for the national interest.[22] The Swedish EPA therefore deems that in order for the activity to be permitted, the licensing authority should, according to Chap. 16 Section 9 of the Environmental Code, require special measures to compensate for the harm to the environment and in particular the designated national interests, in other words compensation for other species than just those protected under the Species Protection Ordinance. The Swedish EPA therefore considers that SKB should supplement the application with proposals for measures to compensate for the damage to the environment.

Oss calls for material describing how stipulated compensatory measures are to be evaluated, monitored and maintained over the long construction and operating period. Oss would also like information on what measures will be taken if things do not work as intended.

[22] SKB R-10-14 p. 95.

Natura 2000

Natura 2000 sites are protected according to the Environmental Code[23] and a licence is required to carry on activities or adopt measures that are liable to affect the environment in such an area.

The Natura 2000 site of Kallriga is located south of Forsmark. The Swedish EPA and HaV say that there is a risk of Kallriga being affected if the final repository is built. The regulatory authorities say that the risk of impact on the Natura 2000 site needs to be described more clearly in the EIS. If the activity could have an appreciable impact on the Natura 2000 site, for example through groundwater lowering, SKB must apply for a licence according to Chap. 7 Sec. 28 of the Environmental Code.

HaV is also of the opinion that the application needs to be supplemented with a description of how the activity could affect the species and ecosystems that have contributed to the designation of Kallriga as a Natura 2000 site. The EPA therefore considers that possible impacts on the Natura 2000 site and national interests need to be described more clearly.

Environmental quality standards for water

Environmental quality standards are legally binding policy instruments described in Chapter 5 of the Environmental Code. Environmental quality standards for water were adopted in December 2009. HaV, the Swedish EPA, the County Administrative Board in Uppsala County and the Swedish Society for Nature Conservation and MKG call for a clear account in the EIS of:

1. which bodies of water will be affected,
2. their current chemical and ecological status,
3. which priority substances (according to Directive 2008/105/EC) may be discharged from the activity
4. appreciable discharges of substances that meet the criteria given in Annex VIII of Directive 2000/60/EC, and
5. the risk that the standards cannot be complied with as a result of the applied-for activity.

[23] Chap. 7 of the Environmental Code.

HaV further writes that the lack of such information in the EIS has in another case been judged by the Superior Environmental Court to be such a serious deficiency that the EIS could not be approved (Case M 568-11).

Leachate

Large quantities of rock material will be extracted in conjunction with the excavation of rock caverns for the spent nuclear fuel. HaV believes that a description is needed of how this material could pollute receiving bodies of water via leaching before the rock spoil is eventually reused for other purposes. The County Administrative Board in Uppsala County calls for an account of how SKB plans to treat this leachate. The treatment process described in SKB's EIS is no longer being considered, since previously unknown high natural values have been encountered. SKB must therefore develop a new treatment process and take it into consideration.

Impact on receiving waters

The County Administrative Board in Uppsala notes the lack of a broad assessment of combined effects of the activity's discharges to water and says that the cumulative effects of discharges to water on the receiving waters and the marine area must be described in the EIS. The County Administrative Board notes the absence of a description of the calculation of total discharges after planned treatment steps for drainage water, leachate, stormwater and waste water.

The County Administrative Board in Uppsala County find that the description of consequences for affected natural values does not include natural values in the marine area that is liable to be affected, i.e. Söderviken, Asphällsfjärden, the Biotest Basin and Öregrundsgrepen. The County Administrative Board finds that supporting material for assessing the impact on natural aquatic environments and organisms is lacking in the EIS.

Bogs

SKB has chosen not to include bogs in the environmental impact statement, since this type of wetland is not dependent on the groundwater table but is supplied with water by precipitation. The Swedish EPA contends in its statement that only the bog vegetation is dependent on nutrients and water from rain. The bog as a whole can be affected by groundwater lowering, causing compaction of the peat, a slowing in the growth rate of the bog and decomposition of the peat. It can also lead to changes in vegetation due to drier conditions. The Swedish EPA therefore thinks that SKB should supplement the application by including bogs in the environmental impact statement.

Management plan

In its application, SKB states that they will, at a later stage, prepare a conservation-oriented maintenance plan for the properties in Forsmark. Measures will be proposed in the plan that can in part counteract the negative effects of the planned activity on natural values. The Swedish EPA believes that this management plan should be included in the application.

Oss calls for a nature and forest conservation plan for the site in Forsmark in case the application is rejected and the project is not realized as planned. The reason is that SKB logged the timber on forest land in Laxemar after the site was no longer being considered for a final repository.

Light disturbances

The Forsmark area is an important breeding site for birds and a known corridor for migratory birds. Oss contends that strong lighting can have consequences for the birds and calls for an action plan aimed at minimizing light disturbances from the construction and operation of the final repository and from the nuclear power plants.

Impact on health

Aside from the above-mentioned aspects, several referral bodies feel that SKB's application ought to be supplemented with a description of the impact of noise and air pollution from transport vehicles.

Psychosocial effects

The Swedish National Council for Nuclear Waste, SSM and Östhammar Municipality say that psychosocial effects have not been given sufficient attention in the EIS, which should be supplemented in this respect.

3.13 Monitoring

According to the application, there are no legal requirements on post-closure monitoring of the repository. SKB's plan assumes that the final repository according to the KBS-3 method can fulfil its function without maintenance or monitoring. Furthermore, the problems exist during operation as well since SKB intends to backfill gradually, as deposition progresses.

Östhammar Municipality finds it a deficiency that questions concerning monitoring and information preservation are omitted from the application. Östhammar Municipality is of the opinion that SKB must give an account in the application of how closure is to be carried out, what measures can be taken if something happens and the waste has to be retrieved, and finally how post-closure monitoring will take place and what information will be preserved and updated. According to the municipality, it is necessary that SKB should, at certain time intervals throughout the operating period and prior to closure, produce plans for how information preservation and monitoring are to be done.

Oskarshamn Municipality calls for supplements of the proposed inspection programme. The municipality contends that the programme is not rigorous enough and that the programme should define what is to be done, with a clear and concise description of measures to be adopted in the event of deviations from established criteria. The inspection programme is intended to verify compliance with the licence conditions. This permits follow-up of protective and precautionary measures.

3.14 Licence conditions

A judgement whereby a licence is granted for an activity shall, where applicable, include provisions regulating such conditions concerning emissions/releases and best available technology as are needed to prevent or limit harmful effects due to pollution as well as such others conditions as are needed to prevent damage or detriment to the environment. Via the conditions, the environmental court specifies the contents of the general rules of consideration in Chap. 2 of the Environmental Code. The court can thus issue conditions regarding e.g. ionizing radiation in conjunct-tion with releases to the environment of radioactive substances that could cause damage or detriment to human health or the environment. The Government or SSM may also issue conditions in this respect with the support of the Nuclear Activities Act.

Since SKB considers SSM to be responsible for stipulating conditions to ensure compliance with the requirements in the Nuclear Activities Act and the Radiation Protection Act, SKB has refrained in its application from proposing its own conditions for compliance with these laws. In addition to conditions linked to the requirements in the Nuclear Activities Act and the Radiation Protection Act, there are also other conditions that SKB must comply with. The absence of proposals for other conditions has been noted by several referral bodies.

The Swedish Agency for Marine and Water Management finds that the question of conditions has not been given sufficient attention in the application. They say that SKB needs to elaborate its description of the conditions which SKB believes should apply to the applied-for activity.

The Swedish EPA believes that many more conditions are needed, including conditions in other areas that those proposed by SKB. The Swedish EPA believes that clear conditions are particularly important, for example with regard to species protected under the Species Protection Ordinance and proposals for compensatory measures for damage to the national interest. In view of this, the Swedish EPA contends that SKB should define which areas the company believes need to be regulated by conditions and define the conditions as precisely as possible at this stage of the process. The Swedish EPA also contends that SKB needs to show how the conditions in the exemption granted from species protection should be coordinated with the conditions in the licence regulating water operations for the final repository.

The County Administrative Board in Kalmar County would like the application to be supplemented with proposals for conditions regulating how the activity will be conducted, i.e. which protective and precautionary measures will regulate the planned activity.

The County Administrative Board in Uppsala County considers that the erection of a final repository is a very big project in an area with very high natural values and with a coast that is very undeveloped except for the nuclear power plant. The County Administrative Board therefore believes that claims should be made for compensation.

Östhammar Municipality points out that it is important that the activity and its predicted environmental consequences, as well as possible precautionary and protective measures, be described in a manner that enables the licensing authority to issue legally correct and proper conditions that are appropriate for self-inspection and supervision.

Oskarshamn Municipality judges it to be a deficiency in the application under the Environmental Code that SKB has made so few proposals for conditions (section 8.3 in the application), for example which protective and precautionary measures regulate the intended conduct of the activity. The municipality is of the opinion that SKB should propose "dynamic" conditions (conditions that are progressively updated), or that it should be determined in the judgement that the conditions are to be re-examined at certain time intervals.

3.15 Reflections

The first part of the process, the so-called supplementing phase, has resulted in 34 statements of opinion from public authorities, county administrative boards and municipalities, universities, NGOs and one private individual. Many of the referral bodies point out that SKB has carried out a very extensive and well-researched project and 4 authorities find the supporting material to be sufficient.

Most of the referral bodies' viewpoints have to do with the safety analysis reports (the appendices SR-Site and SR-Drift), which describe how well the application satisfies the requirements regarding radiation safety according to the provisions of the Nuclear Activities Act and the Radiation Protection Act, along with the Swedish Radiation Safety Authority's regulations and ordinances.

Several of the referral bodies who stated their opinon on the application under the Nuclear Activities Act have previously offered viewpoints in conjunction with the Swedish Radiation Safety Authority's reviews of SKB's RD&D programmes, and many of the questions regarding radiation safety in the final repository have been addressed previously. This applies to the function of the engineered barriers, including canister, buffer and backfill.

Additional information concerning method and site selection is requested from SKB by many of the referral bodies. In particular, the regulatory authorities and the municipalities ask for more detailed descriptions of alternative methods and the criteria on which the choice of site is based. A number of statements raise questions concerning the contents of the environmental impact statement, along with physical protection, the risk of intrusion and monitoring.

A number of new actors in the process, such as the Swedish Agency for Marine and Water Management (HaV) and the Swedish EPA, have offered viewpoints to the Swedish Radiation Safety Authority and the Land and Environment Court that have not been discussed previously. Recurrent points in the statements of these referral bodies are questions concerning the accessibility of the supporting material and clarification of the licensing process. Several statements of opinion have taken up the consequences of the long time perspective in the different phases of the process when it comes to knowledge preservation, monitoring and licence conditions. More information on the environmental impact of the planned activity and planned compensatory measures has been requested by several referral bodies.

The parallel licensing processes impose extra demands on both the supporting material and participation in the processes. Several referral bodies request clarifications when it comes to the differences between the licensing processes and between the supporting material SKB has submitted to SSM and the Land and Environment Court, respectively.

4 To recycle or not to recycle – that is the question ...

4.1 Introduction

The quantity of spent nuclear fuel our Swedish nuclear power plants currently amounts to 6,000 tonnes. A small portion is stored at the nuclear power plants, after which it is shipped to the central interim storage facility for spent nuclear fuel (Clab, owned and operated by Svensk Kärnbränslehantering AB, SKB) at the Simpevarp Peninsula north of Oskarshamn. Here the spent nuclear fuel is then stored pending final disposal. After 40 years of interim storage, the level of decay heat in the spent nuclear fuel is still relatively high. But after encapsulation in a planned facility adjacent to Clab, the temperature on the outside of the canister will not exceed 100 degrees.

In 2011, SKB applied for a licence to build a final repository at the nuclear power plant in Forsmark.[1] This application is based on the KBS-3 method, which entails that the spent fuel assemblies – encased in approximately 6,000 canisters, each consisting of a cast iron insert with a copper shell – are deposited directly in the Swedish bedrock at a depth of about 500 metres.

SKB has been developing the KBS-3 method since the early 1980s, and in a decision from 2001 the Government declared that SKB should use the KBS-3 method as a planning premise for the upcoming site investigations.[2] The same decision also underscored "that final approval of a specific method for final disposal cannot be given until a decision is made on applications under the Environ-

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[1] SKB is owned by E.ON, Vattenfall and Fortum, who in turn are co-owners of the three Swedish nuclear power plants In Oskarshamn (three reactors), Ringhals (four reactors) and Forsmark (three reactors). These NPPs account for about 40% of Sweden's energy production. The regulatory authority for nuclear activities is the Swedish Radiation Safety Authority (SSM).

[2] Government decision of 1 November 2001.

mental Code and the Nuclear Activities Act for a permit to build a final repository for spent nuclear fuel". But the Government statement from 2001 has given the KBS-3 method special status in the method selection process. The Swedish Nuclear Power Inspectorate (SKI) has also on different occasions made a positive evaluation of SKB's system choice and says in its statement to the Government regarding SKB's RD&D (Research, Development and Demonstration) programme 2007 that "disposal in accordance with the KBS-3 method still seems to be the most appropriate planning premise for disposing of the spent nuclear fuel from the Swedish nuclear power programme".[3]

The KBS-3 method has also attracted a great deal of international attention. The Finnish final repository programme is based on the same method. It can also be mentioned that the American equivalent to the Swedish National Council for Nuclear Waste, the *Nuclear Waste Technical Review Board* (NWTRB), regards the KBS-3 method as an important design concept.[4] President Barack Obama abandoned the Yucca Mountain Project in 2008 and appointed a *Blue Ribbon Commission on America's Nuclear Future*, which, in its final report in 2012, mentions SKB's final repository programme in positive terms.[5] After considering various alternatives, the Commission also recommends a geological repository, without going into greater detail regarding its design.

The KBS-3 method is also the disposal concept at the core of the application for a final repository for spent nuclear fuel which SKB submitted to SSM and the Land and Environment Court at Nacka District Court in March 2011[6]. In parallel with the development of the KBS-3 method, alternative methods have also been discussed for spent nuclear fuel disposal. One example is Deep Boreholes, which has on various occasions also been put forward by the Swedish National Council for Nuclear Waste. Another example is different methods for recovery and recycling of spent nuclear fuel. In the KBS-3 method, the spent nuclear fuel is regarded as waste, but several other countries have instead chosen to regard the spent nuclear fuel as a resource.

[3] See SKI's *RD&D Review Statement 2008*, p. 7.
[4] U.S. Nuclear Waste Technical Review Board, "Technical advancements and issues associated with the permanent disposal of high-activity waste - Lessons Learned from Yucca Mountain and Other Programs," 2011.
[5] Blue Ribbon Commission on America's Nuclear Future, Disposal Subcommittee Report to the Full Commission, Updated Report, 2012.
[6] A licence application for erection of an encapsulation plant was submitted back in 2006.

This chapter examines this question in the light of (1) SKB's licence application for construction of a final repository for spent nuclear fuel, (2) the Swedish National Council for Nuclear Waste's previous standpoints in the matter, and (3) conclusions from the seminar arranged by the Swedish National Council for Nuclear Waste on 8–9 November 2012 *The Future of Nuclear Waste – Burden or Benefit?*

4.2 Recycling of spent nuclear fuel

A very limited fraction of the nuclear fuel (about 5%) is used in our present-day nuclear power reactors. According to the KBS-3 method, the unused portions of the fuel will be deposited directly in a final repository. This is usually termed an *open fuel cycle*. An alternative is a *closed fuel cycle*, where the spent nuclear fuel is reused after reprocessing as fuel in existing or future nuclear reactors. This would considerably reduce the quantity of the waste and the length of time for which it is hazardous.

Different system alternatives, including the recycling alternative are dealt with in SKB's application, and the Swedish National Council for Nuclear Waste has offered viewpoints on these to the Land and Environment Court at Nacka District Court (31 Oct. 2012).[7] To shed further light on the recycling alternative, the Swedish National Council for Nuclear Waste held an international seminar on 8–9 November under the theme *The Future of Nuclear Waste – Burden or Benefit?*

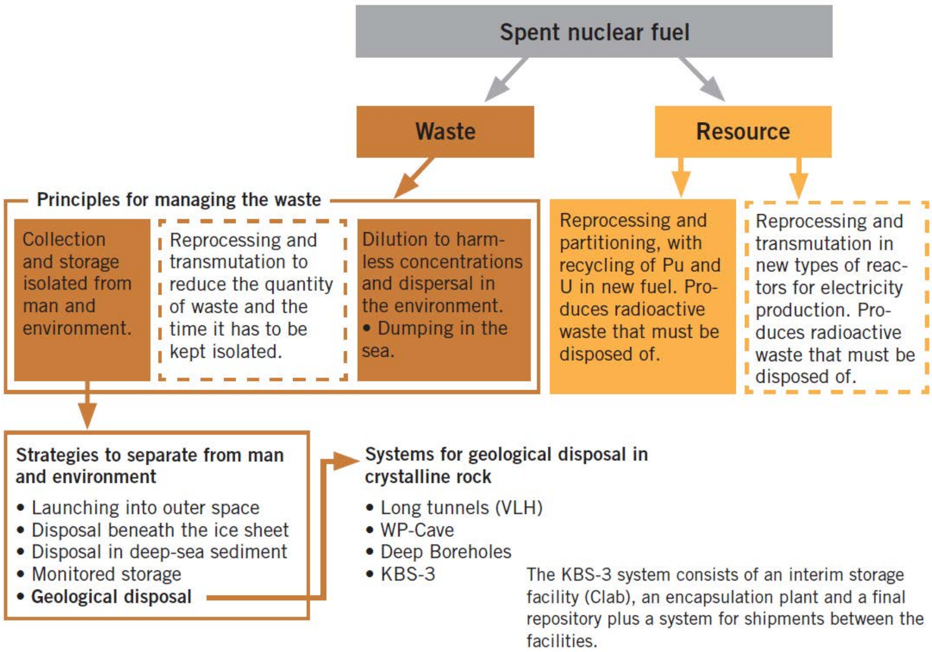
In this chapter, the Council will present SKB's description and assessment of system alternatives. Then the Council will present its position on these issues in its statement of opinion to the Land and Environment Court. After that the Council will give an account of different lessons from the November seminar and also touch upon some questions concerning recycling of spent nuclear fuel that require further analysis and elucidation. In conclusion, the Council discusses some overall perspectives that have previously provided important guidance in other contexts. It should be emphasized that none of the analyses in this chapter should be interpreted as a final

[7] The Swedish National Council for Nuclear Waste's viewpoints regarding the need for supplementary information in an application for a licence for facilities in an integrated system for final disposal of spent nuclear fuel and nuclear waste (M 1333-11). Dnr 43/2012, p. 32.

stand for or against any particular recycling alternative. On the other hand, the Council would like to devote attention to critical questions regarding both the KBS-3 method and the recycling alternatives.

The so-called "top document" in SKB's application for a licence for a final repository for spent nuclear fuel describes two approaches to the management of spent nuclear fuel: as resource or waste. Within these two alternative approaches are several sub-alternatives, which are summarized in the following figure taken from an appendix to SKB's application, Choice of Method (MV/CM):

Figure 3 **Principles, strategies and systems for disposal of spent nuclear fuel. The principles in the dashed boxes are based on technology that is not available today**



Source: SKB's application. Appendix CM, p. 20.

In this context, the Council intends to focus on SKB's description and assessment of the various alternatives that exist within the resource approach, or what can also be called the recycling approach.

The resource approach is based on recovery and recycling according to two alternatives, which SKB describes and judges in the following way:

1. Conventional reprocessing and production of MOX fuel, followed by final disposal of vitrified waste and spent MOX fuel.[8]
2. Transformation (transmutation) of the waste after reprocessing.[9]

Alternative 1 is based on the existing type of light water reactors (LWRs)[10]. The Swedish reactors belong to what is called Generation II.[11] They are moderated and cooled by ordinary water, and the fuel is irradiated by thermal neutrons[12], which are only capable of splitting uranium 235. When the fuel assemblies are taken out of the reactor, approximately 96% recyclable material remains, of which 94% uranium 238, 1% uranium 235 and 1% plutonium (0.25% Pu 238, 0.75% Pu 239). In addition, the fuel contains 4% fission products and 0.1% residual actinides (americium, neptunium and curium)[13]. Plutonium and the residual actinides decay slowly and take about 100,000 years to reach harmless levels.

Reprocessing of the spent nuclear fuel entails first separating (partitioning) uranium and plutonium, and the remaining nuclides comprise high-level waste (HLW). Partitioned uranium and plutonium are converted to MOX fuel, which can be burned in our present-day nuclear reactors. When the MOX fuel has been used, approximately 20% of the plutonium has been consumed. Because it contains plutonium, MOX fuel is more radioactive than ordinary fuel and therefore requires special handling.[14]

According to SKB, reprocessing (in domestic or foreign facilities) is inappropriate for both economic and security-related reasons.

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[8] Mixed Oxide Fuel.
[9] Top document in SKB's application, p. 19.
[10] By *light water* is meant water in which the constituent hydrogen atoms consist mainly of ordinary hydrogen, whose nucleus contains only one proton, in contrast to heavy water, in which the hydrogen nucleus has a proton and a neutron.
[11] Later on the Council will return with a description of more advanced types of nuclear reactors of Generation II, III, III+ and IV.
[12] Thermal neutrons are neutrons that have been slowed down so much by collisions in the water that they are in thermal equilibrium with their surroundings.
[13] Actinides are the series of 15 elements that follow (and include) actinium in the periodic table. Actinides with atomic numbers higher than 92, called transuranics, are formed by nuclear reactions. They all gradually decay to lighter elements while emitting ionizing radiation until a stable end product is reached (lead or bismuth).
[14] See further http://www.stralsakerhetsmyndigheten.se/global/publikationer/ski_import/050621/bc52ca3181a7ed2ab695269ecc131c19/mox.pdf

"Furthermore, the saving of uranium is moderate: 10–20%, depending on how many times the fuel is reprocessed".[15]

Alternative 2 is based on a technique that transforms (transmutes) radioactive substances (radionuclides, for example residual actinides in the spent nuclear fuel) to less hazardous substances.[16] This process is called spallation. The process can take place in special accelerator-driven systems (Accelerator Driven Spallation, ADS). An alternative is to irradiate the high-level nuclides in a nuclear reactor with a much higher neutron energy that in our present-day reactors. Such reactor technology belongs to Generation IV and is not expected to be available for commercial operation for another 30–40 years or more.[17] Generation IV reactors could be operated with spent nuclear fuel from our present-day nuclear reactors and burn not only plutonium, but also the residual actinides, leaving only about 1% of the original quantity of plutonium and actinides, and shortening the time they remain hazardous to about 1,000 years. The disadvantage is that this technology is not currently available and is not expected to become available on a large scale for the foreseeable future. SKB is therefore also critical of this recycling method.

In the Choice of Method (MV/CM) sub-appendix to the application, SKB *alternatives 1* and *2* are described more thoroughly. Reprocessing with recycling of plutonium and uranium is described in section 3.3.1[18] and Partitioning and Transmutation (P&T) in section 3.3.2[19]. In its overall assessment (section 4.3), SKB rejects both alternatives. Reprocessing and separation of plutonium and uranium according to *alternative 1* is an established method and has been used in France and the UK. But SKB describes the situation in Sweden as follows:

> …Ever since the early 1980s, there has been a consensus between political decision-makers and the reactor owners that reprocessing of the spent nuclear fuel from the Swedish reactors should be avoided.[20]

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[15] See further the top document in SKB's application, p. 19.
[16] The method is described in greater detail in the Swedish National Council for Nuclear Waste's *SotAR 2004* (SOU 2004:67), Chap. 8, and *SotAR 2011* (SOU 2011:14), section 4.2.3.
[17] International efforts to develop Generation IV reactors are coordinated by *Generation IV International Forum* (GIF), with thirteen members (including the EU).
See http://www.gen-4.org/. For a more detailed description of Generation IV reactors, see *SotAR 2011*.
[18] SKB's application, Appendix MV (CM), pp. 30–31.
[19] SKB's application, Appendix MV (CM), pp. 32–34.
[20] SKB's application, Appendix MV (CM), p. 56.

The reasons for this are both economical and security-related. One of the economic reasons is that new “fresh” nuclear fuel with enriched uranium has been and is still much cheaper than MOX fuel with plutonium from reprocessing. Furthermore, management and final disposal of the high-level waste and the long-lived low- and intermediate-level waste from reprocessing is very costly. The security-related reasons have to do with the fact that there is concern that plutonium from reprocessing could be used to manufacture nuclear weapons.[21]

When it comes to *alternative 2* – reprocessing and transmutation – it is mainly treated as a method of reducing the quantity of waste and the time it has to be kept isolated, and not as a method in new types of reactors (See Figure 3). There are mainly five objections to *alternative 2*. The *first* is that the method requires extensive radiation protection measures and that the relatively low long-term radiotoxicity of the residual actinides is exchanged for higher short-term radiotoxicity. This may conflict with the legal requirement on optimization and utilization of the best available technology to eliminate radiation doses. The *second* objection is that this type of reprocessing produces pure plutonium, requiring rigorous safeguards. The *third* objection is that the development of a functioning system is expected to be costly and take a long time. The *fourth* objection is that it will take about 100 years to carry out the transmutation. And the *fifth* objection is that the method produces a certain quantity of long-lived, high-level waste (fission products) that have to be disposed of in a safe manner. “SKB therefore does not regard transmutation as a realistic alternative for managing spent nuclear fuel from today’s Swedish reactors”.[22] However, SKB intends to keep track of and support scientific and technical development efforts in the field.

[21] SKB’s application, Appendix MV (CM), p. 56 – See further Appendix AH (AG), p. 21: “Objections have been raised to disposing of the spent nuclear fuel in the form it has after interim storage, since more energy could be extracted from the fuel before it is disposed of. Extracting more energy requires reprocessing. It is not currently considered economically defensible, or otherwise appropriate, to reprocess nuclear fuel in new plants in Sweden, or to send spent nuclear fuel abroad for reprocessing.”

[22] *Integrated account of method, site selection and programme prior to the site investigation phase* (2000), in particular Part II, Chap. 4, and Grundfelt 2010 (R-10-12). Grundfelt has roughly the same arguments as SKB.

4.3 The Council's view of the recycling alternatives

The Swedish National Council for Nuclear Waste has, in seminars and reports, often returned to the discussion of alternative methods to the KBS-3 method. These include the Deep Boreholes method. This method calls for the spent nuclear fuel to be deposited at a much greater depth than in the KBS-3 method. This alternative was the subject of a seminar in 2007[23] and has, at the Council's initiative, been further explored in a report from 2011 by Professor Karl Inge Åhäll.[24]

Recycling and transmutation are other alternatives to the KBS-3 method that have been dealt with by the Swedish National Council for Nuclear Waste. The Council has been publishing state-of-the-art reports *(SotAR)* since 1986 and review statements on SKB's RD&D programmes *(RD&D reports)* since 1993. The question of reprocessing of spent nuclear fuel according to *alternative 1* was dealt with in KASAM's [25] first *SotAR in 1986*[26], but has subsequently only been discussed briefly as a part of the overall discussion on alternative methods for nuclear fuel management and in connection with reviews of other countries' nuclear waste programmes. Partitioning and Transmutation (*alternative 2*) has, on the other hand, been thoroughly dealt with, for the first time in *SotAR 1986*[27], but in greater detail in *SotAR 1992*[28]. The treatment here is on a more descriptive level. A firmer position is taken in the Council's *RD&D review 2002*[29], where Partitioning and Transmutation (P&T) is thoroughly analyzed and SKB is urged to actively track developments in this field.[30] KASAM also argues for an amendment of the Nuclear Activities Act so that:

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[23] *Deep Boreholes. An alternative for final disposal of spent nuclear fuel?* (SOU 2007:6e).
[24] Karl-Inge Åhäll, *Deponeringsdjupets betydelse vid slutförvaring av högaktivt kärnavfall i berggrunden – en karakterisering av grunda och djupa slutförvar – 2011*. See also *Blue Ribbon Commission on America's Nuclear Future*, Disposal Subcommittee Report to the Full Commission, Updated Report, 2012, pp. 28–29.
[25] Samrådsnämnden för kärnavfallsfrågor, KASAM, became an independent committee called Statens råd för kärnavfallsfrågor in 1992. The English name (Swedish National Council for Nuclear Waste) remained the same. The name was changed via supplementary terms of reference in 2009.
[26] See *SotAR 1986*, pp. 124–126.
[27] See *SotAR 1986*, p. 35.
[28] See *SotAR 1992*, (SOU 1992:50), pp. 20–45.
[29] *RD&D Review 2002,* (SOU 2002:63).
[30] *RD&D Review 2002*, p. 108.

> …the Government is not formally prevented from granting a licence, in Sweden, for a facility for partitioning and transmutation *if* the continued development work indicates that such a facility is desirable.[31]

The Council's basic attitude is evident from the following quotation:

> However, the possibility cannot be ruled out that new knowledge and new research might lead to the conclusion that the choice of the method which appears to be most promising at present must be reconsidered at some time in the future. This view has guided the basic approach to the nuclear waste management issue that KASAM has given expression to since the end of the 1980s and which has also been reflected in the Government decisions since the beginning of the 1990s in connection with the review of SKB's RD&D programmes.[32]

The Council returned to the question of P&T in a special chapter *SotAR 2004*. Here the issue is dealt with from technical, economic and ethical aspects. Different scenarios are formulated, advantages and disadvantages are weighed against each other. The ethical analysis ends up in the following assessment:

> To allocate resources for further P&T research at this stage is also in line with the view that our generation should give future generations the best possible opportunities to decide whether they want to choose P&T as a method for disposing of spent nuclear fuel, instead of direct disposal alone (in accordance with the KBS-3 method, for example).[33]

The basic value hinted at in this quote could be described as the principle of every generation's right to determine for themselves which method they want to use to manage spent nuclear fuel (and other environmentally hazardous material). It could be called the principle of intergenerational autonomy.[34] This principle has been asserted in different contexts by the Council and has been called, after the Council's previous acronym, the *KASAM principle*. It was formulated back in the late 1980s and justified in the following manner in *SotAR 1998*:

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[31] *RD&D Review 2002*, p. 109. Such an amendment was also made in the Nuclear Activities Act in 2010.
[32] *RD&D Review 2002*, p. 101. – *the RD&D Reviews* 2005, 2008 and 2011 are worded more briefly and confirm the importance of further research in the area.
[33] The Swedish National Council for Nuclear Waste returns to the question in *SotAR 2011*, where special attention is devoted to partitioning and transmutation through the development of Generation IV reactors (see *SotAR 2011*), pp. 65–70).
[34] In contrast to the principle of intragenerational autonomy, i.e. that different groups – such as states or nations – within the same generation are autonomous in relation to each other. This autonomy – like intergenerational autonomy – is constrained by other moral principles (even though many states claim that other states never have the right to interfere in a country's "internal" affairs).

> We should also apply to future generations the same attitudes toward human beings that we consider to be fundamental to the view that we have of ourselves and of our own responsibility. According to this attitude, commonly called the humanistic view, future generations should be guaranteed the same rights as ourselves to integrity, ethical freedom and responsibility as we ourselves enjoy. Our assessment of the future consequences of our technical systems must also weigh in this right or, using a key term, provide scope for *freedom of choice*. At the same time, freedom of choice as a value to be weighed into our choice of strategy is given greater weight due to both the inherent uncertainty and the realization that all technical systems are designed by fallible human beings.

This is a brief background to the twin conclusions drawn by the multidisciplinary seminar in 1987, known as the KASAM principle: *A final repository should be designed to render monitoring and controls unnecessary, but not impossible*.[35]

The KASAM/autonomy principle thus entails that future generations should not only have the freedom to utilize the spent nuclear fuel if they want to, but also the freedom not to do so. The freedom not to utilize it (and to treat it as waste) is just as important as the freedom to utilize it as a resource. The question is then which spent nuclear fuel management method is compatible with this freedom of choice.

Based on the KASAM/autonomy principle, different kinds of arguments can be advanced against the recycling alternatives. The creation of the institutional and technical systems for transport, reprocessing and utilization of fissionable material that are needed to realize recycling alternatives is difficult to reconcile with the autonomy principle. The great financial and knowledge-related investments required by the recycling alternatives will necessarily put constraints on the ability of future generations to choose freely among waste management methods. In a broader societal perspective, the recycling alternatives can also have other negative consequences.[36]

The Council's statement of opinion to the Land and Environment Court of 31 Oct. 2012 cites two other principles as well, *the safety principle* and the *responsibility principle:*

[35] *SotAR 1998, p.* 13, and *SotAR 1987*, p. 92. For a modification of this principle, see Kåberger and Swahn 1993. See also the concluding part of this chapter.
[36] See further under 4.5. "Other problems with the recycling alternatives."

1. "**The purpose** of the applied-for activity is to dispose of the spent nuclear fuel in order to protect human health and the environment from the harmful effects of ionizing radiation from the spent nuclear fuel, now and in the future". (*The safety principle* according to SKB's application, top document, p. 4).
2. "… it is morally right that the generation that benefits from the nuclear power should also take responsibility for finding a solution to the waste problem." (*The responsibility principle* according to former Minister for the Environment Minister stryk parentes Andreas Carlgren, UNT 1 April 2011). [37]

The Council observes that these principles may sometimes come into conflict with each other, so that it may in practice be difficult to fully satisfy one principle without violating another. Three such conflicts are possible:

One concerns the relationship between *the responsibility principle* and the *safety principle*. It is not completely certain that the current generation will be able to dispose of the spent nuclear fuel so that human health and the environment are adequately protected "from the harmful effects of ionizing radiation from the spent nuclear fuel, now and in the future".[38]

The second possible conflict is between *the responsibility principle* and *the KASAM/autonomy principle*. If we in our generation have to find a safe method of disposing of the spent nuclear fuel, there may be no other alternative than geological direct disposal, which may limit the freedom of choice of future generations.[39]

A conflict is also possible between *the KASAM/autonomy principle and the safety principle*. If we are to safeguard the right of future generations to choose freely between utilizing or not utilizing our spent nuclear fuel, this may require us to manage our nuclear fuel in a manner that is not optimally safe for people who will live in the far future. The only option may be deposition of the spent

[37] The Swedish National Council for Nuclear Waste's viewpoints to the Land and Environment Court, Dnr 43/2012, p. 6.
[38] The Swedish National Council for Nuclear Waste's viewpoints to the Land and Environment Court at Nacka District Court, Dnr 43/2012, p. 6.
[39] This is true at least after closure of the repository. "After final closure of the repository, safety- and safeguard-related considerations must be given priority over the principle of freedom of choice of future generations" (see *SotAR 2010*, p. 49). SKB has on different occasions pointed out that a repository according to the KBS-3 method permits retrieval (unlike the Deep Boreholes concept, for example). But there is no doubt that such retrieval is an economically costly and technically complicated procedure and that it can thereby be described as a constraint on the freedom of choice of future generations.

nuclear fuel in a modified type of KBS-3 repository that can be left without monitoring and controls, but does not prevent monitoring and controls. The current type of KBS-3 repository limits the possibilities of future generations to retrieve the fuel and use it as a resource. But a non-closed repository with openable copper canisters could entail a higher risk for future generations, compared to a repository that has been permanently closed.

SKB has in different contexts asserted the relevance of the responsibility principle in making a decision in the alternatives issue.[40] The responsibility principle has also been cited as a decisive argument *against* the recycling alternatives and *for* choosing direct disposal according to the KBS-3 method.[41] There is no doubt that the recycling alternatives entail that a responsibility and a burden are passed on to future generations. But the Council notes that the spent nuclear fuel may not necessarily be only a burden to future generations, but also a resource. According to the autonomy principle, future generations (including those nearest in time) are entitled to decide for themselves whether they want to utilize this resource or not. This would mean that the present generation should not exercise its responsibility to manage the spent nuclear fuel in such a way that a future generation is prevented or hindered from exercising its autonomy.

The situation is complicated by the fact that management of the spent nuclear fuel must not only take the three aforementioned principles into consideration (the responsibility principle, the safety principle and the KASAM/autonomy principle). Two other principles – the conservation principle and the sustainability principle – must also guide the choice of disposal method, according to the Environmental Code. The Council refers to the Environmental Code's requirements in its recent statement to the Land and Environmental Court:

> According to Chap. 2 Sec. 5 of the Environmental Code, anyone who pursues an activity or adopts a measure shall conserve raw materials and energy and reuse and recycle them wherever possible. This is what is meant by *the conservation principle*.

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[40] See for example *Systemanalysis* (2000, R-00-32, p. 24).

[41] SKB (2000) *Systemanalysis* (R-00-32, p. 72). Another problem with the recycling alternatives is that they require a re-examination of existing energy policy. Such a re-examination has also taken place. See SKB's application, Appendix MV (CM), p. 23. The responsibility principle is cited in this context (1) as an argument against monitored storage, but not anymore (2) as an argument against the recycling alternatives, and as an argument for the KBS-3 method (SKB's application, Appendix MV (CM), pp. 59–60).

> The conservation principle has been interpreted to mean that energy and raw material must be used as efficiently as possible and their use should be minimized; *the sustainability principle* entails that whatever is extracted from nature shall be used, reused, recycled and disposed of in a sustainable manner with the least possible consumption of resources and without harming nature. […]
>
> It is the Council's considered opinion that SKB should give greater consideration to the consequences of the possible development and operation of new types of nuclear power reactors, for the timetable and for the nuclear fuel programme. One question that can be asked is what it means for a planned final repository that reactors in the future might use as fuel what we today regard as waste?[42]

In summary, it is not only the autonomy principle and the responsibility principle that can be difficult to satisfy at the same time. It may also be difficult for our present generation to both dispose of the spent nuclear fuel safely and at the same time satisfy the conservation principle. The conservation principle speaks against direct disposal and in favour of recycling (according to alternative 1 or 2 above). Resolving this conflict of values needs to be the subject of an in-depth analysis, in the Council's opinion. It would be of great value if SKB had provided material that would permit a detailed analysis of these value conflicts and an assessment of to what extent it is possible to resolve them.

The legal status of the recycling alternatives should also be clarified. Relevant analyses can be found in SKB's programme for social science research. In the report *Nationellt ansvar för använt kärnbränsle i en utvidgad europeisk union?*[43] ("National responsibility for spent nuclear fuel in an enlarged European Union?"), Per Cramér, Sara Stendahl and Thomas Erhag write that a shift occurred at the end of the 1970s from reprocessing to direct disposal, but that demands to prohibit reprocessing of spent nuclear fuel were not formulated in the 1970s or later. Moreover, reprocessing contracts were signed with French Cogéma and British Sellafield in accordance with the requirements of the Stipulations Act. Although fuelling permits were granted for the Oskarshamn 3 and Forsmark 3 nuclear power reactors in 1984 with reference to the KBS-3 method, the Nuclear Activities Act, in which the question of the method for management of the spent nuclear fuel was left open, was en-

[42] The Swedish National Council for Nuclear Waste's viewpoints to the Land and Environment Court at Nacka District Court, Dnr 43/2012, p. 32.
[43] SKB (2011) R-07-11.

acted that same year. This is evident from Section 10, which reads in its entirety:

> The holder of a licence for nuclear activities shall be responsible for ensuring that all measures are taken that are required for
> 1. maintaining safety, with reference to the nature of the activity and the conditions in which it is conducted;
> 2. *the safe management and final disposal of nuclear waste arising in the activity or nuclear material arising therein that is not re-used, and*
> 3. safe decommissioning and dismantling of facilities in which activities will no longer be pursued until all activities at the facilities have ceased and all nuclear material and nuclear waste has been placed in a repository that has been closed and sealed.[44]

It is evident from clause 2 that final disposal of spent nuclear fuel with or without prior reprocessing represents two equivalent alternatives, legally speaking.

Finally, the Council would like to reiterate the requirements which SKB – most recently in its licence application for a final repository, Appendix MV (CM) – has formulated as governing the choice of method. They are:

> Overall requirements (in e.g. international conventions[45])
>
> Safety requirements (according to laws and government regulations)
>
> Radiation protection requirements (according to the Radiation Protection Act and government regulations)
>
> Requirements on physical protection and safeguards, and
>
> Environmental requirements.

More concrete principles for SKB's assessment are then derived from these requirements. They are summarized in four different points:

- Security, radiation protection and environmental considerations shall be in focus in connection with the construction, operation and closure of the final repository.
- The final repository shall be designed to prevent illicit trafficking in nuclear fuel both before and after closure. Long-term safety shall be based on a system of passive barriers.

[44] Council's italics. For the Nuclear Activities Act and the difference between nuclear material and nuclear waste, see SKB (2011). R-07-11, pp. 19–22.
[45] *Nuclear Waste Convention*, *1997*. Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management (SÖ 1999:60).

- The final repository is intended for spent nuclear fuel from the Swedish nuclear power plants and shall be created within Sweden's boundaries with the voluntary participation of the concerned municipalities.
- The final repository shall be established by those generations that have derived benefit from Swedish nuclear power and be designed so that it will remain safe after closure without maintenance or monitoring.[46]

Based on these principles and in consideration of a technical description of the different alternatives, SKB's fundamental conclusion is that geological disposal according to the KBS-3 method fulfils all of these requirements and that all other methods (including the recycling alternatives) do not. In its application, SKB provides a detailed description of the KBS-3 method, but describes the recycling alternatives in much more general terms. In view of this, the Council found it urgent to gain a better understanding of the recycling alternatives.

4.4 The seminar *The Future of Nuclear Waste – Burden or Benefit?*

The purpose of the international seminar on *The Future of Nuclear Waste – Burden or Benefit?* on 8–9 November 2012 was to investigate and describe different alternatives for management and disposal of spent nuclear fuel in the light of new technologies. In particular, the emergence of new reactor technologies and their ability to reduce the quantity and radiotoxicity of spent nuclear fuel were to be discussed. The central issue was thus recycling compared with direct disposal, but other issues that were indirectly related to the central issue were also discussed, such as climate change.

The Council's newsletter 2012:3 contains a detailed look at the different contributions and some of the reactions of the seminar delegates. A more condensed thematic review will be presented here:

The international regulatory framework

New reactor technology

[46] SKB's application, Appendix MV (CM), p. 26.

Experience and plans of different countries

Availability of uranium

Ethical issues

Climate change

Inevitably, these themes partially overlap each other.

The international regulatory framework

The first theme concerns *the international regulatory framework*. In other words, it concerns the overall requirements that SKB has also identified in its licence application for a final repository. Magnus Vesterlind referred in his introductory address to the provisions of the IAEA's Nuclear Waste Convention from 1997 and quoted the following from the preamble to the convention, where the contracting parties jointly declare the following:

> Recognizing that the definition of a fuel cycle policy rests with the State, some States considering spent fuel as a valuable resource that may be reprocessed, others electing to dispose of it.[47]

According to the same convention, responsibility for ensuring the safety of spent fuel management rests with the State, regardless of whether direct disposal or recycling is chosen.

New reactor technology

The second theme concerns *new reactor technology* and how such new technology influences the management of the spent nuclear fuel from the light water reactors that are in use (e.g. in Sweden). This issue was touched upon in most of the presentations, but particularly the ones by Janne Wallenius, Professor of Reactor Physics at the Royal Institute of Technology, Christophe Poinssot, Professor of Radiochemistry at the National Institute of Nuclear Science & Technology in France, Ane Håkansson, Professor of Applied Nuclear Physics at the Department of Physics and Astronomy at Uppsala University, and Charles Forsberg, Executive Director of the Nuclear Fuel Cycle Project at MIT (Massachusetts

[47] Nuclear Waste Convention, 1997.

Institute of Technology) in the USA. The overall picture that emerges is even more complicated than the two different recycling alternatives described by SKB in its application.

With reference to the comprehensive study of different waste reduction technologies that was published in 2007 within the framework of the EU's Sixth Framework Programme (*Red-Impact*)[48], six different scenarios can be distinguished instead of two. *Red-Impact* distinguishes between two main scenarios, A and B. In contrast to main scenario A, main scenario B is based on partitioning and transmutation of long-lived residual actinides in the spent nuclear fuel.

Main scenario A can be resolved into three different scenarios: A1, A2 and A3. A1 is a reference scenario with an open fuel cycle concluding with direct disposal of spent nuclear fuel. A2 is equivalent to SKB's recycling alternative 1, i.e. single recycling (mono-recycling) of uranium and plutonium and production of MOX fuel, which is disposed of after use. A3 is a type of multi-recycling of plutonium in an advanced type of fast reactor, developed from fast breeder reactors. [49]

Main scenario B can in its turn be subdivided into three scenarios: B1, B2 and B3. The main component in all three B scenarios is Generation IV reactors, which can extract up to 50 times more energy from the same quantity of fuel than is possible with today's reactor technology. Such reactors can be found together with other technical systems, for example ADS plants or fast reactors.

In summary, six different scenarios can thus be distinguished:

Scenario A1: once-through open fuel cycle according to e.g. the KBS-3 method and the now-abandoned Yucca Mountain Project.

Scenario A2: mono-recycling of plutonium and uranium from spent nuclear fuel transformed to MOX fuel (Generation II/III reactors – equivalent to SKB's alternative 1 above).

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[48] D Greneche, L Boucher, E Gonzalez, M Cuñado, J Wallenius, C Zimmerman and J Marivoet 2007. This report is also an important point of departure for Grundfelt in SKB Report R-10-12.

[49] A breeder reactor uses plutonium as nuclear fuel and produces more fuel than it consumes. This technology has been known since the 1950s, and great hopes were attached to breeder reactor technology in the 1960s in Sweden and other countries. Since nuclear weapons can be made from plutonium, development of breeder reactors was halted in both the USA and Sweden, but France had a breeder reactor in use (Superphoenix) up until 1998. See further Fjaestad 2010.

Scenario A3: multi-recycling of plutonium and uranium for use in a new type of fast breeder reactor (Generation III+).

Scenario B1: burning of residual actinides and plutonium from spent nuclear fuel by transmutation in Generation IV reactors (equivalent to SKB's alternative 2 above).

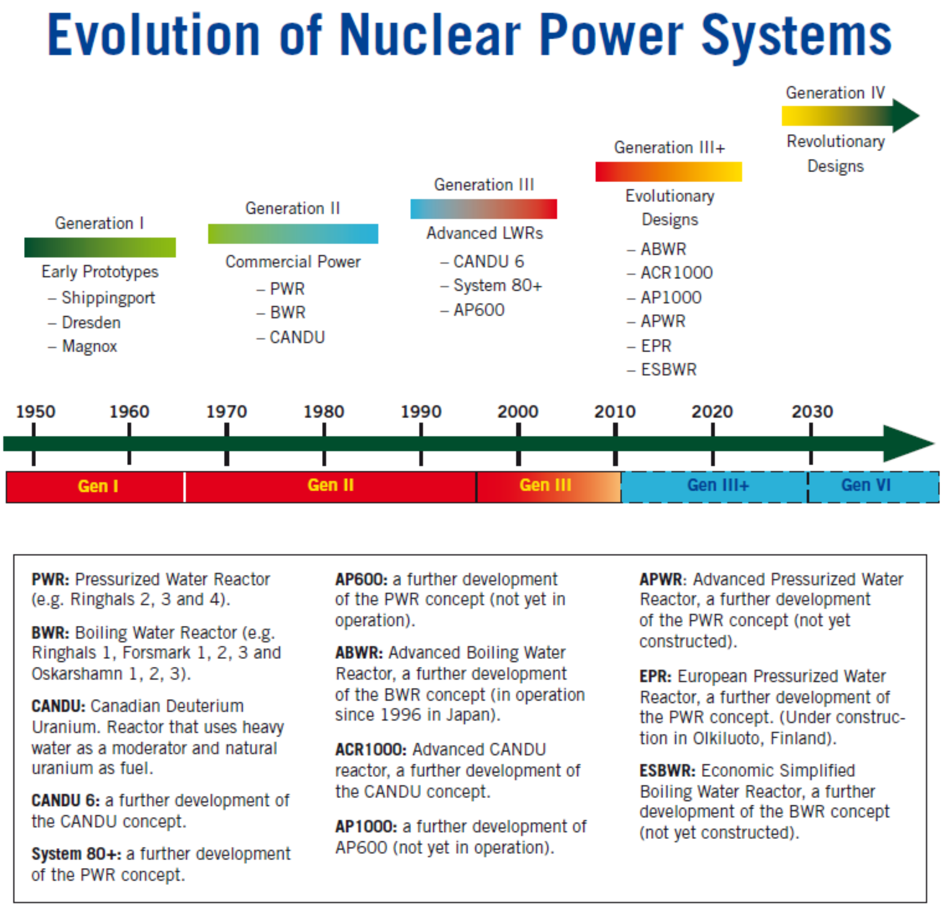
Scenario B2: A2 *plus* a second waste stream that transmutes plutonium and actinides in an ADS plant.

Scenario B3: B2 *plus* a multi-recycling of plutonium in fast breeder reactors. (Not subject to closer study in *Red-Impact*).[50]

Chronologically, Generation IV International Forum (GIF) provides the following estimated timetable for the evolution of nuclear power.

[50] The main results can (according to SKB Report R-10-12, p. 30) be summarized as follows:
• Final disposal in a deep geological repository is unavoidable, even with Partitioning and Transmutation (P&T).
• The reduction in long-lived actinide activity achieved by P&T reduces the risks associated with human intrusion in the final repository, but has a marginal effect on long-term safety, since the actinides have such low solubility that they do not contribute significantly to the long-term risk.
• P&T can reduce the heat output from the deposited waste and thereby permit denser deposition.
• P&T gives rise to streams of long-lived intermediate-level waste and waste containing volatile radionuclides, which require special attention.
Various sub-alternatives can also be formulated. See e.g. *Red-Impact*, p. 65.

Figure 4 **Evolution of nuclear reactor systems**



Source: Based on the figure Evolution of Nuclear Power. GIF, http://www.gen-4.org/

Figure 4 provides a good overview of the expected evolution of technology in the nuclear power field, but it also gives rise to a number of critical questions. In the *first* place, it is possible that the predicted evolution of e.g. Generation IV reactors is overly optimistic. According to the Council's previous assessment, light water reactors will probably be the primary choice for the rest of the present century.[51] In the *second* place, the figure gives the impression that this evolution of technology is predetermined with-

[51] *SotAR 2011* (SOU 2011:14) p. 67.

out any freedom of choice for future generations. In fact, the freedom of choice of future generations is something that can be both broadened and constricted by the current generation. And even those who welcome the evolution described in Figure 4 may underestimate the probability of technical setbacks and cost increases.

The different speakers at the November scenario were in relative agreement in their description of these different scenarios, but differed with regard to the fundamental question of whether we can determine in the current situation whether the spent nuclear fuel should be regarded as waste or as a resource. Wallenius, Poinssot and Håkansson thought that it is possible to answer this question today and that the spent nuclear fuel should be regarded as a fuel resource according to one of the above scenarios. With future reactor technology it would be possible, for example, to burn not only uranium and plutonium, but also residual actinides, which would otherwise remain harmful for hundreds of thousands of years. The quantity of waste would also be reduced to a few percent of the quantity that would have to be disposed of according to SKB's application.

Charles Forsberg differed from the other speakers in that he did not think there is a clear-cut answer to the question of whether the spent fuel is a burden or a resource. Like the American Blue Ribbon Commission, he therefore advocated final disposal of the spent nuclear fuel with an inherent flexibility for retrieval of deposited fuel in the event that a future generation should decide to close the fuel cycle by reprocessing and use of the fuel in future nuclear power reactors.[52]

Experience and plans of different countries

The evolution of reactor technology is very closely related to *the third theme* regarding the experience and plans of different countries with regard to direct disposal or recycling of spent nuclear fuel. Last year's State-of-the-Art Report[53] contains a detailed summary of current plans for spent nuclear fuel management in Finland, France, Germany, Switzerland and the USA. The seminar

[52] "Flexibility is needed because the program must operate over very long timeframes in which major changes in technology, institutions, and societal values are inevitable but frequently unpredictable. The capacity to adapt will be essential." See the *Blue Ribbon Commission's final report* on nuclear waste, p. 62.
[53] *SotAR 2012* (SOU 2012:7).

supplemented this analysis with an account of the Japanese situation by Shiego Nomura, Executive Director of the Japan Atomic Energy Agency, JAEA.

In summary, three different approaches to spent nuclear fuel management can be distinguished today.

The *first* approach entails a preference for direct disposal. Finland and Sweden belong to this group.

The *second* approach entails a preference for recycling either in the form of established reprocessing technology (according to scenario A2, i.e. mono-recycling and MOX fuel) or in the form of more or less advanced plans according to scenario A3 (multi-recycling and breeder reactors), or in the longer term B1 (transmutation in Gen IV reactors), B2 (mono-recycling and MOX fuel + transmutation according to the ADS method) or B3 (mono-recycling and MOX fuel + transmutation according to the ADS method + multi-recycling and breeder reactors). France, China, Japan (before Fukushima), Russia and the Netherlands favour such an approach.

The *third* group includes countries that have not yet made any definite decision, for example the USA (after the decision to abandon the Yucca Mountain Project), the UK, Ukraine, Switzerland, Belgium, Taiwan and Canada.

Japan has an extensive programme for recycling of spent nuclear fuel according to scenario A2 (mono-recycling and MOX fuel). At the same time, research and development are being conducted on scenarios B1 (transmutation in Generation IV reactors) and B2 (mono-recycling and MOX fuel + transmutation according to the ADS method). Different Partitioning and transmutation (P&T) pilot plants are in operation. The reactor accidents in Fukushima on 11 March 2011 have created considerable uncertainty concerning the future direction of Japan's spent fuel management plans. Siting of a final repository is also an open question.

Availability of uranium

A *fourth theme* at the seminar was the question of uranium mining and the future availability of uranium. There were several different questions under this theme during the seminar. How much would the need for freshly mined uranium be reduced if different recycling alternatives were realized? What do we know about the future availability of uranium? And what social, environmental and other external costs does uranium mining entail?

Gene Rowe from the Nuclear Waste Technical Review Board (NWTRB, an advisory body to the American government in nuclear waste matters) presented a study whose objective was to estimate the saving of "fresh" uranium that would be achieved by reprocessing of the spent nuclear fuel from the Swedish nuclear power programme with subsequent production of MOX fuel (compared with direct disposal according to the KBS-3 method). He clarified that the answer to this question is dependent on what assumptions are made, regarding for example Swedish reactor operating lifetimes and reprocessing capacity. If it is assumed that the Swedish reactors have an operating lifetime of 40 years and that 50 tonnes of spent nuclear fuel is reprocessed to MOX fuel from 2025, the saving is 3.7%. But if it is assumed that the reactor operating lifetime is 50 years and that 400 tonnes of fuel is reprocessed from 2020, the saving is 40.2%. (Rowe also calculated a whole series of other scenarios between these extremes.)

The value of such recycling of uranium is naturally also dependent on the availability and cost of "fresh" uranium. Nomura and Forsberg gave an account of current research on extraction of uranium from seawater. The concentrations are low but the amounts are very great (about 10,000 times as much as other sources). If a breakthrough occurs in this technology within the next few decades, the price of uranium will come down, and mining of uranium and the reprocessing alternatives will become comparatively less interesting.

At the seminar, Gabrielle Hecht, Professor of History at the University of Michigan, presented social, ecological and political perspectives on the uranium issue.

> Uranium mining has long been an important part of the economies of African countries – Nigeria and Gabon, for example – and this has had an economic and political influence on the countries' international relations. Whether uranium mining is considered a nuclear activity or not affects how the activity is managed with respect to safety requirements, international agreements and working conditions.[54]

[54] Quoted from the Swedish National Council for Nuclear Waste's newsletter 2012:3, p. 4.

Ethical issues

Ethical issues comprised the *fifth theme* at the seminar. They were addressed by Benham Taebi, Assistant Professor of Philosophy at Delft University of Technology and ethics researcher at Uppsala University. There was agreement that it was possible to make an ethical comparison of different future scenarios for the management of spent nuclear fuel. Of particular importance is the ethical comparison between scenario A1 (direct disposal) and scenario B1 (transmutation in Generation IV reactors).

According to Taebi, there is a conflict of interest between the present generation and future generations when it comes to safety. In scenario A1 (direct disposal without reprocessing), final disposal is of great importance for the safety of both the present and future generations. Transmutation according to scenario B1 entails that the duration of the toxicity of the final waste is greatly shortened and that the final repository does not have to meet as rigorous requirements as a repository that has to be safe for more than 100,000 years. However, transmutation also entails greater risks for the present and future generations. Hazardous actinides have to be separated and managed. This agrees with SKB's claim that "the result of the transmutation will be to exchange the relatively low long-term radiotoxicity of the actinides for a relatively greater radiotoxicity with a shorter time span."[55]

This brings up a fundamental ethical question, namely whether it is right to expose present and future generations to the relatively greater radiotoxicity of the long-lived actinides in order to reduce their long-term radiotoxicity for generations who will live far in the future? It is not unreasonable to answer this question in the affirmative. Those who use nuclear power according to scenario B1 (transmutation in Generation IV reactors) and share in its benefits should also share in the comparatively higher risks involved in handling the actinides. Direct disposal would reduce the risks, but the problem will still remain for the generations who will follow in 10,000, 25,000 and even 100,000 years.[56]

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[55] *SKB's application*, Appendix MV (CM), p. 57.

[56] "…if one must choose between transferring the risks associated with HLW onto remote future generations, or transferring these risks to close future generations, the latter is preferable because of the closer relation between actual benefits and the risks associated with the benefits". (Löfquist 2008, p. 264.)

Climate change

Climate change was *the sixth theme* at the seminar. A decisive reason for encouraging the trend towards Generation IV reactors is that it enables us to reduce the use of fossil fuels. If this is true, the threat of climate change is an additional argument in favour of the recycling alternatives. *Generation IV International Forum* (GIF) emphasizes this argument, as does Christophe Poinssot in his presentation. But how relevant and viable is the climate argument when it comes to choosing the best energy system?

This question was addressed in a special presentation by Fredrik Hedenus, a researcher at the Chalmers University of Technology. His conclusion was that the climate target of a 2 degree increase in the Earth's average temperature by 2100 can be met even without nuclear power and new nuclear power technology. But this is predicated on a massive expansion of wind power from the present-day situation and of solar and hydroelectric power between 2050 and 2100. The costs are also projected to be higher than if the focus is on nuclear power, mainly in the form of scenario A3 (multi-recycling and breeder reactors). According to Hedenus, however, this is based on two prerequisites: in the first place, good and relatively inexpensive supplies of uranium – mainly due to a breakthrough in extraction of seawater uranium – and in the second place, improved systems for prevention of nuclear weapons proliferation. If these prerequisites are fulfilled, the climate target could be achieved with about 3,000 reactors in 2050 and about 6,000 reactors in 2070. Light water reactors would be a part of the global nuclear power fleet for a long transitional phase.

4.5 Other problems with the recycling alternatives

The seminar *The future of Nuclear Waste – Burden or Benefit?* helped shed light on many important research areas with a bearing on the future energy supply. But an evaluation of the seminar also reveals that certain issues require further elucidation – or were simply not taken up. In this section the Council would like to take a brief look at some examples of what may need to be elucidated in the continued process. Some other subjects for social science research are described in the concluding section.

The nuclear power issue was the subject of intensive discussions in the 1970s. The debate concerned not only technical issues such as reactor safety and waste management, but also the social and political consequences of the nuclear power programme. Social scientists pointed out the risks of large-scale energy systems and advocated lifestyle changes and a strengthening of local communities in better balance with nature. In the late 1970s, the Institute for Futures Studies conducted extensive studies of the relationship between energy systems and other societal issues.[57] According to these studies, ensuring freedom of choice in the 21st century required (1) a slowdown in the rate of increase in energy use, (2) flexible energy supply systems, and (3) a reorganized energy organization.[58] A similar study today could clarify the prerequisites for the next generation's freedom of choice in the middle of this century.

The Council previously addressed SKB's arguments against the recycling alternatives. The Council would like to return to an economic argument, namely that recycling of plutonium and uranium from the spent nuclear fuel (alternative 1) and transmutation of the spent nuclear fuel (alternative 2) will be more expensive than direct disposal according to the KBS-3 method. According to the analysis in the *Red-Impact* report, there is some evidence for this claim. The cost calculation in the report includes costs for development, construction, operation, fuel, waste, and decommissioning and dismantling.[59]

Table 1 Red-Impact study's calculations of electricity costs for different scenarios. 1 MkW (megakilowatt) is equivalent to the electricity used by a family of four for cooking during one year.

	Euro/MkW
Scenario A1 (direct disposal):	23
Scenario A2 (mono-recycling and MOX fuel):	25
Scenario A3 (multi-recycling and breeder reactors):	27
Scenario B1 (transmutation in Gen IV reactors):	28
Scenario B2 (A2 + transmutation according to ADS method):	32

[57] See *Energi och samhälle* 1975, plus the reports that followed up until 1978 – e.g. Wene 1976.
[58] See Lönnroth 1977, p. 524.
[59] *Red-Impact* 2008, p. 156.

According to this calculation, SKB's recycling alternative 1 (=A2) will be 2 Euro/MkW more expensive than A1; alternative 2 (=B1) will be 5 Euro/MkW more expensive than A1.

Thus, the recycling alternatives A2 and B1 are more expensive, but the difference between them and the direct disposal alternative A1 is not dramatic. According to another study, the cost of introducing a fully closed fuel cycle in Sweden could lead to an increase in the price of nuclear-generated electricity by 15±10%.[60]

SKB also says "that new 'fresh' nuclear fuel with enriched uranium has been and still is much less expensive than MOX fuel with plutonium from reprocessing".[61] According to the *Red-Impact* study, the total cost of continued operation according to the KBS-3 method is lower – but not much lower – than future operation with light water reactors according to scenario A2 (mono-recycling and MOX fuel). The operating costs ("Facility Operational Costs") include costs for mining and conversion, enrichment, fuel fabrication, reprocessing and operation and maintenance of reactors. The costs for construction and operation of the final repository in scenario A2 are, however, much lower than in the reference scenario A1 (geological disposal).[62]

SKB also cites safety-related arguments against the recycling alternatives. *The Red-Impact* study has devised a "proliferation resistance index," which is a combination of different measures of the ability of the different scenarios to prevent the spread of plutonium. The result is that the recycling scenarios A3 (breeder reactors) and B1 (Generation IV reactors) rate higher values of this index than other scenarios. This is because plutonium is reduced by burning in fast reactors and Generation IV reactors.[63] This result weakens SKB's safety-related arguments against the recycling alternatives.

The attempts to formulate a *proliferation resistance index* are based on a method called *Simplified Approach for Proliferation Resistance Assessment* (SAPRA). The author of this method is AREVA, France's counterpart to SKB, but unlike SKB AREVA is an advocate of recycling. At the same time, there are good reasons to question the attempt to simplify the question of the risk of nuclear weapons proliferation by means of a *proliferation resistance index*. The feasibility and desirability of preventing such proliferation

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[60] See Zakova & Wallenius 2013, p. 18.
[61] SKB's application, Appendix MV (CM), p. 56.
[62] *Red-Impact*, p. 154. It is unclear where the costs for the actual construction of a reprocessing plant appear in this analysis.
[63] *Red-Impact* p. 163.

is ultimately a political question. What provision does SAPRA make for such judgements?[64] Ultimately it is a question of weighing together scientific and ethical values – and the uncertainty entailed in such a procedure. The quantitative measures in the *proliferation resistance index* give the impression that such uncertainties can be eliminated. But is this really possible? This question leads us to a more general question about acting under uncertainty.

4.6 The Council's view of ethical action under uncertainty

In conclusion, the Council would like to offer some overall perspectives that have guided the Council's deliberations on different occasions. The basic criteria for making a decision in the nuclear waste issue were often discussed during the Council's first years. The Council – then called KASAM – frequently returned to the concept of ethical action under uncertainty.[65] Every answer to the question of how to manage the spent nuclear fuel is associated with uncertainty. This was summarized KASAM in its State-of-the-Art Report from 1998:

> We have a responsibility to search for the optimum solution on the basis of the knowledge that we have today. Since our knowledge of the long-term evolution of the repository is imperfect, our assessment of the consequences of our solution will be uncertain. For this reason, we must choose a solution that is sufficiently open to allow future generations freedom of choice. However, there are inevitably crucial cutoff points in time, in terms of both preserving freedom of choice and taking responsibility for the consequences of our actions. Our opportunity for assuming moral responsibility declines with time on a sliding scale.[66]

In awareness of this overall uncertainty – and with openness for the judgements of future generations – our generation must nevertheless make a decision based the knowledge at our disposal. It is then of fundamental importance that the different future alternatives be defined and articulated as comprehensively and completely as possible. It is also crucial that the scientific knowledge base be as

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[64] These reflections are inspired by Acton 2009, see specifically pp. 56 ff.

[65] The concept is closely associated with Anne-Marie Thunberg's work at KASAM (under Camilla Odhnoff's chairmanship 1986–2000). See SKN Reports 1988 and 1991 and KASAM 1993 *Acceptans Tolerans Delaktighet*, pp. 28–34.

[66] *SotAR 1998*, p. 4. See also *SotAR 2004*, Chap. 9.

reliable as possible. In addition, we must have a clear underlying set of values, in other words we must be clear about the goals we wish to achieve and the values that should guide the activity about which we are deciding.

The fundamental question is then how to weigh together all these factors: the future alternatives, the scientific knowledge base and our ethical values. Absolute certainty in these three areas is unattainable. The future alternatives must be defined in awareness of the unforeseeable; the knowledge base is characterized by an unavoidable incompleteness; and the value base will always be subject to dissenting opinions (for example how the responsibility principle, the safety principle and the KASAM/autonomy principle are to be reconciled, if it is not possible to fulfil all three). We can reduce this uncertainty, but never eliminate it.

In other words, the future alternatives, the knowledge base and the underlying set of values must be described in awareness of the unavoidable uncertainty. There is of course one way to dodge this uncertainty. "Certainty regarding the evolution of society can be gained...at the price of freezing this evolution, blocking opportunities for renewal, and replacing openness with closedness and rigorous control". [67]The alternative is to live constructively with the uncertainty, inspired by *confidence* and *flexibility*. Both of these concepts need to be further explored in the continued discussion of spent nuclear fuel management.

Confidence has become a key concept in social science research in recent years. Confidence and risk are two sides of the same coin. The Swedish National Council for Nuclear Waste was early in pointing out the need for a greater understanding of how people perceive risk.[68] This issue is particularly relevant for judging the future alternatives and scenarios regarding how the spent nuclear fuel is to be managed. A lack of confidence can contribute to exaggerated risk perceptions, while unwarranted confidence can obscure real risks. An important future task for the Council is to forge a link between risk research and confidence studies by social scientists.

Flexibility is another way to deal with the unavoidable uncertainty. The goal is to allow much freedom of choice as possible for the next generation. This is what Charles Forsberg said at the seminar in November 2012, and it was also stressed by the Council in its

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[67] Anne-Marie Thunberg i *Acceptans Tolerans Delaktighet*, p. 28.
[68] See *SotAR 1986*, p. 49.

most recent state-of-the-art report. The Swedish National Council for Nuclear Waste would like to conclude this report by calling to mind SKB's *RD&D programme* 2010 and its introductory section about "Flexibility in the face of changed premises," which notes that some changes in premises may require substantial and far-reaching adjustments. Examples are additional facilities or facility sections, or "changes in the layout of a final repository". Another example, as SKB also points out, is the construction of new nuclear power reactors. But changes in premises may also include the advent of *new types* of nuclear power reactors, for example Generation IV reactors, which would drastically alter the requirement specification for a final repository.[69]

[69] See *SotAR 2012*, pp. 24–27.

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Committee terms of reference 1992:72

Scientific committee charged with investigating questions concerning nuclear waste and decommissioning and dismantling of nuclear facilities etc.

Decision at Government meeting of 27 May 1992. Conducted by the head of the Ministry of the Environment and Natural Resources, Minister Johansson.

My proposal

I propose that a special scientific committee be appointed charged with investigating questions concerning nuclear waste and decommissioning and dismantling of nuclear facilities and of giving advice in these matters to the Government and certain public authorities.

Background

In Gov. Bill 1991/92:99 regarding certain appropriation matters for the budget year 1992/93 and changes in the national organization in the nuclear waste field, the Government proposed that the National Board for Spent Nuclear Fuel be abolished as a separate agency and that its activities be transferred to the Swedish Nuclear Power Inspectorate. The Bill proposed that the scientific council – KASAM – tied to the National Board for Spent Nuclear Fuel be given a more independent position and be tied directly to the Ministry of the Environment and Natural Resources as a commission instead of being administratively tied to an authority.

The Government (1991/92:NU22, rskr.226) has decided in favour of the Government's proposal for a changed national organization in the nuclear waste field.

Thus, a special scientific committee charged with investigating questions concerning nuclear waste and decommissioning and dismantling of nuclear facilities and of giving advice in these matters to the Government and certain public authorities should be appointed.

Task

The committee should

- every three years, starting in 1992, submit by not later than 1 June a special report describing its independent assessment of the state of the art in the nuclear waste field.
- not later than nine months after the point in time specified in Section 25 of the Ordinance (1984:14) on Nuclear Activities, submit a report describing its independent assessment of the programme for the comprehensive research and development work and other measures which the the holder of a licence to own or operate a nuclear reactor shall prepare or have prepared according to Section 12 of the Act (1984:3) of the Act on Nuclear Activities.

The committee should also offer advice in matters relating to nuclear waste to the Swedish Nuclear Power Inspectorate and the Swedish Radiation Protection Authority when requested to do so.

Whenever necessary and economically feasible, the committee should undertake foreign travel to study facilities and activity in the nuclear waste field and arrange seminars on general topics in nuclear waste management.

The committee should comply with the Government's instructtions to state committees and special investigators as regards the thrust of its proposals (Dir. 1984:5) and the EU aspects of the investigations (Dir. 1988:43).

The committee should consist of a chairman and at most ten other members. It should also be allowed to engage outsiders for special assignments whenever necessary and economically feasible.

Chairman, members, experts, consultants, secretary and other assistants should be appointed for a defined term.

The committee's task shall be regarded as completed when the Government has made a decision on the licence application for a final repository for spent nuclear fuel and high-level nuclear waste in Sweden.

Petition

With reference to the above, I petition that the Government authorize the head of the Ministry of the Environment and Natural Resources,

- to appoint a special scientific committee – subject to the Committee Ordinance (1976:119) – with not more than eleven members charged with investigating questions concerning nuclear waste and decommissioning and dismantling of nuclear facilities and of giving advice in these matters to the Government and certain public authorities,
- to appoint chairman, members, experts, consultants, secretary and other assistants.

I further petition that the Government order that the costs be charged to appropriations under the fourteenth title "Commissions etc.".

Decision

The Government concurs with the rapporteur's suggestions and approve his petition.

Committee terms of reference 2009:31

Supplementary terms of reference for the Swedish National Council for Nuclear Waste (M 1992:A)

Decision at Government meeting of 8 April 2009

Summary of task

The Swedish National Council for Nuclear Waste was established by a decision at a Government meeting on 27 May 1992 (dir. 1992:72). The Swedish National Council for Nuclear Waste shall investigate and shed light on matters relating to nuclear waste and decommissioning and dismantling of nuclear facilities etc. and give advice to the Government in these matters. Aside from the Government, important target groups for the Swedish National Council for Nuclear Waste are also concerned public authorities, the nuclear power industry, municipalities, interested organizations, politicians and the mass media.

The Swedish National Council for Nuclear Waste shall possess broad scientific qualifications in natural science, technology, the social sciences and the humanities.

The task of the Council shall be regarded as completed when the Government has decided on a final repository for spent nuclear fuel and high-level nuclear waste in Sweden.

These terms of reference replace the terms of reference from 27 May 1992.

Task

The Swedish National Council for Nuclear Waste shall assess the Swedish Nuclear Fuel and Waste Management Co's research, development and demonstration programmes (RD&D programmes), applications and other reports of relevance for the final disposal of nuclear waste. The Council shall – not later than nine months after the Swedish Nuclear Fuel and Waste Management Co has submitted its RD&D programme in compliance with Section 12 of the Act (1984:3) on Nuclear Activities – submit its independent assessment of the research and development activities and the other measures described in the programme.The Council shall also follow the work being done on decommissioning and dismantling of nuclear facilities.

In the month of February every year, starting in 2010, the Council shall submit a report on its independent assessment of the state of the art in the nuclear waste field.

The Council shall investigate and shed light on important issues in the nuclear waste field, for example by holding hearings and seminars, so that it can make well-founded recommendations to the Government.

The Council shall also keep track of other countries' programmes for management and disposal of nuclear waste and spent nuclear fuel. The Council should also follow and, where necessary, participate in the work of international organizations on the nuclear waste issue.

These terms of reference replace the terms of reference from 27 May 1992 (dir. 1992:72).

Organization

The Swedish National Council for Nuclear Waste shall consist of a chairman and not more than ten other members (one of whom also acts as deputy chairman). The members shall have broad scientific qualifications in fields related to the nuclear waste issue. It can engage outsiders for special assignments whenever necessary and economically feasible. Chairman, members, experts, consultants, secretary and other assistants shall be appointed for a defined term.

Timetable

The task of the Council shall be regarded as completed when the Government has decided on a final repository for spent nuclear fuel and high-level nuclear waste in Sweden.

(Ministry of the Environment)

Kärnavfallsrådet

Swedish National Council for Nuclear Waste

Statement of opinion

31/10 2012 Dnr 43/2012

Nacka District Court
Land and Environment Court
Unit 3
P.O. Box 1104
131 26 NACKA, Sweden

The Swedish National Council for Nuclear Waste's viewpoints regarding the need for supplementary information in an application for a licence for facilities in an integrated system for final disposal of spent nuclear fuel and nuclear waste (M 1333–11)

On 16 March 2011, the Swedish Nuclear Fuel and Waste Management Co (SKB) submitted an application to the Land and Environment Court at Nacka District Court for a licence for facilities in an integrated system for final disposal of spent nuclear fuel and nuclear waste.

In a communication dated 5 April 2011, the Land and Environment Court at Nacka District Court asked the Swedish National Council for Nuclear Waste whether the application documents needed to be supplemented in any respect by the applicant before a public notification pursuant to the Environmental Code can be issued. The Council's viewpoints regarding the need for supplementary information shall be submitted to the Land and Environment Court at Nacka District Court by 1 November 2012.

The Swedish National Council for Nuclear Waste

The Swedish National Council for Nuclear Waste is an independent scientific council charged with the task of examining issues relating to nuclear waste and the decommissioning and dismantling of nuclear facilities etc. and advising the Government in these matters on the basis of a broad scientific perspective including the natural sciences, technology, the social sciences and the humanities.[1] In order to be able to give sound advice to the Government, the Council keeps track of the development of other countries' final repository programmes as regards the management and disposal of nuclear waste and spent nuclear fuel.

The Council shall also assess the SKB's research, development and demonstration programmes (RD&D programmes), applications and other reports of relevance for the final disposal of nuclear waste.

The members of the Council are:

[1] Dir.2009:31 Supplementary terms of reference for the Swedish National Council for Nuclear Waste (M 1992:A).

- Torsten Carlsson (Chairperson), former chairman of the municipal executive board in Oskarshamn
- Carl Reinhold Bråkenhielm (Deputy Chairperson), Professor Emeritus of Empirical Life Philosophy Studies at Uppsala University, Senior Professor, Ersta Sköndal University College
- Lena Andersson-Skog, Professor, Economic History, Umeå University
- Willis Forsling, Professor Emeritus, Inorganic Chemistry, Luleå University of Technology
- Mats Harms-Ringdahl, Professor, Radiation Biology, Stockholm University
- Tuija Hilding-Rydevik, Associate Professor, Land and Water Resources specializing in EIA, Swedish University of Agricultural Sciences, Director of Swedish Biodiversity Centre
- Karin Högdahl, Associate Professor, Geology, Uppsala University
- Lennart Johansson, Associate Professor, Radiophysics, Norrland University Hospital
- Thomas Kaiserfeld, Professor of History of Ideas and Sciences, Lund University
- Jenny Palm, Professor of Technology and Social Change, Linköping University
- Clas-Otto Wene, Professor Emeritus, Energy Systems Technology, Chalmers University of Technology

Experts at the Swedish National Council for Nuclear Waste are Hannu Hänninen, Professor of Materials Science at Aalto University School of Science and Technology, and Ingvar Persson, Bachelor of Laws and former General Counsel at the Swedish Nuclear Power Inspectorate

The Administrative Director of the Swedish National Council for Nuclear Waste is Holmfridur Bjarnadottir, while the scientific secretary is Peter Andersson.

Background to the Council's viewpoints

SKB is applying for a licence for final disposal of spent nuclear fuel according to the KBS-3 method. The review process for licensing covers the encapsulation plant, shipments from Oskarshamn to Östhammar and the final repository. The purpose of the applied-for activity is "to dispose of the spent nuclear fuel in order to protect human health and the environment from the harmful effects of ionizing radiation from the spent nuclear fuel, now and in the future"[2]. The final repository is a measure aimed at achieving this purpose and thereby comprises a protective measure to be judged, based on the principle of the best available technology, pursuant to Chap. 2 Sec. 3 of the Environmental Code.

It is, however, urgent that the treatment of the application not lead to a limitation of perspective in the nuclear waste issue. The period of time for which the spent nuclear fuel must be isolated to render it harmless to human health and the environment is almost incomprehensibly long, and the risk analysis for a final repository should cover about a hundred thousand years (the length of a glacial cycle) in order to shed light on reasonably foreseeable external stresses on the final repository.

The assessment of the final repository's protective capability for the first thousand years after closure shall be based on quantitative analyses of the effects on human health and the environment. For the time following the first thousand years after closure, the assessment of the final repository's protective capability shall be based on different conceivable scenarios.

Different possible methods for final disposal of the spent nuclear fuel should therefore be considered and alternatives to the KBS-3 method should be thoroughly examined in the court. The Council further assumes that the process in the Land and Environment Court will include all circumstances of importance for the question of permissibility.[3] Nor are there any formal obstacles to prevent the Land and Environment Court from examining all questions related to nuclear safety and radiation protection.[4]

The Council therefore expresses viewpoints that shed light on SKB's application from a broad perspective, including to what

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[2] Application under the Environmental Code, top document, page 4.
[3] See Gov. Bill 1997/98:45 Part 2 p. 235.
[4] See the Superior Environmental Court's judgement MÖD 2006:70 (M 3363-06).

degree the application contributes to well-underpinned decision-making.

Introduction

Levels for meaningful analysis

The application is very extensive and is based on complex analyses of results from different branches of the natural sciences. It also contains assumptions about sequences of events that extend over long geological periods of time and presumes a well-executed development of technology. Construction and operation extend over at least three generations.

The disposition of SKB's application is such that it is difficult to get an overview of the application. The purpose of Table 1 is therefore to provide an overview of the processes set in motion by the application, what decisions are required in processing the application, what the construction of the final repository entails, and how the safety of the facility is guaranteed.

In this perspective, analysis and decision processes are seen to proceed in parallel on four different levels and one support level. Analyses and discussions of goals and means can be pursued independently on each level, but are conditional upon the results of the processes on the other levels.

The base for the final repository project consists of the results of the work with expert discussions and safety assessments on the level "Site description and barriers". This work must be supported by scientific and technical research and development. Conversely, a final repository can only be realized if all actors on the top level have decision-making competence. The demands on transparent and legitimate processes for realizing the final repository are extremely high. These demands are met in different ways for the decision-making process and construction of the final repository. Table 1 distinguishes between the organizational processes aimed at creating the legitimate premises for being able to realize a reasonably safe final repository (Level 2: Staging), and the work of physically putting the repository in place, i.e. design, build, operate and close the repository (Level 3: Industrial Project Final repository). The processes on the two levels proceed in parallel but are conditional upon each other. An important link between these two levels is the control processes in SKB for guaranteeing that the requirements of the safety assessment are met. The decision-making process are thus pursued independently on each level but influence each other, and this influence must be clearly shown.

Stable decisions on final disposal must furthermore also include the ethical dimension.

The ethical dimension

From the very start of its activities, the Council has stressed the relevance of ethical issues to the nuclear waste issue, for example in the choice of final disposal method. In the Preface to the report from the seminar "Ethics and nuclear waste" (1988), Camilla Odhnoff (then chairperson of KASAM, the former name of the Swedish National Council for Nuclear Waste) and Olof Söderberg (then Director General of the National Board for Spent Nuclear Fuel) write the following:

> Opinions clash with exceptional heat in the issue of nuclear waste. The topic engages both reason and emotions. What is right and what is wrong when it comes to consequences many thousands of years ahead in time?

The relevance of ethics for the nuclear waste issue has also been affirmed by the Government, public authorities and industry. One can also distinguish how *basic ethical values* are manifested in Government statements, regulatory requirements and SKB's industrial planning. A distinguishing characteristic of these basic values is that they have been regarded as binding and based on general moral judgements. Examples of such basic values are the following (the italicized terms are the Council's):

> 1. **The purpose** of the applied-for activity is to dispose of the spent nuclear fuel in order to protect human health and the environment from the harmful effects of ionizing radiation from the spent nuclear fuel, now and in the future.
> (*The safety principle* according to SKB's application, top document, p.4).
>
> 2. … it is morally right that the generation that benefits from the nuclear power should also take responsibility for finding a solution to the waste problem.
> (*The responsibility principle* according to former Environment Minister Andreas Carlgren, UNT 04 April 2011).

> 3. A final repository should be designed to render monitoring and controls unnecessary, but not impossible.
> (*The KASAM principle* according to KASAM's state-of-the-art report 1987, p. 92).

The Swedish National Council for Nuclear Waste has, in various contexts, underscored the need to have these basic values expressly formulated (see e.g. KASAM's state-of-the-art report 2004, Chap. 11). One of the fundamental reasons for such a formulation is to enable conflicts between these different basic values to be analyzed and handled. For example, two such conflicts can be distinguished between the above principles. *In the first place*, let us consider the relationship between the safety principle and the responsibility principle. There does not necessarily have to be a conflict, but on the other hand it is not completely certain that the current generation will be able to dispose of the spent nuclear fuel so that human health and the environment are adequately protected "from the harmful effects of ionizing radiation from the spent nuclear fuel, now and in the future". *In the second place*, a similar tension can be seen between the safety principle and the KASAM principle. It may be that and monitoring and controls are not unnecessary at all, but rather necessary to fulfill the safety principle. There are similar conflicts between other basic values as well.

This need for articulated basic values and conflict management has to some extent been met in SKB's application. However, the Council notes the absence of a coherent discussion of basic values in the nuclear waste issue and ways and means to handle possible conflicts between these basic values.

Table 1 Levels for the Council's analysis of SKB's application. Examples of goals, processes and actors for reaching the goals are given at each level.

Level	Goals and means	Actors
Level 1: National decision	Goal: to develop competence to make decisions about the final repository Means: clarifying the implications of the application	National politicians – will prepare themselves for the Government decision Municipalities – have participated in the process for 20 years SSM – has participated in the process for 20 years Land and Environment Court – has participated since the application was submitted in March 2011 Swedish National Council for Nuclear Waste – has participated in the process since 1992
Level 2: Staging	Goal: to realize a reasonably safe final disposal Means: - the EIA process - Licensing - The control process that guarantees that the final repository fulfils the demands of the safety assessment	SKB SSM Land and Environment Court Municipalities Swedish EPA Swedish National Council for Nuclear Waste
Level 3: Final repository (industrial level)	Goal: to put in place a reasonably safe final repository, i.e. to design, build, operate and close a facility that leads to a reasonably safe final repository Means: - Building code (design premises) - Monitoring procedures	SKB SSM Swedish EPA Swedish National Council for Nuclear Waste
Level 4: Site description and barriers	Goal: to guarantee that a reasonably safe final repository can be built Means: - Safety assessment - Expert discourses - Site investigations	SKB SSM Swedish National Council for Nuclear Waste
Support level: Research and development	Goal: support levels 1- 4 Means: - Scientific methodology - New knowledge	Swedish universities International experts

A reasonably safe final repository is a repository that meets the established safety requirements. By making the distinction “reasonable safety” at level 2 in the table, the Council wishes to indicate its standpoint that the assessment of the long-term safety of a final repository is the result of a process of interaction between standards, values, science and technology. This expression is less static than “established safety requirements”. At the same time as it includes the established requirements, it also allows room for the changes and advances in knowledge and technology that are expected to result from the final repository process as it is described in the above table. Expressed in another way: The requirements on safety may change during the decision process, and methods must be available to clarify and handle these changes.

The Council’s viewpoints are mainly concerned with the application’s Top Document and the Appendices MKB/EIS (miljö-konsekvensbeskrivning = environmental impact statement), AH/AG (allmänna hänsynsregler = general rules of consideration), PV/SS (platsvalet = site selection), MV/CM (metodvalet = choice of method), KP/MP (kontrollprogram = monitoring programmes), plus Appendices SR, SR-Site and SR-Drift/Operation (the safety analysis reports).

- The application’s Top Document is closely related to the questions that are asked at the national decision-making level, i.e. whether the top document is of the quality required to mobilize decision-making competence, in other words to develop the competence required to make decisions on the final repository for spent nuclear fuel.
- The Appendices MKB/EIS, AH/AG and MV/CM are linked to level 2 and pose questions concerning how SKB has staged the decision processes up to and including the licensing process.
- KP/MP links levels 2 and 3. It has management and control functions on level 2, and a function for monitoring of the external environment during construction and operation on level 3.
- Appendix SR – “Safety analysis report for final disposal of spent nuclear fuel” with the sub-appendices SR-Drift/Operation and SR-Site – is the most voluminous appendix. Appendix SR describes how SKB intends to organize construction and operation after a licence to build the repository is obtained and

belongs to level 2. SR-Drift/Operation deals with the processes and verifications that are required to put a reasonably safe final repository in place and how to do this under level 3. SR-Site is the main document for level 4 and its link to natural science research and technology development, and Appendix PV/SS is a part of the background material for the decision process under level 4.

The Council bases its statement of opinion on its members' areas of competence and questions which the Council has raised on previous occasions, such as in the Council's reviews of SKB's Research, Development and Demonstration (RD&D) programmes and the Council's state-of-the-art reports (the reports on the current state of knowledge in the field that are submitted annually to the Environment Minister).

Need for supplementary information

It is the Council's considered opinion that the application should be supplemented with the following information for permissibility assessment by the Land and Environment Court:

Table 2 Summary of the Council's viewpoints on the need for supplementary information

Viewpoints on the application's top document	
1 Accessibility See page 17	It is the Council's considered opinion that - SKB should improve the searchability of the application material, particularly from the top document to the appendices and with clearer references to background reports. - links to relevant places in the background material would improve the searchability of the application and thereby provide a better basis for a decision.
2 Decision process See page 18	It is the Council's considered opinion that - the application should be supplemented with a description of the decision process, the parallel processes and the roles and responsibility of the actors in the process. - the application should be supplemented with an analysis of the situation that could arise if the work with the final repository were to be severely delayed or unsuccessful.
3 Responsibility and ownership See page 19	It is the Council's considered opinion that - responsibility and ownership conditions for the spent nuclear fuel and the final repository should be clarified in SKB's application. This includes the division of responsibility between the reactor owners and SKB, as well as between the state, the municipality and the landowners after closure. - the division of responsibility between the reactor owners and SKB should be clarified based on the obligations borne by the reactor owners.
4 Safety and radiation protection See page 20	It is the Council's considered opinion that - the application should be supplemented with the information that is included in the application under the Nuclear Activities Act but is absent from the application under the Environmental Code.
5 Physical protection See page 21	It is the Council's considered opinion that - the application should be supplemented with information on physical protection.
6 Financing See page 22	It is the Council's considered opinion that - SKB should explain what other guarantees besides the assets in the Nuclear Waste Fund are at the company's disposal to ensure that sufficient funds are available to repair the environmental damage or carry out any other remediation measures occasioned by the activity. - SKB should explain what means are available to SKB to complete the final repository project in the event the assets of the Nuclear Waste Fund do not suffice to cover the costs incurred by the final repository works.
7 Preservation of knowledge See page 23	It is the Council's considered opinion that - SKB's application should be supplemented with a plan of action for preservation of information and knowledge. The plan should describe how SKB intends to preserve information on the final repository during the deposition period and transfer knowledge for future generations to administer.

Viewpoints on the application's appendices	
8 Environmental Impact Statement See page 24	
8.1 Formal requirements on the EIS See page 24	It is the Council's considered opinion that - the application should be supplemented to satisfy the Environmental Code's requirements on the environmental impact statement as a basis for an assessment of long-term safety, description and assessment of the choice of method, the so-called "no action alternative" (zero alternative) and what underlies SKB's choice of site. - the appendices that describe site and choice of method should be included in the EIS.
8.2 Scope of description and assessment of possible environmental effects – radiological risks and cumulative effects See page 24	It is the Council's considered opinion that - the cumulative effects of a nuclear accident in one of the nuclear facilities and what impact they might have on the final repository should be described in greater detail in the EIS. - An overall picture of the activity and risk factors associated with its execution must be provided in the EIS. SKB must provide a clearer description of the impact of the activity on human health and the environment, as well as the risks entailed by the activity and the consequences of possible nuclear accidents.
8.3 Account of choice of site and method, including no action alternative See page 25	It is the Council's considered opinion that - The EIS should provide a clearer account of why SKB has chosen Forsmark, compared with Laxemar and other possible sittings in Sweden (which have previously been considered in the process), i.e. the account included in Appendix Site Selection. - The EIS should be supplemented with a clearer description and impact assessment of the so-called "no action alternative," a description of the consequences if the activity or the measure is not implemented. It is the Council's considered opinion that effects and consequences of delays in the process that could lead to a realization (albeit time-limited) of the no action alternative should be described and assessed. - The EIS should be supplemented with a comparative account of alternative methods for final disposal with respect to safety, radiation protection and environmental impact, and SKB should justify its support for the chosen method against the background of such an account.
8.4 Scope of the activity with regard to construction phase, operating phase and decommissioning phase See page 27	It is the Council's considered opinion that - The EIS should, in accordance with the Environmental Code, describe the whole system and its impact on the environment during all of its phases. The Council thereby believes that decommissioning and dismantling of Clab and the encapsulation plant should also be included in the EIS.
8.5 Physical protection/risk of intrusion See page 27	It is the Council's considered opinion that - a description of physical protection and risks as a consequence of intentional human actions should be provided in the EIS. - The EIS should also be supplemented with the information in Appendix VP/AC –

	"Activity, organization, leadership and management" – that is included in the application under the Nuclear Activities Act and has been submitted to the Swedish Radiation Safety Authority.
8.6 Description of psychosocial effects See page 26	It is the Council's considered opinion that - psychosocial effects have not been explored sufficiently in the EIS. - The EIS does not describe the direct and indirect effects which the planned activity or measure might have on human health and should be supplemented in this respect.
8.7 Impact on natural values See page 28	It is the Council's considered opinion that - SKB should supplement the application with a discussion of how red-listed species will be affected and how the impact on these species can be minimized. - The EIS should be supplemented with the information contained in SKB reports SKB R-10-16, "Vattenverksamhet i Forsmark Ekologisk fältinventering och naturvärdesklassificering samt beskrivning av skogsproduktionsmark" and SKB P-11-04, "Underlag till ansökan om dispens enligt artskyddsförordningen Vattenverksamhet i Forsmark" so that the Land and Environment Court can assess the magnitude of the environmental consequences of SKB's planned activities. - SKB should supplement the application with results from its pilot studies where they intend to show that the compensatory measures have the intended effects.
8.8 Consultation viewpoints See page 28	It is the Council's considered opinion that - The EIS should be supplemented with an account of how the viewpoints expressed during the consultations have been taken into account.
9 Viewpoints on Appendix Site Selection See page 29	It is the Council's considered opinion that - SKB should include in its safety analysis report a scenario where a calculation is made of how many canisters would be affected by fracture propagation and formation of new fractures in zone WNW0123, and what consequences this might have for long-term safety. - SKB should provide a detailed explanation of why they rule out the possibility that the zone could, in the event of future earthquakes, propagate through the northwestern part of a future repository in Forsmark.
10 Viewpoints on Appendix Choice of Method See page 31	It is the Council's considered opinion that - the background material cited in the application regarding choice of method should be included in the application documents, in particular the report "Jämförelse mellan KBS-3-metoden och deponering i djupa borrhål för slutligt omhändertagande av använt kärnbränsle"[5]. - the references cited for the alternative method Deep Boreholes should be updated with more recent and relevant references with the results of the latest research. - a more thorough investigation is required of how extending the operating times of the nuclear power plants would affect the interim storage of spent nuclear fuel, in other words on site storage would be required or if the current interim storage facility for spent nuclear fuel, Clab, would suffice. - SKB should more clearly examine the consequences of the fourth generation reactors for the nuclear fuel programme.

[5] Grundfelt, 2010: Jämförelse mellan KBS-3-metoden och deponering i djupa borrhål för slutligt omhändertagande av använt kärnbränsle R-10-13.

	- the issue of reversibility and retrievability should be examined in SKB's application with regard to the consequences of reversibility and retrieval in different phases of the execution of the final repository project and the safety analysis report. - SKB should explain why the spent nuclear fuel will not be reused and recycled according to the Environmental Code's general rules of consideration (the conservation and sustainability principles).
11 Viewpoints on Appendix Technical Description See page 35	It is the Council's considered opinion that - the appendix should be supplemented with a description of how SKB intends to handle logistics and possible disturbances between three continuously ongoing processes in the underground activities involving extensive rock works, deposition and backfill/plugging of deposition tunnels. - the appendix should be supplemented with references that make it possible to study in detail processes and designs, i.e. to go from what is called level 0 in SKB's safety assessment (equivalent to Appendix TP/TD) to deeper levels (cf. Fig. 4-1 on page 8 in Appendix SR). - the appendix should be supplemented with a flow chart for Buffer Production equivalent to the flow charts given for the processes Rock Works, Deposition and Backfilling.
12 Viewpoints on Appendix Monitoring Programmes See page 36	It is the Council's considered opinion that - SKB should provide a coherent overall picture of the monitoring programmes. - SKB should explain how they will monitor conditions during the operating period in sealed parts of the repository (plugged deposition tunnels) to ensure that they evolve in accordance with the assumptions in the safety assessment. - There is no description in the application of monitoring programmes for release monitoring or environmental monitoring. - SKB should supplement the proposal for monitoring programmes with an explanation of why radiological monitoring of the interim storage in Clab is performed as a part of Clab's self-monitoring programme but is not included in the proposal.
13 Viewpoints on Appendix Safety Analysis Report See page 38	It is the Council's considered opinion that - SKB should conduct a system analysis to clarify the implications of and relationships between the three main elements safety assessment, building code/design premises and initial state, and show how Figure 3-1 in Appendix SR will be realized in the organization of and relationships between the two main processes Construction and Safety Assessment. – In the application, SKB should describe a measurement programme that makes it possible to define the initial state at one and the same time. If SKB should arrive at the conclusion that it is impossible with today's measurement technology to measure the state of deposited canisters and tunnels after backfilling without disturbing the barriers, then SKB must explain why a monitoring programme is unnecessary. See further "Need for supplementary information" under Chapter 14.2 "Viewpoints on the engineered barriers".
14 Viewpoints on Appendix SR Site. See page 43	
14.1 Viewpoints on the geosphere	It is the Council's considered opinion that - the application should be supplemented with additional knowledge about the rock

See page 43	stresses at planned repository depth in Forsmark. - the cause of the high rock stresses and the stress field around the lens should be described better. The same applies to the importance of the direction and size of the rock stresses for planning and construction of the tunnels to and in the final repository. - In preparation for the future detailed planning of the repository, SKB should investigate hydraulic connections along the important Singö Zone. - SKB should study the transport properties in the bedrock, and in particular investigate the difference between unaffected rock and the rock that has been affected by the tunnelling work (EDZ). - the structure A1 should be characterized geologically and its hydrological relationship with the zones ENE0810 and ENE0060A be determined. - SKB should continue the measurements and long-term monitoring of possible rock movement, including creep, in Forsmark during construction and operation of the repository. - SKB should further examine the claim that there are no future exploitable mineral resources in the Forsmark area before the possibility of mineral deposits in the north/northeasterly direction outside the tectonic lens and in the water-covered unexposed area can be ruled out with certainty.
14.2 Viewpoints on the engineered barriers See page 49	
Specific viewpoints on the canister See page 50	It is the Council's considered opinion that - SKB should describe the safety functions of the canister that include the consequences of creep and corrosion, particularly in welded joints. - creep and creep modelling of the entire canister under different mechanical stresses should be investigated. - results of corrosion tests in a laboratory environment should be compared with and interpreted on the basis of repository-like conditions. - formation and transport of hydrogen from copper corrosion in an oxygen-free environment under high external pressure in the final repository should be investigated. The influence of hydrogen on the mechanical properties of the canister should be described. - a description of the damage tolerance of the cast iron insert and the reliability of nondestructive testing for detecting small defects should be included.
Specific viewpoints on the buffer See page 52	It is the Council's considered opinion that - SKB should investigate how the long-term strength of the bentonite blocks in the deposition holes is affected by a diminishing water content due to drying-out. A particular issue here is the verticality (uprightness) of the copper canisters in the deposition holes. - SKB should investigate how the chemical and physical properties of the buffer are affected by long-term exposure to high temperature in the deposition holes. - SKB should investigate how the interaction between buffer, rock and canister – as well as between buffer and backfill – will function under conditions with a very uneven water supply.

	- SKB should find out more about how rapidly the oxygen in the air and pore water in the buffer is consumed and what the mechanisms for this are in unsaturated vs. water-saturated bentonite. - SKB should investigate and describe the consequences of artificially saturating the buffer in the deposition holes with water by injecting an optimal amount of water of known composition and temperature. The procedure should be combined with a monitoring system specially developed for the purpose.
Specific viewpoints on the backfill See page 54	It is the Council's considered opinion that - SKB should investigate how the mechanical stability and capacity to sorb water of the bentonite blocks in the backfill is affected by the fact that conditions will vary in different parts of the deposition tunnels for a long period of time. - SKB should investigate how blasting and other activities in adjacent tunnels affect blocks and pellets in already backfilled tunnels. - SKB should investigate how the fraction of bentonite pellets in the backfill can be reduced by shaping the contours of the bentonite blocks to fit the roof and walls of the deposition tunnels. - SKB should investigate how buffer and backfill interact during very dry periods and whether the influx of water is very uneven. - SKB should investigate the possibility of activating the surfaces of the mineral particles in the bentonite before compaction in order to speed up the wetting process.
15 Viewpoints on Appendix SR-Operation See page 56	It is the Council's considered opinion that - a discussion of unforeseen events should be included in SR-Drift/Operation. - concrete and measurable quality requirements to be applied to the final repository must be established and presented by SKB in order for the court to be able to form an opinion about the quality requirements. Furthermore, SKB should specify how the quality requirements can be measured. - SKB should describe the use and quantity of concrete in the final repository (including concrete in deposition holes). - relevant excerpts from the production reports should be presented in SR-Drift so that the Land and Environment Court can judge the final repository's requirements on engineered and natural barriers. - SKB should present a detailed logistic description of the deposition sequence, including the distance from main tunnels to deposition holes. This description should take into account e.g. blasting of new deposition tunnels in the dry rock in Forsmark. - SKB should explain whether the bentonite in deposition holes is planned to be produced in a separate line from the bentonite for deposition tunnels in order to avoid the risk of mixing bentonite grades with different quality requirements.

1 Accessibility

One of the most important functions of the application is to serve as a basis for decisions by decision-makers at the national and municipal level. Responsibility for the decision to build or not to build a proposed repository ultimately rests with the country's political bodies, in the last instance the Government. Municipal decision-makers also play an important role in the process. In this way, the application and the material presented in support of the application serve an important democratic function, namely to provide politicians with comprehensive information on the matter that can be understood by a layman.

Even though review requires complex analyses, the actual review process must be clear and transparent and be possible for concerned citizens to follow. The safety assessment must also be described in a way that can be understood by laymen, since it is included in the material which the politicians must consider.

It is the Council's considered opinion that the supporting material is not sufficiently transparent as regards structure, readability and accessibility, which undermines the role of the application as a decision-making basis. As examples, let us consider the main report for the project SR-Site and report R-10-42 (English version R-11-07). These reports are very large, and virtually the same issues or phenomena are mentioned at several different places and under different headings. Readability would therefore be greatly improved by an introductory overview. An index at the end of report III for SR-Site would also be valuable, where definitions of terms could also be included.

Important information concerning the choice of alternatives or the safety of the facility have the character of general information on how the facility is envisaged to work. For more detailed information, the reader is referred to underlying documents in the safety analysis report. This information can be hard to find in the large body of material, and certain information is only found in the application under the Nuclear Activities Act but is absent from the application under the Environmental Code.

The Council's assessment of the need for supplementary information:

SKB should improve the searchability of the application material, with clear references to background reports. All references in the top document should be made directly accessible via a link system developed for text in PDF format. This would substantially facilitate a fair and thorough review of the application and its appendices.

All material referred to shall be accessible in the application.

2 The decision process

The review that takes place in the municipalities of Östhammar and Oskarshamn is crucial in determining whether the facility is to be permitted. The municipal council in both municipalities must either approve or reject the final repository before the Government makes a decision on permissibility according to the Environmental Code. The Government may only permit the activity if the municipal council in the municipality where the facility will be sited has approved it – the municipal veto. The top document plays an important role in this context. It may be the main document which the members of the municipal council will consult.

The municipal veto has, however, been provided with a "veto valve" when it comes to facilities for interim storage or final disposal of nuclear material or nuclear waste. The Government may permit the activity without the approval of the municipal council if it is of the utmost importance for the national interest that the activities be realized.

However, in order for the activity to be permitted without the municipality's approval, no other more suitable site must be available for the activity.[6] This refers not only to the suitability of the site from technical and economic perspectives, but also from ethical, social and environmental perspectives. The reasons given by the municipalities for their attitudes must also be taken into consideration. Thus, a site in a municipality that approves the siting may be considered more suitable than a site in a municipality that opposes an establishment, even if a siting in the latter municipality

[6] Cf. Chap. 17 Sec. 6 paragraph 4 of the Environmental Code.

entails less of an intrusion in the environment, lower costs, etc. In summary, the right of the Government to override the municipal veto must be exercised extremely restrictively.

A brief description of the parts of the licensing process, with a focus on permissibility, is provided in Chapter 9 of the top document, "Permissibility". It is the Council's considered opinion that a clearer picture of the responsibility borne by different actors in the process would be valuable for the handling of the application. This applies, for example, to the municipality's role in the process, the municipal veto and the veto valve. A description of the planned timetable for the treatment of the application and the uncertainties and risks of delays inherent in the decision process, plus an analysis of the consequences of these uncertainties and risks, would make the material more complete.

The Council's assessment of the need for supplementary information:

The application should be supplemented with a description of the decision process, the parallel processes and the roles and responsibility of the actors in the process.

It is the Council's considered opinion that the application should be supplemented with an analysis of the situation that could arise if the work with the final repository were to be greatly delayed or unsuccessful.

3 Responsibility and ownership

Responsibility for and ownership of the spent fuel and the final repository, both during the deposition phase and after closure, is an important issue in considering the application.

According to the Nuclear Activities Act, the reactor owners and other nuclear activity licensees are obligated to safely manage and dispose of the nuclear material, spent nuclear fuel and nuclear waste that has arisen in the activity and will not be reused. This obligation entails a long-term commitment for the reactor owners. Responsibility to fulfill the obligations remains until all activities at the facilities have ceased and all nuclear material and nuclear waste has been placed in a final repository that has been permanently closed.

According to the Nuclear Activities Act, the reactor owners are also responsible for the costs of the management and final disposal of the spent nuclear fuel and the nuclear waste.

In this context, SKB is a contracted consultant to the reactor owners and therefore does not share in the legal responsibility incumbent upon the reactor owners for final disposal of the spent nuclear fuel. SKB's responsibility concerns pre-closure safety, including physical protection of the facilities for which the company has a licence under the Environmental Code and the Nuclear Activities Act.

It is the Council's considered opinion that this responsibility (rights and obligations) for the spent fuel and for the final repository after closure should be clarified in the application.

The Council's assessment of the need for supplementary information:

Responsibility and ownership conditions for the spent nuclear fuel and the final repository should be clarified in SKB's application. This includes the division of responsibility between the reactor owners and SKB, as well as between the state, the municipality and the landowners after closure.

The division of responsibility between the reactor owners and SKB should be clarified based on the obligations borne by the reactor owners.

The division of responsibility between the reactor owners and the state should be clarified in the event it is decided to design the repository so the nuclear waste is retrievable.

4 Safety and radiation protection

The purpose of SKB's application is to dispose of the spent fuel in such a way that it will not, now or in the future, cause any harm to human health or the environment. The final repository comprises the protective measure to be judged pursuant to the general rules of consideration in the Environmental Code. Construction of the rock cavern with its consequences for human health and the environment must also be assessed in the light of these provisions.

The Land and Environment Court's examination of the application should consider all circumstances with a bearing on licensing.[7]

The travaux préparatoires to the Environmental Code and its consequential legislation do provide some guidance on how examination under the Code can be coordinated with examination under the Nuclear Activities Act or the Radiation Protection Act when it comes to questions relating to detriment to the environment caused by ionizing radiation in conjunction with the operation of a nuclear facility. But the travaux préparatoires provide hardly any guidance on the question of how thoroughly the Land and Environment Court should examine the facility's safety, in view of the fact that the safety aspects are also examined in parallel pursuant to the Nuclear Activities Act and the Radiation Protection Act.

In the Council's opinion, there can hardly be any detriment caused by ionizing radiation in conjunction with the operation of the final repository and the encapsulation plant as long as the facilities remain capable of preventing nuclear accidents. In the Council's opinion, it is therefore only natural that examination under the Environmental Code should include the detriment caused by ionizing radiation that could result from failure of the barriers or the deep repository at one or two points, which could cause a nuclear accident.

Important information on safety and radiation protection of relevance to the permissibility question is found in the application under the Nuclear Activities Act but is absent in the application under the Environmental Code. The application under the Environmental Code should therefore be supplemented with all information regarding safety and radiation protection that is included in the application under the Nuclear Activities Act so that the review under the Environmental Code can address all questions regarding safety and radiation protection in a meaningful way.

In the opinion of the Swedish National Council for Nuclear Waste, it is not satisfactory that the Land and Environment Court should have less adequate material than the Swedish Radiation Safety Authority when it comes to determining whether the final disposal facilities satisfy the requirements on safety and radiation protection based on the rules of consideration in Chap. 2 of the Environmental Code.

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[7] See Gov. Bill 1997/98:45 Part 2 p. 235.

The Council's assessment of the need for supplementary information:

The application should be supplemented with the information that is included in the application under the Nuclear Activities Act but is absent from the application under the Environmental Code, for example

- information on activity, organization, leadership and management in conjunction with the site investigation phase and in conjunction with the construction of the final repository.
- background reports and appendices to the safety analysis report (appendices AV/DE, VP/AS and VU/AC).
- sub-appendices to SR-Drift and SR-Site.
- preliminary plan for decommissioning and sub-appendix to the appendix Platsval – lokalisering av slutförvaret för använt kärnbränsle ("Site Selection – Siting of the final repository for spent nuclear fuel") Comparative analysis of safety related site characteristics, TR-10-54.

5 Physical protection of the final repository

An important part of safety at the final repository and Clink (Clab and the encapsulation plant as an integral unit), as well as at other nuclear facilities, is the so-called physical protection that is required to protect the facility from inadvertent intrusion, sabotage and other such harm that could cause a nuclear accident, as well as to prevent illicit trafficking in nuclear material.

The scope and design of the physical protection of the final repository is an important question. The question is relevant both during the operating phase, when spent nuclear fuel is deposited, and after the facility has been closed and sealed. A terror attack on the final repository is a risk that should be included in the examination under the Environmental Code.

Safeguards against nuclear non-proliferation entail international control to ensure that nuclear fuel is not used to produce nuclear weapons. An international agreement between the IAEA (International Atomic Energy Agency), Euratom and the EU's Member States[8] regulates how this control is to take place. The agreement also applies to geological repositories, even though it is not adapted to this type of facility. Discussions are still being conducted on how the international requirements on safeguards should be designed for a geological repository. In a policy document in 1988[9], an advisory group to the IAEA said that safeguards for a final repository should be maintained as long as a safeguards agreement is in force. How such safeguards are to be designed is not specified in the application. See also Chapter 8.5.

The Council's assessment of the need for supplementary information:

Information on physical protection should be included in the application under the Environmental Code.

6 Financing

A prerequisite for safe management of the spent fuel and the nuclear waste is that the necessary resources are available for this purpose.

According to the Act (1984:3) on Nuclear Activities (the Nuclear Activities Act), the holder of a licence for nuclear activities is responsible for taking all necessary measures for the safe management and final disposal of all nuclear waste arising in the activities. This obligation remains until it has been fulfilled.

The Act (2006:647) on Financial Measures for the Management of Residual Products from Nuclear Activities (the Financing Act) contains provisions aimed at securing the financing of the licensees' general obligations that follow from the Nuclear Activities Act. To this end, the holder of a licence to own or

[8] INFCIRC/193: agreement between the community, its member states who do not have nuclear weapons and the IAEA, which entered into force on 21 February 1977, supplemented by additional protocol 1998/188/Euratom, which entered into force on 30 April 2004, and Commission Regulation (Euratom) No 302/2005 of 8 February 2005 on the application of Euratom safeguards.

[9] STR-243 (Revised) "Spent fuel disposed in geological repositories is subject to safeguards in accordance with the applicable safeguards agreement. Safeguards for such material are maintained after the repository has been back-filled and sealed, and for as long as the safeguards agreement remains in force. The safeguards applied should provide a credible assurance of non-diversion".

operate a nuclear facility that gives or has given rise to residual products shall pay a fee – the nuclear waste fee. The fee shall cover such a large fraction of the costs that it is equivalent to the fee-liable licensee's share of all fee-liable licensees' residual products.[10] The reactor owners' fees are determined by the Government every three years. The paid-in fees are deposited in the Nuclear Waste Fund. The purpose of the financing system is to minimize the risk that the state will be forced to pay the costs that are the responsibility of the licensees.

The Swedish Radiation Safety Authority has been instructed by the Government to review the Financing Act and the Financing Ordinance. This assignment is being carried out in consultation with the National Debt Office and Nuclear Waste Fund. According to the Swedish Radiation Safety Authority, the initial analyses reveal a deficit in the balance sheet for the nuclear waste system, due among other things to falling market rates. The Authority notes that further analyses are needed, along with a comprehensive overview of the financing system with regard to decisions concerning fund management, fees and guarantees.

Such a situation constitutes a problem in terms of an increased risk in that it leads to a deficit in the financing system which – despite mechanisms with new cost bases and new decisions regarding fees and guarantees every three years – can be difficult to finance in the intended way further down the line.

The Council's assessment of the need for supplementary information:

It is the Council's considered opinion that SKB should explain what other guarantees besides the assets in the Nuclear Waste Fund are at the company's disposal to ensure that sufficient funds are available to repair the environmental damage or carry out other remediation measures occasioned by the activity.

SKB should explain what means are available to SKB to complete the final repository project in the event the assets of the Nuclear Waste Fund do not suffice to cover the costs incurred by the final repository works.

[10] Cf. Sec. 7 of the Act (2006:647) on Financial Measures for the Management of Waste Products from Nuclear Activities (the Financing Act).

7 Preservation of knowledge

Access to information and knowledge is a prerequisite for future generations to be able to make well-founded decisions and avoid inadvertent intrusion.

According to the application, SKB is participating in international cooperation within the OECD/NEA and the IAEA regarding information preservation far into the future. SKB has also conducted two studies on information transfer which dealt with theories of knowledge preservation, surveyed the work that had been conducted on the subject in both Sweden and other selected countries, and contained proposals on how knowledge can be preserved over long periods of time.[11]

The results of these studies are not included in the application, and the top document[12] states that "The problem of long-term knowledge preservation should be solved no later than by the time of closure of the repository in about 70 years. Then society can decide which type of information it wants to preserve and how. It is SKB's ambition to preserve and administer information in such a manner that society has the option of choosing the alternatives for the future that are then deemed suitable."

It may seem as if the question of information and knowledge preservation is not of such great importance for the design of a final repository and that SKB's proposal to wait before deciding on a plan of action is therefore reasonable. The question of what information and knowledge is to be preserved is, however, intimately associated with the question of how the processes and systems that will preserve this information and knowledge are to be designed. Since documentation of the actual construction work is a crucial part of the corpus that information and knowledge preservation processes should transfer to future generations, it may be too late to decide at the time of closure which information is to be preserved and how. The conclusion is that a plan of action for information and knowledge preservation, including which information and knowledge can and should be preserved, should be devised even before the start of the deposition period and then be adjusted and amended as the work proceeds.

[11] SKB P-07-220, Kunskapsbevarande för framtiden – Fas 1 och SKB P-08-76, Bevarande av information om slutförvar av använt kärnbränsle – förslag till handlingsplan.

[12] Application under the Environmental Code, top document, page 14.

The Council's assessment of the need for supplementary information:

It is the Council's considered opinion that SKB's application should be supplemented with a plan of action for preservation of information and knowledge. The plan should describe how SKB intends to preserve information on the final repository during the deposition period and transfer this knowledge to future generations.

8 Viewpoints on Appendix MKB/EIS – Environmental impact statement

8.1 Formal requirements on the environmental impact statement

The environmental impact statement (EIS) is central in the application process. An acceptable EIS comprises a so-called "process prerequisite" for examination of a licence application by the Land and Environment Court under the Environmental Code and is a prerequisite for the Government's examination under the Nuclear Activities Act.[13]

The Environmental Code stipulates requirements on what an EIS must contain when the activity or measure is likely to have a significant environmental impact. The question of what content the EIS should have is a formal question to be decided by the Court and the Government.

It is the Council's considered opinion that it is of the utmost importance that the information presented in the EIS is so comprehensive that it is clearly evident in all issues what SKB's standpoints are and what basis SKB has for these standpoints.

The Council finds that this is not the case when it comes to background information for assessment of environmental effects regarding long-term safety, description and assessment of the choice of method, the no action alternative and the basis for SKB's choice of site.

[13] See NJA 2009:321, cf. also Sec. 5 c of the Nuclear Activities Act.

The Council's assessment of the need for supplementary information:

It is the Council's considered opinion that the application should be supplemented to fulfil the Environmental Code's requirements regarding information as a basis for assessment of environmental effects regarding long-term safety, description and assessment of the choice of method, the no action alternative and the basis for SKB's choice of site.

The appendices that describe site selection and choice of method should be included in the EIS.

8.2 Scope of description and assessment of possible environmental effects – radiological risks and cumulative effects

The EIS describes the consequences which the whole system for interim storage, encapsulation and final disposal is projected to have on the environment. The radiological risks are however described cursorily, with reference to the fact that radiation and radioactive releases from the final repository comply with the requirements of the Swedish Radiation Safety Authority.

SKB has chosen not to include the safety assessment as a part of the EIS but to present it as an appendix to the applications.

Section 4.4.3 of the EIS discusses the role of the safety assessment (SR-Site) in the EIS. There it says that SKB's consultations were concluded in February 2010, before SR-Site was finished, but that on request, SKB held a special consultation meeting on the safety assessment and its role in EIS in May 2010. It says further on page 64 that "The results that are relevant to the assessment of environmental consequences are also presented in the EIS". However, long-term safety is probably the aspect that it is most urgent to deal thoroughly with in the EIS, and it is unlikely that any result from the assessment would not be relevant to the EIS.

SKB's application calls for siting the final repository close to the three nuclear power reactors and a repository for low- and intermediate-level radioactive waste. Moreover, additional nuclear activities are planned in the area, including an extension of the final repository for short-lived low- and intermediate-level waste (SFR).

Another purpose of the EIS is to identify and assess factors in the activity's surrounding environment that could affect its safety.[14]

> *The Council's assessment of the need for supplementary information:*
>
> The cumulative effects of a nuclear accident in one of the nuclear facilities and what impact they might have on the final repository should be described in greater detail in the EIS.
>
> An overall picture of the activity and risk factors associated with its execution must be provided in the EIS. This means that SKB must provide a clearer description of the impact of the activity on human health and the environment, as well as the risks entailed by the activity and the consequences of possible nuclear accidents.

8.3 Description of alternative sites and method, including the no action alternative

According to Chapter 6 Section 7 of the Environmental Code, the licence applications shall describe alternative sites, if such are possible, and alternative designs. The applicant, in this case SKB, shall also explain why a certain alternative was chosen.[15] The applicant shall also provide a description of the consequences if the activity or measure is not implemented (the "no action alternative").

The Bill for the Environmental Code[16] discusses alternative solutions, and examples are given of some possible alternatives, for example other ways to produce energy or choosing other means of transport, such as a high-speed rail line instead of an airport for domestic flights.

Based on these examples, it would appear as if the requirements on an account of alternative designs could be very extensive. The commentary on the Environmental Code[17] states that it should be reasonable to require such a detailed account of the alternatives

[14] Cf. Chap. 6, Sec. 3, paragraph 2 of the Environmental Code.
[15] Cf. Chap. 6, Sec. 7, paragraph 2, point 4 of the Environmental Code.
[16] Gov. Bill 1997/98 II p. 64 and I p. 292, cf. also SOU 1996:103 Part 1 p. 307.
[17] Bengtsson et al. p. 6:26.

that they can be weighed against the applied-for activity in the permissibility assessment.

SKB has chosen to present parts of the documents that should be included in the EIS according to the Environmental Code in appendices to the application, namely the general rules of consideration, site selection and choice of method.

Description of site selection

It is important that the EIS explain on what grounds SKB has made its site selection and what other methods are possible for final disposal of the spent nuclear fuel (to fulfil the purpose of the project), and provide an assessment of environmental effects and their consequences. This is also important with regard to access to information on the assessment of the final repository's environmental effects.

Description of choice of method

A thorough and clarifying account should be given in the EIS of alternative methods for disposal of spent nuclear fuel, where the different alternatives and their environmental impact are described and compared and SKB explains the reasons for its choice of method. Other comparable ways of disposing of the spent nuclear fuel should be described by SKB. This applies particularly to the alternative Deep Boreholes, which should be updated with the latest research findings and current research, as well as a description of alternative solutions involving partitioning and transmutation (P&T). Solutions involving P&T have particular relevance in conjunction with the development of new technology in the nuclear power field.

A clearer account is needed of why SKB has chosen Forsmark, compared with Laxemar and other possible sitings in Sweden that have been considered during the process.

The no action alternative

The EIS also describes the no action alternative, which is a description of the consequences if the activity or measure is not implemented, for example continued interim storage at Clab. The no action alternative has thereby been restricted to prolonged interim storage, more precisely to the impact, effects and consequences of continued storage at Clab and the evolution of the environment on the sites that are then not used for the final repository. It is the Council's considered opinion that this description needs to be supplemented and that this definition of the no action alternative gives far too simplified a picture. For it is not a foregone conclusion that issued permits allow for continued transportation of spent nuclear fuel to Clab – especially not if uncertainties exist regarding the possibilities of transferring the fuel to a final repository later on. In such a situation, the spent fuel may have to be stored at the reactors, which requires new facilities. The consequences of such a scenario should be explored in the EIS. It is doubtful whether such a constriction is compatible with the comparability criterion. One of the most important functions of a no action alternative is to provide a basis for comparison of the different paths of action that are possible. In certain cases, such as this one, the no action alternative serves not only as a basis for comparison, but also a possible path of action – an "action alternative". This makes the impact assessment of the no action alternative even more meaningful.

The EIS therefore needs to be developed and supplemented with a description and impact assessment of the no action alternative. The contradictory assertions on page 79 of the EIS to the effect that a no action alternative is not feasible should be corrected. The fact that the no action alternative contains great uncertainties is not sufficiently good reason to omit large parts of the impact assessment. Instead, the uncertainties should be reduced as far as possible through the EIA process and then be reported openly and appropriately in the Chapter 11 of the environmental impact statement.

The Council's assessment of the need for supplementary information

The EIS should be supplemented with a clearer account of why SKB has chosen Forsmark, compared with Laxemar and other possible sitings in Sweden (which have previously been considered in the process), i.e. the account included in the appendix Site Selection.

The EIS should be supplemented with a comparative account of alternative methods for final disposal with respect to safety, radiation protection and environmental impact, and SKB should justify its support for the chosen method against the background of such an account.

The EIS should be supplemented with a clearer description and impact assessment of the no action alternative, a description of the consequences if the activity or the measure is not implemented. It is the Council's considered opinion that effects and consequences of delays in the process that could lead to a realization (albeit time-limited) of the no action alternative should be described and assessed.

8.4 Scope of the activity with regard to construction phase, operating phase and decommissioning phase

The chronological scope used in the description of environmental effects in the EIS varies depending on the activity being described. The activity assessed in the EIS is mainly limited to the final repository system's construction and operating phase. As regards decommissioning and dismantling, reference is made to a separate EIS that will be produced for decommissioning of the interim storage facility, Clab, and the encapsulation plant.

The Council's assessment of the need for supplementary information

The Swedish National Council for Nuclear Waste is of the opinion that the EIS should, in accordance with the Environmental Code, describe the whole system and its impact on the environment during all of its phases. The Council thereby believes that decommissioning and dismantling of Clab and the encapsulation plant should also be included in the EIS.

8.5 Physical protection/risk of intrusion

According to information on page 270 of the EIS, the safety assessment does not include human actions that lead to intentional intrusion in the final repository. This restriction to only inadvertent intrusion stems from SSM's regulations. However, the principle that an EIS, according to the above, should contain the information needed to identify and assess the risks of impact on man and the environment should also apply to intentional impact.

It would appear to be indisputable that intentional human impact cannot be ruled out during either the construction of the facility or its long operating phase. Risks that are associated with intentional human actions should therefore be described in the EIS.

The Council's assessment of the need for supplementary information

A description of physical protection and risks as a consequence of intentional human actions should be provided in the EIS. The EIS should also be supplemented with the information in Appendix VP/AS – "Activity, organization, leadership and management" – that is included in the application under the Nuclear Activities Act and has been submitted to the Swedish Radiation Safety Authority.

8.6 Description of psychosocial effects

The description of psychosocial effects is very cursory and does not include an assessment of psychosocial effects. The conclusion that "a final repository in Oskarshamn or Östhammar would have less or much less psychosocial effects than in any other municipality in the country" (page 302, section 12.1.3.2) indicates that psychosocial effects can be expected to occur regardless of where the facility is built, but does not clarify how great they can be expected to be – either in the identified municipalities or in some other municipality. Since there is no description of how great the psychosocial effects can be expected to be if the final repository is sited in "some other municipality", the comparison lacks relevance.

The EIS treats the psychosocial effects mainly from a present-day perspective and only briefly mentions the psychosocial conditions of future generations. A generally formulated conclusion states that: "… as long as no major accidents occur it is likely that the population's attitude to the final repository will become increasingly positive." (Ibid.). It is not clear what studies, expert assessments or other evidence this conclusion is based on.

The Council's assessment of the need for supplementary information

Psychosocial effects have not been investigated to a sufficient extent in the application. The EIS does not describe the direct and indirect effects which the planned activity or measure might have on human health and should be supplemented in this respect.

8.7 Impact on natural values

There are a number of red-listed species in the impact area. Neither the EIS nor its appendices concerned with water operations contain summaries of these species or how they are affected.

SKB has applied to the County Administrative Board in Uppsala County for an exemption from the Species Protection Ordinance for activities that affect protected species in the area. In order for SKB to obtain an exemption, they have to compensate for the areas where habitats for protected species are affected.

The Council's assessment of the need for supplementary information

SKB should supplement the EIS with a discussion of how red-listed species will be affected and how the impact on these species can be minimized.

In order for the Land and Environment Court to be able to assess how great the environmental consequences of SKB's planned activities will be, the EIS should be supplemented with the information contained in the reports SKB R-10-16, Vattenverksamhet i Forsmark Ekologisk fältinventering och naturvärdesklassificering samt beskrivning av skogsproduktionsmark and SKB P-11-04, Underlag till ansökan om dispens enligt artskyddsförordningen.

In order for the Land and Environment Court to be able to frame conditions to limit the impact on the high natural values that exist in the area, SKB should include information on the results of its pilot studies where they intend to show that the compensatory measures have the intended compensating function.

8.8 Consultation viewpoints

The EIS shall be preceded by a consultation procedure between the activity operator, regulatory authorities and private citizens. The consultation shall comprise a part of the work with the environmental impact statement, and there shall be an opportunity for the various stakeholders to influence the form and content of the EIA via their viewpoints. Information on the consultations that have taken place should be included in the application.

The Council's assessment of the need for supplementary information

The EIS should be supplemented with a detailed account of how the viewpoints expressed during the consultations have been taken into consideration.

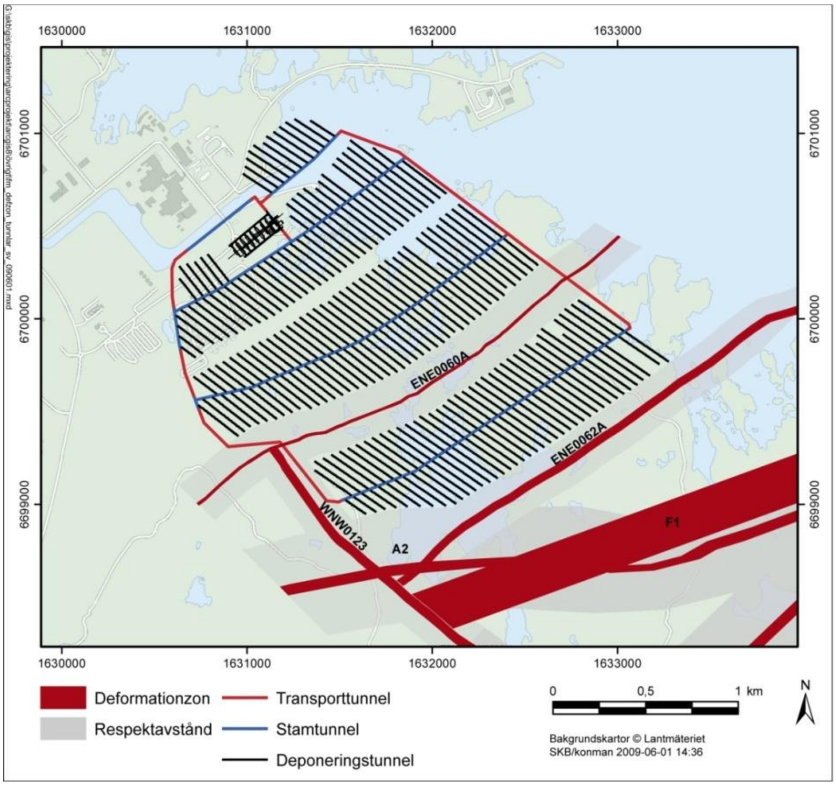
9 Viewpoints on Appendix PV/SS – Site Selection

The appendix Site Selection provides a good background, but the documents contain many unsubstantiated claims, and critical reflections are almost entirely absent. The description of Forsmark is suffused with optimism, while an equivalent assessment of Laxemar is couched in more pessimistic terms. This appendix does not allow for any great confidence in Laxemar as an alternative site for a final repository spent nuclear fuel. This could naturally have consequences for the future if unforeseen events render a final repository in Forsmark impossible.

In June 2009, SKB published the open report *Slutförvar för använt kärnbränsle i Forsmark – underlag och motiv för platsval* ("Final repository for spent nuclear fuel in Forsmark – basis of decision and reasons for site selection"). The layout for Forsmark presented in this report shows that the deposition area in the southwest is bounded by a deformation zone called WNW0123 or ZFMWNW0123 (see Figure 1 and also Figure 10–118 in SR-Site). It does not seem to be established that this zone ends roughly perpendicular to the deformation zone ENE060A, even though the direction has been determined in at least two boreholes.

If the zone WNW0123 is the younger of the two zones, it is reasonable to assume that it ends at the zone ENE060A, as SKB has suggested in its model. If, however, the situation is reversed, the zone WNW0123 could have an undocumented continuation past this zone (i.e. ENE060A). If this is the case, it is not impossible that, in the event of future earthquakes, the zone could propagate straight through the repository in a northwest direction and thereby affect a large number of canister positions in the western part of the repository, leading to great consequences for the integrity of the repository. This scenario has been completely overlooked by SKB in SR-Site, where the zone that comes closest to this repository volume (Figure 10–118 and Figure 1) is not considered at all. SKB should therefore consider whether the layout for Forsmark needs to be revised. It is notable that the concept of fracture propagation and new fracture formation (in zone (ZFM) WNW0123) is not mentioned in SR-Site, nor has this been modelled.

Figure 1 **Layout of final repository in Forsmark. The figure also shows layout-determining deformation zones and respect distances to them**[18]



Deformationzon = Deformation zone
Respektavstånd = Respect distance
Transporttunnel = Transport tunnel
Stamtunnel = Main tunnel
Deponeringstunnel = Deposition tunnel

[18] Slutförvar för använt kärnbränsle i Forsmark – underlag och motiv för platsval ("Final repository for spent nuclear fuel in Forsmark – basis of decision and reasons for site selection"), SKB open report, 2009.

The Council's assessment of the need for supplementary information:

It is the Council's considered opinion that SKB should include in its safety analysis report a scenario where a calculation is made of how many canisters would be affected by fracture propagation and formation of new fractures in the zone (ZFM)WNW0123, and what consequences this might have for long-term safety.

SKB should provide a detailed explanation of why they rule out the possibility that the zone could, in the event of future earthquakes, propagate through the northwestern part of a future repository in Forsmark.

It is the Council's considered opinion that SKB should include in its safety analysis report a scenario where a calculation is made of how many canisters would be affected by fracture propagation and formation of new fractures in zone WNW0123, and what consequences this might have for long-term safety.

SKB should provide a detailed explanation of why they rule out the possibility that the zone could, in the event of future earthquakes, propagate through the northwestern part of a future repository in Forsmark.

10 Viewpoints on Appendix MV/CM – Choice of method

Choice of method is presented in Appendix CM, which is largely identical to SKB report P-10-47, published in October 2010. The appendix briefly summarizes the different alternative methods, with history and variants. The choice of method is furthermore dealt with in the application's top document, sections 5.1 – 5.3, and in Appendix EIS, sections 3.5 "The KBS-3 method" and 3.6. Other methods.

The methods that constitute the alternatives which, according to SKB, remain when those methods that have for different reasons been deemed to be unrealistic or in conflict with international conventions have been eliminated, such as launching into outer space or dumping in the ocean, are presented below. The remaining alternatives are all based on some form of geological disposal. Even the alternative of partitioning and transmutation does not alter this in principle – the residual products remaining after P&T will also require a repository.

In comparison with the KBS-3 method, which is based on the results of more than 30 years of research, evaluation of alternative solutions will inevitably be less thorough. In practice, the decision-makers will have to answer the question: “Is KBS-3 a sufficiently safe method for its purpose?” The question of whether a safer method exists cannot be answered on the basis of existing research.

10.1 Deep boreholes

Any comparison between KBS-3 and the alternative that has comprised the main alternative, Deep Boreholes, will therefore be less than fair, and SKB itself only makes this comparison in qualitative terms. SKB does not include in its application the report on the comparison they themselves have made between these alternatives (SKB R-10-13 – Jämförelse mellan KBS-3-metoden och deponering i djupa borrhål för slutligt omhändertagande av använt kärnbränsle (“Comparison between the KBS-3 method and disposal in deep boreholes for final disposal of spent nuclear fuel”). This report gives reasons why SKB has chosen not to further evaluate the main alternative. These reasons are summarized in the following bulleted points. The first of these points can be regarded as the crucial one.

- It would take another 30 years or more and at least SEK 4 billion to develop our knowledge of Deep Boreholes to such a level that a fair comparison can be made.
- No development work is being pursued internationally today on Deep Boreholes as a method for final disposal of spent nuclear fuel.
- It is not known today what the consequences might be of a future glaciation or an earthquake for the safety of a final repository in deep boreholes.
- In the case of disposal in deep boreholes, mishaps could occur that cannot be rectified, for example a canister could get stuck before reaching disposal depth, which means that a leaky canister could get stuck in a position with flowing groundwater.

Many references that deal with Deep Boreholes are old and do not reflect the state-of-the-art. In order for a fair comparison to be made between the KBS-3 method and Deep Boreholes, the latest research findings must be presented.

10.2 Closed fuel cycle

There are different ways of regarding nuclear fuel and nuclear waste which in turn determine how the spent nuclear fuel is treated. A so-called open fuel cycle can be used, which means that the fuel is used once and then, after interim storage, is disposed of directly in a final repository. This is the method that has been the planning premise on which SKB has based its work since the 1980s. Certain other nuclear power countries in Europe, such as France and Great Britain, have instead chosen a closed fuel cycle. The spent nuclear fuel is reprocessed, producing uranium and plutonium that are used to fabricate a type of nuclear fuel that can be used once again.

SKB writes in Appendix AH/AG – General rules of consideration – that "Objections have been raised to disposing of the spent nuclear fuel in the form it has after interim storage, since more energy could be extracted from the fuel before it is disposed of. Extracting more energy requires reprocessing. It is not currently considered economically defensible, or even appropriate, to reprocess nuclear fuel in new plants in Sweden, or to send spent nuclear fuel abroad for reprocessing."

According to Chap. 2 Sec. 5 of the Environmental Code, anyone who pursues an activity or adopts a measure shall conserve raw materials and energy and reuse and recycle them wherever possible. This is what is meant by the conservation principle.

The conservation principle has been interpreted to mean that energy and raw material must be used as efficiently as possible and their use should be minimized; the sustainability principle entails that whatever is extracted from nature shall be used, reused, recycled and disposed of in a sustainable manner with the least possible consumption of resources and without harming nature. The importance of efficient energy use and better energy conservation is emphasized. This means that the energy system should also be made more sustainable. According to Chap. 2 Sec. 7, the requirement to conserve raw materials and energy is absolute, and no exemption in this respect is allowed in the Code, provided that compliance is not unreasonable in a given case.

In the Council's opinion, it is not relevant in this context to assert, as SKB does, that it is not economically defensible in the short perspective to reuse the spent nuclear fuel.

It is the Council's considered opinion that SKB should give greater consideration to the consequences of the possible development and operation of new types of nuclear power reactors, for the timetable and for the nuclear fuel programme. One question that can be asked is what it means for a planned final repository that reactors in the future might use as fuel what we today regard as waste.

10.3 Retrievability

Retrievability and reversibility are two concepts that are currently being discussed in the national waste management programmes in many countries. They refer to the possibility of retrieving the nuclear waste from the final repository before, and possibly even after, repository closure.

The trend of recent decades has given added weight to the question of retrievability. Discussions in other countries and international bodies also warrant reconsideration of the question. Furthermore, in the opinion of the Council there are technical future scenarios that have lent weight to the requirement on retrievability. Reversibility is furthermore a crucial element in the model for stepwise decision-making that follows from the requirements specified in SSM's regulations.

The Council's assessment of the need for supplementary information:

SKB R-10-13, "Jämförelse mellan KBS-3-metoden och deponering i djupa borrhål för slutligt omhändertagande av använt kärnbränsle" ("Comparison between the KBS-3 method and disposal in deep boreholes for final disposal of spent nuclear fuel"), should be included in the application documents.

The references cited for the alternative method Deep Boreholes should be updated with more recent and relevant references with the results of the latest research.

SKB should explain why the spent nuclear fuel will not be reused and recycled according to the Environmental Code's general rules of consideration (the conservation and sustainability principles).

The Council considers that a more thorough investigation is required of how extending the operating times of the nuclear power plants would affect the interim storage of spent nuclear fuel, in other words if on site storage would be required or if the current interim storage facility for spent nuclear fuel, Clab, would suffice.

It is the Council's considered opinion that SKB should give greater consideration to the consequences of the possible development and operation of new types of nuclear power reactors for the nuclear fuel programme. One question that can be asked is what it means for a planned final repository that reactors in the future might use as fuel what we today regard as waste.

It is the Council's considered opinion that SKB should shed further light on the question of reversibility and retrievability in the application. Reversibility and retrievability are important elements in e.g. Finland's final repository programme, and reversibility is also a crucial element in the model for stepwise decision-making that follows from the requirements specified in SSM's regulations.

Method	Description in application	Others SKB reports	Council´s comments
KBS-3	Described in detail in application – Appendix CM contains a brief summary of the method.		Chosen method.
Deep Boreholes	Described in summary in Appendix CM, sections 3.4.2 and 4.4.2 (6 pages)	Grundfelt, 2010: Jämförelse mellan KBS-3-metoden och deponering i djupa borrhål för slutligt omhändertagande av använt kärnbränsle R-10-13	Has also been described in a large number of RD&D programmes, which have summarized the current state-of-the-art in the area.
Partitioning and Transmutation (P&T)	Summarized briefly. If all waste produced to date is to be transmuted, this will take 100 years or more. It is noted that it is important to participate in international development efforts and to maintain competence in the field.	Partitioning and transmutation. Current developments – 2010 SKB Technical Report TR-10-35 Partitioning and transmutation. Annual report 2009, SKB Report R-10-07	Partitioning and transmutation does not eliminate the need for disposal of radioactive waste, it just alters the premises. Less rigorous requirements on the long-term durability of the engineered barriers, slightly smaller volume of high-level waste, but perhaps larger volume of low- and intermediate-level waste.
WP-Cave	Denser tunnel system for deposition; the water flow has been reduced by drainage. Requires initial (about 100 years) air cooling.	Systemanalys. Val av strategi och system för omhändertagande av använt kärnbränsle. SKB Report R-00-32	Originally a proposal for underground siting of nuclear reactor. Hydraulic cage. Approximately 10 repository units would be needed. In the proposed form, the encapsulation is of steel. Requirements on the rock similar to KBS-3, but more important that fracture zones are absent.
DRD (Dry Rock Deposit)	Dry disposal method. Drained rock caverns.	Systemanalys. Val av strategi och system för omhändertagande av använt kärnbränsle. SKB Report R-00-32	The proposers see this more as a temporary storage method pending technological development permitting new and better methods. Safer storage than on the surface.
Ni action alternative	There is no analysis of this alternative in Appendix CM	What happens if a deep repository is not built? The zero alternative – Extended interim storage in Clab. SKB Report R-00-31	Entails in practice continued storage in Clab until the question of a long-term final storage method is resolved. The Council has described the no action alternative (previously called the zero alternative) in Nuclear Waste State-of-the-Art Report 2007, section 3.2.

11 Viewpoints on Appendix TD – Technical Description

According to SKB, the purpose of Appendix TD is to describe, pursuant to Chap. 22 Sec. 1 of the Environmental Code, the applied-for activity and the facilities. Factors of importance for its environmental impact are in particular described.

SKB's goal with the appendix is to describe facilities, activities, emission sources, land use etc. during construction, operation and decommissioning to an extent and level of detail so that the Land and Environment Court can prepare the matter for the Government's permissibility assessment without requiring supplementary information.

The chronological scope used in the description of environmental effects varies depending on the activity being described. The activity assessed is mainly limited to the final repository system's construction and operating phase.

The Council's assessment of the need for supplementary information:

The technical description should be supplemented with an account of how SKB intends to handle logistics and possible disturbances between three continuously ongoing processes in the underground activities involving extensive rock works, deposition and backfill/plugging of deposition tunnels.

The technical description should be supplemented with references that make it possible to study in detail processes and designs, i.e. to go from what is called level 0 in SKB's safety assessment (equivalent to Appendix TP/TD) to deeper levels (Cf. Fig. 4-1 on page 8 in Appendix SR).

The technical description should be supplemented with a flow chart for Buffer Production equivalent to the flow charts given for the processes Rock Works, Deposition and Backfilling.

12 Viewpoints on Appendix MP – Proposal for monitoring programme

The purpose of the proposed monitoring programme is to describe how SKB intends to monitor the environmental impact of the activity. At least two additional monitoring programmes are required in addition to this monitoring programme: one to verify that the design premises (building code) are observed and one to monitor the internal environment (work environment). These monitoring programmes are described in other parts of the application. The application does not include a monitoring programme for how the environment evolves in the closed parts of the repository (plugged deposition tunnels). Above all, there is no account of how SKB will ensure that the changes will take place in accordance with the assumptions in the long-term safety assessment. There is also no integrated account that provides an overall picture of the monitoring programmes. Such an integrated account is extra important since the monitoring programmes can be assumed to be dependent on each other.

It is mentioned on page 3 of the monitoring programme proposed by SKB that the programme does not include monitoring of radiological releases or monitoring of the surrounding environment. This must be regarded as a serious deficiency, since Chapter 10 of the Environmental Code requires the activity operator to compensate for damage without exemptions or time limits. The reason given why the programme does not include radiological monitoring is that no radioactivity will be released from the final repository. This is a claim which SKB is obliged to substantiate, according to Chap. 2 Sec. 1 of the Environmental Code.

The application should therefore be supplemented with a discussion and account of alternatives that include the establishment of a monitoring programme for radiological release monitoring or environmental monitoring. Otherwise arguments are needed as to why such a monitoring programme has not been established.

It is desirable to supplement the application with a discussion of whether it may be suitable in the future to introduce radiological release monitoring and environmental monitoring for the final repository as well, since it is not impossible that radioactivity may be involuntarily released from the facility during the long period of time the repository is supposed to function.

There are several reasons for the aforementioned conclusion. One reason is the discussion of recent years of the effectiveness of the planned barrier and the risk of copper corrosion.[19] Another is the risk of various events that could affect the facility after the initial state has been achieved.[20] A discussion of monitoring programmes for the final repository should also include time frames for when such monitoring should be started and concluded (possibly due to scenario analyses that are presented).[21]

Furthermore, it is noted that additional monitoring may be needed beyond what is included in the monitoring programmes proposed by SKB, and that they will then be collected in self-monitoring programmes. The proposal should be supplemented with reasons why such monitoring is not included in the proposed monitoring programmes.

The Council's assessment of the need for supplementary information

SKB should provide a coherent overall picture of the monitoring programmes, not least since the monitoring programmes can be assumed to be dependent on each other.

SKB should explain how they will monitor conditions during the operating period in sealed parts of the repository (plugged deposition tunnels) to ensure that they evolve in accordance with the assumptions in the safety assessment.

There is no description in the application of monitoring programmes for release monitoring or environmental monitoring or, alternatively, reasons why such programmes have not been established.

SKB should supplement the proposal for monitoring programmes with an explanation of why radiological monitoring of the interim storage in Clab is performed as a part of Clab's self-monitoring programme but is not included in the proposal.

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[19] See Application under the Environmental Code, App. SR-Site, vol. 1, pp. 162–176 and vol. 3, pp. 590–614.
[20] See Application under the Environmental Code, App. SR-Drift, chapter 3, pp. 24–29.
[21] See Application under the Environmental Code, top document, p. 18.

13 Viewpoints on Appendix SR – Safety analysis report for final disposal of spent nuclear fuel

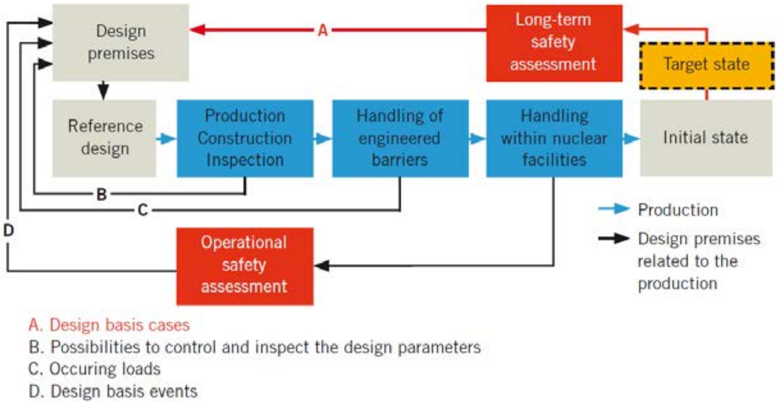
Appendix "SR - Safety analysis report for final disposal of spent nuclear fuel" introduces the sub-appendices SR-Drift/Operation and SR-Site and is referred to in the following as "Main Appendix SR". The point of departure for the discussion of supplements to Main Appendix SR is SKB's understanding of the relationships between Initial State, Safety Assessment and Design Premises such as these relationships are depicted in Figure 3–1 and the comments on this figure on pages 5–6.[22]

While Figure 3–1 in Main Appendix SR depicts sound and reasonable relationships between different activities, states and information flows, the actual *staging*, in other words the way in which SKB *intends* to *realize these activities*, states and information flows according to the present application *will* ***not*** *be able to guarantee reasonable long-term safety*. This conclusion is based on the analysis made in chapters 2 and 3 of the Council's Nuclear Waste State-of-the-Art Report 2012.[23]

The intention of the Council's demands for supplements to Main Appendix SR is to clarify that the current staging of Figure 2 (reproduction of Figure 3–1 in Main Appendix SR) cannot guarantee that reasonable long-term safety will be achieved in the repository. The Council hopes that the viewpoints offered here will initiate a process at SKB to remedy this deficiency.

[22] In the following, consideration has also been given to the discussion of the process loop "Safety assessment-Design premises-Initial state-Safety assessment" in TR-10-12 "Design and production of the KBS-3 repository", pages 26-27.
[23] SOU 2012:7. Nuclear Waste State-of-the-Art Report 2012 – long-term safety, accidents and global survey.

Figure 2 **Reproduction of Figure 3–1 in Appendix SR with addition of target state**



In accordance with the analysis in the Council's Nuclear Waste State-of-the-Art Report 2012 (Chapter 3), the Council has inserted a hypothetical Target State between the Initial State and the Assessment of Post-Closure Safety. The target state is characterized by the fact that the requirements on the engineered barriers are satisfied with respect to long-term safety.

There are many feedbacks to "Design premises" in Figure 2, but the main loop is the one that passes through "Safety assessment (=Assessment of post-closure safety) → Design premises → Initial state → Safety assessment".[24] Other feedbacks to "Design premises" can be regarded as disturbances to which the main loop must adapt. SKB's figure indicates that "Design premises" are derived from the safety assessment, but that production and operation may require modifications, which must not conflict with the safety assessment. It could also be concluded from the figure that all design premises must *be fulfilled and verified in* the initial state. This may be a hasty conclusion! The review in the 2012 state-of-the-art report shows that at least two important design premises, one for the buffer and one for deposition holes, relate to the target state and are thus *in principle impossible to verify before*

[24] In the system literature, the closed loop "Safety assessment-Design premises-Initial state-Safety assessment" is characterized as a "cybernetic loop".

repository closure! This has considerable consequences for the definition and use of the concept of initial state.

The concept of initial state and the relationships between the different elements in the main loop “safety assessment-design premises-initial state” are discussed in the following. SKB’s definition and use of the term “initial state” leads to confusion in the relationships between the elements of the main loop. Since Figure 2 shows how SKB intends to lead construction and operation of the final repository, the confusion leads in turn to uncertainty regarding SKB’s ability to carry out an industrial project extending over nearly a century. The discussion concludes with proposals for supplementary information.

The concept of “initial state”

The term “initial state” plays a central role in the whole terminology SKB has created in order to show that SKB can build a reasonably safe final repository in Forsmark. The initial state is *the only part of the main loop that corresponds during the construction period to something that is **physically** put in place to create the final repository and whose properties can therefore be verified directly by measurements*.

The “final repository” project can be compared with an industrial project, which produces for a market. In the latter case, two verifications are made to insure conformance of promised to actual, physical performance – the first in the form of the producer’s inspection against his own design, the second via the market’s judgement of the product. If the market finds that the product is not up to scratch, the product will not be sold, and already sold products may have to be recalled. In the final repository project, this market verification has been replaced by inspection of the product, i.e. the initial state, through the safety assessment, which is furthermore largely performed by the producer. Verification that the initial state fulfils the design premises is thus the only opportunity for society to physically verify that SKB lives up to its promises. It is therefore extremely important that the initial state be clearly defined, and that its properties can be measured and verified against all design premises. The following review of Main Appendix SR indicates the need for supplementary information concerning both definition and verifiability. (The appendix to this document contains a compilation of the occurrence of the term "initial state" in Main Appendix SR.)

The top document should provide the most authoritative definition of the initial state:

> Initial state
> Properties of the spent nuclear fuel and the engineered barriers when they are finally put in place in the final repository and are not handled further in the final repository. Properties of underground openings at the time of final deposition, backfilling and closure.

This definition can be compared with definitions and use of the term in the safety assessments documents. SR-Site (Vol. 1 p. 145) rejects the interpretation of "finally put in place" = closure of the repository and states that "There is no obvious definition of the time of inception of the initial state". The conclusion for SR-Site is:

> Based on these considerations, SR-Site defines the initial state for the engineered barrier system as the state at the time of deposition/installation, and for the geosphere and the biosphere as the natural, undisturbed state at the time excavation of the repository begins.

Two reflections can be made. In the first place, the definition in the application entails that the initial state will extend over a period of several decades, since SKB intends to backfill and plug deposition tunnels progressively as the deposition holes are filled with canisters and buffer. Since the design premises may be changed during the construction period, this means that different parts of the initial state will be related to different design premises. SKB has no measurement programme to follow the evolution of e.g. water saturation of the buffers in plugged tunnels. Without such a measurement programme, SKB has no other choice than to reject the possibility of an initial state that describes the situation of the whole repository at a specific point in time, for example closure. In the second place, the definition of the initial state for the geosphere in SR-Site differs from the definition in the top document. Naturally, we don't know today what the rock will look like at the time of final deposition, but "initial state" is a key concept whose definition must remain fixed even if the content is altered by new knowledge and experience. The term must have the same definition for the builder as for the safety assessor.

A central issue is the relationship between design premises and initial state. It is stated on page 5 of the Main Appendix:

> In order for the final repository to be safe, its barriers must maintain their barrier functions for a long time after closure. To do this, their properties must conform to the design premises stipulated in /4/ when they are placed in the final repository and will not be subject to any further handling. The properties of the finished technical barriers and the underground openings constitute an important part of the description of the repository's initial state."

The interpretation of this passage seems to be unambiguous: The initial state shall fulfil the design premises. But the situation is complicated by the fact that some of the design premises can never be fulfilled in the initial state, but only in the target state. SotAR 2012 (pp. 22-23) discusses two such premises, for total water flow up to water saturation and for the density of the buffer at water saturation. It may take as long as a thousand years after closure for the buffer to become water-saturated. In the application, this lack of agreement is handled by introduction of a reference design (Main Appendix SR page 6):

> The reference design of the engineered barriers and the underground openings shall agree with the design premises. Production shall be executed and verified so that the barriers and the underground openings conform in the initial state to the specification provided by the reference design. New safety assessments may lead to revised design premises and thereby modified design, production and initial state.

In other words, the initial state must be verified against the reference design, not against the design premises. The question is what is meant by "conform to". A concrete example of how "conform to" should be interpreted is given in SR-Site on page 160:

> The total amount of water flowing into an approved deposition hole must be less than 150 m3 between installation of the buffer and the time when the buffer becomes water-saturated. In the case of the present reference design, the judgement is made that the design premises are fulfilled if potential deposition holes with inflows of less than 0.1 l/s are approved.

Conformity between design premises and reference design is thus in this case the result of a judgement. This kind of conformity does not have to be problematical in itself, since the strength of the circular logic in Fig. 2 is that incorrect judgements should correct themselves when the loop is run through. If clear definitions of the elements in the loop or of the relationships between them are lacking, however, such a “reformulation” of design premises may have disastrous consequences – although not necessarily during the construction period! This brings our attention to the next link in the chain: the relationship between initial state and safety assessment.

SKB states in Main Appendix SR on page 5:

> The initial state is one of the points of departure for assessment of post-closure safety in SR-Site.”

The above discussion leads to the question: Which initial state?

Is it the initial state according to the definition in the top document or the one in SR-Site? Is the initial state assumed to fulfil all design premises or only the verifiable premises in the reference design? How, for example, does the safety assessment problematize the issues of total water flow and buffer density after water saturation?

The fact that these questions must be asked at this point in the application process indicates a need for supplementary information. In the next section, the observations are summarized under three headings and related to the Council’s earlier positions in State-of-the-Art Report 2012 and in the Council’s review of RD&D programme 2010[25].

Questions concerning the initial state and the main loop (safety assessment-design premises-initial state)

The discussion of the initial state brings up three big questions that must be straightened out.

- The term “*initial state*”. Many of the uncertainties surrounding the term “initial state” would be resolved if the initial state described the state of the whole final repository at the same time. The Council’s review of RD&D programme 2010 noted that “two reasonable requirements on the concept of ‘initial state’ are (1) that it refers to the state of the repository’s components at one and the same time, and (2) that the

[25] SOU 2011:50. The Swedish National Council for Nuclear Waste’s Review of the Swedish Nuclear Fuel and Waste Management Co’s (SKB’s) RD&D Programme 2010.

information on this state is based as far as technically possible on measurements at or close to this point in time".

- *Initial state and safety assessment*. This problem complex is discussed in the Council's Nuclear Waste State-of-the-Art Report (SotAR) 2012[26] Chapter 3, and was also an important theme in the Council's presentation of SotAR 2012 on 6 March 2012. What does SKB mean with the claim that "The initial state is one of the points of departure for assessment of post-closure safety in SR-Site."? Is it assumed that initial state fulfils all design premises or only the verifiable ones as they are expressed in the reference design? To what extent does the target state instead constitute a point of departure for the safety assessment? See section 14.2 in this statement of opinion.
- *Initial state and building code*. Several of requirements in the design premises will not be fulfilled in the initial state. For example, the requirement on buffer density or the total water flow in a deposition hole. Instead, they reflect the situation in the target state. It is thus impossible to realize all design premises in the initial state, and SKB's handling of this problem via the reference design was discussed in section 1. A very important question for construction and operation of the final repository is how SKB intends to handle this discrepancy between design premises and initial state in its project organization. How is this discrepancy reflected in the dialogue within SKB between the two main processes Construction and Safety Assessment? How does the Construction process hand over its results to the Safety Assessment process if SKB's definition of the initial state is the starting point for their dialogue? Will the Construction process say "initial state" and mean that it has fulfilled the reference design, while the Safety Assessment process thinks it is analyzing an initial state that fulfils all design premises? SotAR 2012, pages 28–29, emphasizes that the dialogue between Construction and Safety Assessment must be held on all levels – from production of buffer, canister and deposition holes to production of a complete final repository. Everyone must be aware of the distinctions in the main loop.

[26] SOU 2012:7. Nuclear Waste State-of-the-Art Report 2012 – long-term safety, accidents and global survey.

The Council's assessment of the need for supplementary *information*

System analysis of the main loop "Safety assessment – Design premises – Initial state". The Swedish National Council for Nuclear Waste's review of RD&D programme 2010 pointed out the need for a system analysis to study the relationship between the processes Construction and Safety Assessment and the roles of the key concepts Design Premises and Initial State. This analysis and the one in State-of-the-Art Report 2012 show that it is necessary to include the safety assessment and take a closer look at the whole main loop safety assessment-design premises-initial state. The system analysis should start with Figure 2 and clarify the relationships between the three main elements safety assessment, building code/design premises and initial state, and show how Figure 2 will be realized in the organization of and relationships between the two main processes Construction and Safety Assessment.

Proposal for measurement programme. Description of a measurement programme that makes it possible to define the initial state at a given point in time. If SKB should arrive at the conclusion that it is impossible with today's measurement technology to measure the state of deposited canisters and tunnels after backfilling without disturbing the barriers, then SKB must explain why a measurement programme is unnecessary. ANDRA, the French National Agency for Radioactive Waste Management, has informed the Council that they are currently developing a monitoring programme for measurement of critical parameters in the repository for at least 100 years after closure. They consider this to be both necessary and possible to do without affecting the long-term safety of the repository. It must be possible to carry out a similar programme in Sweden as well.

Study of artificial water saturation of the buffer. See further "need for supplementary information" under viewpoints on the buffer and backfill in section 14.2 "Viewpoints on the final repository's engineered barriers".

14 Viewpoints on Appendix SR Site – Long-term safety for the final repository at Forsmark

14.1 Viewpoints on the geosphere

Rock stresses

The rock stresses at different depths in different rock domains are of great importance for whether the rock is suitable for hosting a repository. The stress conditions can affect the design and construction of the repository, and in the longer term its durability as well. There is thus a risk of so-called spalling, both in the ramp and tunnels and in the deposition holes, where the stress is reinforced by the heat from the fuel.

There is also great uncertainty regarding the magnitude of the rock stresses at repository depth in Forsmark. Different measurement methods give different results. Older measurements using the overcoring method, carried out during the construction of Forsmark 3, are considered unreliable, since the measurement method was not sufficiently advanced at the time of data acquisition. They give values of up to 60 MPa for the maximum horizontal stress ($\sigma1$) at repository depth. As is evident from Figure 4–15 on page 124 of the English version of SR-Site (TR-11-01), there is *only one acceptable measurement* of $\sigma1$ (in borehole KFM01B) at repository level, and four with low confidence in the target volume, and no measurements at repository level above the gently dipping deformation zone A2. No stress measurements have been performed in fracture domain FFM06 in the candidate area. The stress state is expected to be similar in fracture domain FFM01.

There is thus only one reliable measurement of$\sigma1$ at repository depth, which gives a value of 41 MPa, twice as high as in Laxemar at 500 metres depth. Measurements by hydraulic fracturing (HTPF inversion) at this depth in Forsmark give a value of about 20 MPa[27], which is normal for $\sigma1$ in Swedish bedrock (22 MPa), but is not reported in the main document.[28] It may seem good that SKB chooses to use a high but uncertain value for $\sigma1$ in its models. However, this uncertainty has consequences for a proper understanding of fracture propagation in connection with a

[27] SKB, 2010a: Site selection – siting of final repository for spent nuclear fuel. R-11-07.
[28] SKB: Long-term safety for the final repository for spent nuclear fuel at Forsmark. Main document from the SR-Site project, Vol. 1.

pressure increase that would occur in connection with freezing of buffer in the event of a permafrost level at repository depth.[29]

Instead of assuming that the stress state at repository depth is the same in the rock volume, it is recommended that new measurements be performed with other methods or with an improved version of the overcoring method, which works poorly in the quartz-rich rock in Forsmark. The overcoring cylinder (bit) could be modified according to report R-07-26 and larger diameters of the boreholes could be tested. But SKB judged this to be far too costly. Instead they plan to await the information from deformation measurements in conjunction with tunnelling, which entails considerable measurement difficulties and gives far too late information.

The Council's assessment of the need for supplementary information

Knowledge of the rock stresses at planned repository depth in Forsmark should be improved.

SKB should better explain the cause of the high rock stresses and the stress field around the lens and describe the importance of the orientation and magnitude of the rock stresses for planning and construction of the tunnels to and in the final repository.

Groundwater and fracture system

Hydraulic properties in fracture domains and deformation zones have been studied in both cored boreholes (22 holes) and percussion boreholes (32). However, uncertainties remain regarding the hydraulic properties in fractures and zones around the tectonic lens.

During the retreat of the most recent inland ice sheet, glacial meltwater was injected hydraulically down to a depth of about 550 metres in the Forsmark area. Brackish Littorina water also occurs in the bedrock, along with equally old pre-Holocene water. SDM[30]

[29] Stephansson, O., 2011: Synpunkter på valda delar av SKB: Fud-program 2010, Rapport till Kärnavfallsrådet.
[30] SKB, 2008: Site description of Forsmark at completion of the site investigation phase: SDM-site Forsmark. TR-08-05, 545 pages.

presents hydrogeochemical data from four fracture domains (FFM01, FFM02, FFM03 and FFM04) and from fracture zones. A mixture of water types occurs in the upper 200 metres at the level where the frequency of hydraulically interconnected gently dipping water-bearing fractures is high. Brackish water from the Littorina Sea is present in the target fracture domain FFM01 down to 300 metres, and below that older, more saline water. No hydrogeochemical data are reported from the similar, centrally situated target volume FFM06[31], which is to be regarded as a serious omission.

The candidate area (fracture domains FFM01 and FFM06) is bounded on the southeast by FFM03, a steeply dipping fracture zone, and on the NO and SW by the Singö zone and the Eckarfjärden Zone, respectively. FFM03 contains several open and partially open fractures down to 1,000 metres, and water from the Littorina Sea has been encountered at depths down to 600–700 metres, which shows that relatively young water (4,500 years) occurs at great depths. However, interference tests show that there is no hydraulic contact between the northeastern portion of the target volume and the bedrock on the northeastern side of the Singö Zone.

The target volume, FFM01, has a very low fracture frequency below 400 metres, but at about 1,000 metres below this volume there is a gently dipping structure (A2) that gives seismic reflection. This structure is connected to an east-southeasterly zone[32] and probably also the steeply dipping zone ENE0060A. Neither in SDM[33] nor in the main document I is the geological significance of A1 described, which has been interpreted in Stephens and Juhlin as a complex geological unit.[34] Extrapolated to the surface, it coincides with the banded rock types, including amphibolite. In the southeastern part of the candidate area, several of the gently dipping fracture zones occur close to or alongside of the contact with amphibolite.[35]

Propagation of existing fractures can be caused by a number of processes such as rock excavation, thermal loading, the swelling

[31] SKB, 2008.
[32] Figs. 4-12, SKB 2011.
[33] SKB, 2008.
[34] Juhlin, C. and Stephens, M.B., 2006. Gently dipping fracture zones in Paleoproterozoic metagranite, Sweden: Evidence from reflection seismic and cored borehole data and implications for the disposal of nuclear waste. Journal of Geophysical Research, Vol.111, pp. 1-19.
[35] SKB, 2011.

pressure of the buffer, permafrost and pressure gradient increase in conjunction with deglaciation. Knowledge of the fracture networks as such is inadequate, and the way these networks are interlinked is poorly characterized.[36]

The transport properties of the bedrock are important for a number of reasons, among others as sinks for radionuclides that might be transported from a leaking repository. Investigations have been carried out in different ways and a special retardation model has been tested. However, uncertainty is still great regarding sorption for many species in different types of groundwater and different rock types with differing porosity and cation exchange capacity, such as for example the excavation-damaged zone (EDZ).

The Council's assessment of the need for supplementary information:

Since it is unclear whether hydraulic connections exist at other places along the important Singö Zone, this should be thoroughly investigated prior to the future detailed planning of the repository.

The rock stress at repository depth should be confirmed, since it is of great significance for modelling of fracture propagation. It is noteworthy that structure A1 is not better defined and should therefore be geologically characterized. If the structure is water-bearing, its relationship to ENE0810 and ENE0060A should be determined.

The uncertainties regarding transport properties should be cleared up by means of sorption studies in both laboratory-scale and field tests. It is thereby particularly important to determine the difference in sorption properties between unaffected rock and the excavation-damaged zone (EDZ).

Rock movements

Possible movements in the bedrock along certain zones have previously been monitored by GPS measurements at a number of stations and on a number of occasions in Oskarshamn and Forsmark. Such measurements have been conducted in Finland for a long time. Instrumentation and processing technique have been

[36] Stephansson, 2010.

developed, making it possible to obtain increasingly accurate and reliable results.

Traces of previous and possible future seismic activity are described in the main document. It is noted that no morphological lineaments have been recognized as representing late- or post-glacial faults, nor have affected Quaternary sediments been found that can be unambiguously related to seismic activity. It is also noted that the greatest uncertainty, and the one that is most difficult to reduce, concerns the expected frequency of future earthquakes of varying magnitude. Different models with pessimistic assumptions have been devised, and the repository is designed to withstand earthquakes of a magnitude of 6 or more on the Richter scale. However, not enough attention is given to ongoing movements in the bedrock, including creep, in a longer, coherent perspective.

Continuous GPS measurements have been carried out to monitor horizontal creep movements in the bedrock since 2005, and in 2004 a seismic monitoring station was installed in Forsmark to record local, and small, movements in the bedrock. Measurements using satellite technology (DInSAR), which were carried out during a limited period, did not detect any movements along major lineaments. SKB is not planning to resume measurements with this method, but seven ground-based thermally and physically stable GPS stations are planned, and SKB is considering , or in the same document planning, to install a local seismic network (SKB 2010c).[37] Modern satellite technology, such as DInSAR, covers a greater area than single GPS stations, and there is every reason to continue measurements of possible movements in the bedrock, including horizontal creep movements, in Forsmark for long-term monitoring during construction and operation of the repository.

[37] SKB, 2010c: R-10-08, Ramprogram för detaljundersökningar vid uppförande och drift av slutförvar för använt kärnbränsle, 111 pages.

The Council's assessment of the need for supplementary information:

It should be clearly stated whether the planned seven ground-based GPS receivers will be stationary or not.

SKB should not just *consider* installing a local seismic network, but actually do so.

It is urgent that SKB resume measurements with modern satellite technology (for example DInSAR) to verify that no (vertical) movements are taking place along major lineaments during construction and operation of the repository.

Mineral resources

With respect to mineral resources, the granitic bedrock in the candidate area in Forsmark can be regarded as barren. The surrounding volcanic rock does, however, contain iron mineralizations and a number of small abandoned mines and test pits. The ones that are close to the candidate area in Forsmark are very small and are not expected to warrant future exploitation. [38] This is supported by the fact that the deposits west of Forsmark (Liängen and Bondgruvan) were considered insignificant even while they were being mined.[39] Skedika Mines, south of the tectonic lens, were, however, productive until they were closed in 1905 down to a depth of about 200 metres. Besides the fact that the ore became poorer with depth, other reasons for the mine closure were technical difficulties with fractured rock and the large influx of water.[40]

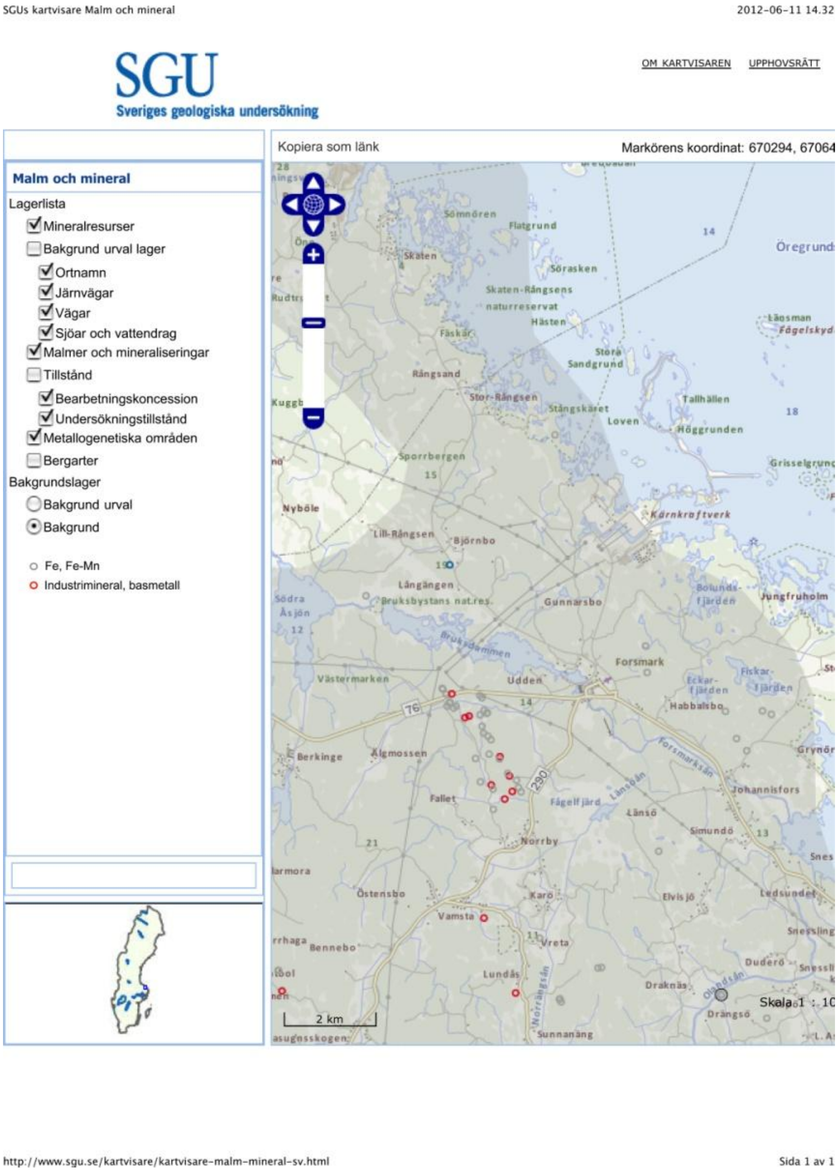
Geologically, the candidate area in Forsmark belongs to the Bergslagen district, which is rich in mineral deposits of widely varying kinds, and mining operations have been pursued continuously in the district for nearly 1,000 years. The mineralizations are for the most part associated with volcanic rocks, or with streaks of marble and skarn that occur in these rocks. Compared with the rest of Bergslagen, northwestern Uppland is relatively sparsely, but not negligibly, mineralized.

[38] SKB 2010b.
[39] Geijer P. och Magnusson, N.H., 1944: De mellansvenska järnmalmernas geologi. Geological Survey of Sweden, Ca 35, 654 pages.
[40] Geijer and Magnusson 1944.

Dannemora Mine, for example, which has now resumed mining operations, has one of the largest iron ore deposits in Central Sweden. Prospecting activities are being pursued in the area, including in the vicinity of Forsmark, where a number of exploration permits have been issued for both iron and base metals such as copper, zinc and lead, as well as silver (Figure 3). The prospectivity of the deposits is considered good (SGU, 2012).[41]

[41] SGU, 2012: (http://www.sgu.se/kartvisare/ kartvisare-malmmineralsv.html?zoom=588048.48893,6565081.224432,718223.418636,6761137.36856.

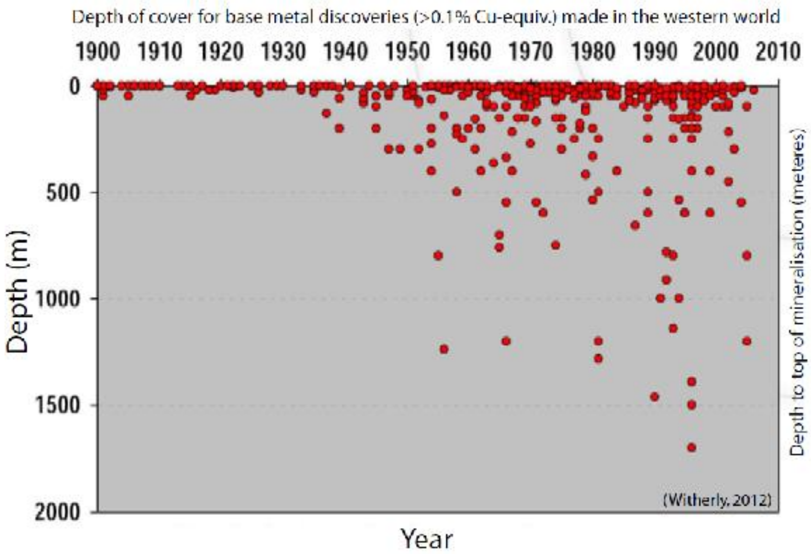
Figure 3 SGU's map viewer, ores and minerals over current mining and prospecting projects



Geological maps show that the same type of rock, a volcanite that is a host rock for the mineralizations, also occurs east and north of the tectonic lens. The area is largely covered with water, and according to SKB no mineralizations have been encountered on the projecting islands. The water-covered area has not been explored, however, and it is therefore possible that both iron (hematite) and sulphide mineralizations (with e.g. copper, zinc and lead) could occur.[42]

In 3D models of the distribution of the rock types in the candidate area, the potentially ore-bearing volcanite first appears at a depth of more than 1,000 metres (Figure 4).[43] In view of the fact that large near-surface mineral deposits are more or less known, prospecting will more likely take place at the depth of potential mineralizations that are not exposed on the surface. Depending on demand, deposits with low concentrations of the sought-after resource may also be of interest to the mining industry.

Figure 4 **The depth to the top of large base metal mineralizations found in the western world between 1900 and 2010**



[42] Toverud, Ö., 2010: Jämförande bedömning av platserna Forsmark och Laxemar som lämpliga för slutförvar av använt kärnbränsle. Report to Swedish National Council for Nuclear Waste, Bromma Geokonsult.
[43] Witherly, K., 2012: The evolution of minerals exploration over 60 years and the imperative to explore undercover. Mining Geophysics, 292-295, figure 4.

Prospecting for deep mineralizations is mainly done by means of geophysical surveys employing gravimetric, magnetic and electrical methods. Just north of the tectonic lens there is a low-magnetic, positive gravimetric anomaly of unknown geological character (i.e. the cause of the geophysical anomaly is not known). In other words, the possibility that the anomaly consists of a mineralization cannot be ruled out. The repository in itself will also constitute a powerful geophysical anomaly, and it is not clear how inadvertent (or intentional) intrusion can be prevented during any future prospecting campaigns.

The Council's assessment of the need for supplementary information:

SKB should provide further support for the claim that future exploitable mineral resources are absent in the Forsmark area so that it can be known with certainty that there are no mineral deposits north and northeast of the tectonic lens and in the water-covered unexposed area with an interpreted (and potentially mineralized) deposit of volcanite.

14.2 Viewpoints on the repository's engineered barriers

The engineered barriers (copper canister and bentonite buffer) are, along with the backfill, important guarantors of the long-term safety of the final repository for high-level spent nuclear fuel.

The safety assessment is the instrument SKB uses to describe possible scenarios for the evolution of the final repository and calculate the probabilities of different outcomes. The so-called initial state is used as a starting point for the calculations. The initial state corresponds to the state immediately after deposition for fuel, canisters, buffer, backfill and closure.

There are many detailed requirements that comprise premises in the safety assessment, but which SKB admits are not fulfilled in the initial state. In the Council's opinion, an analysis is lacking of the consequences if some of these requirements are not met for a very long time or ever. There is a clear need for SKB's application to provide a more specific description of the initial state of the engineered barriers and describe how they then achieve the target state that is then expected to prevail for the rest of the pre-closure period.

The transition will be brought about by a number of natural processes that can take a very long time, perhaps thousands of years, but that are of great importance for predicting the long-term safety of the repository. Since conditions in different parts of the repository vary, achievement of the target state will also exhibit great time variation. This means, for example, that the bentonite buffer will become water-saturated at different times in different deposition holes, and that the backfill in the deposition tunnels will not achieve its optimal function for a very long time and with great variation depending on where the tunnels are situated. Care should thus be taken not to idealize the initial state, which by definition corresponds to the state directly after deposition of the canisters with fuel, emplacement of buffer and backfill and repository closure, since this initial state is often far from the state that is striven for in the long term.

SKB's application should therefore be supplemented with a more thorough account of how the transition from the initial state to the target state will take place, in view of the uneven distribution of groundwater inflow from the rock and the buffer's water saturation, the temperature gradient in the deposition holes, the copper canister's original surface coating of oxides, oxygen consumption in the bentonite buffer, the buffer's mineral composition and impurities, the influence of different types of bacteria and the composition of the groundwater.

The processes leading to the target state occur naturally given a long enough time. These processes are absolutely not uncomplicated and are characterized by both desirable and less desirable portions. There are many reasons for this, but it mainly has to do with the fact that the water saturation of the buffer in the deposition holes can be expected to take a very long time, and that the canister will have a relatively high temperature during this period.

Specific viewpoints on the canister

The copper canister is the most important barrier in the KBS-3 system, since it contains the spent nuclear fuel and prevents radionuclides from escaping. The canister also attenuates ionizing radiation and prevents further uranium fission (criticality). It must therefore be fabricated and sealed with high reliability.

According to SR-Site, the canister should fulfil three safety functions: provide a corrosion barrier (Can1), withstand isostatic load (Can2) and withstand shear load (Can3) in the repository. This means that there are three different conceivable types of canister failure: ruptures and cracks due to corrosion, due to isostatic pressure or due to shear movements.

The canister's mechanical properties are affected to a high degree by creep (transport of copper atoms in the shell), which, according to the design report[44], is the most important damage mechanism, but which is nevertheless not taken into account in SR-Site.

It is the Council's considered opinion that the application should be supplemented with an account of knowledge concerning creep in copper canisters and how it affects damage tolerance. The weld metal in particular is a critical point, and the Council considers that SKB should explore the consequences of high local strains in the canister and devise a validated creep model showing how the integrity of the copper shell can be maintained under different loads.

According to the definition of the safety function of the canister to provide a corrosion barrier (Can1), the thickness of the copper must remain >0. This required thickness is in practice far too small, since mechanical loads and creep will break the canister apart long before this. The safety criterion for copper corrosion must be formulated in a new way that takes into account different mechanical loads on the copper canister.

Copper corrosion in oxygen-free water causes hydrogen evolution. SKB's continued research programme with respect to copper corrosion should also include the role of hydrogen in different mechanisms of copper corrosion and in creep. High pressures are expected on the canister in the final repository due to water saturation of the bentonite, which affects the formation and transport of hydrogen, and hydrogen uptake in copper, which degrades the canister's mechanical properties (hydrogen embrittlement) and influences creep and changes in the copper's material structure.

[44] SKB TR-10-28.

The copper canister's insert of cast iron meets high demands on strength and high damage tolerance under isostatic loading. In conjunction with rock shear, however, relatively small defects in the insert can initiate cracking. The size of a critically damaging defect in the insert can in unfavourable cases be only 4.5 millimetres in depth, which imposes rigorous demands on fabrication and nondestructive testing.

The technical specifications on the ductility (ultimate elongation and fracture toughness) of the insert material should be developed, along with requirements on the microstructure of the insert material.

At present, SKB describes the methods for quality control of cast iron inserts and the copper shell as preliminary and their reliability is being evaluated. The reliability of the methods has been judged on the basis of studies of artificial defects, but they should in the future be described with actual natural defects.

The Swedish National Council for Nuclear Waste has offered many viewpoints on different aspects of the copper canister's safety functions in a number of reviews of SKB's RD&D programmes[45] and annual state-of-the-art reports[46] which are in part reiterated in our present statement.

The Council's Nuclear Waste State-of-the-Art Report 2012 deals with the issues that have to do with the canister's initial state and the transition to a long-term stable state – the target state.

The initial state of the canister describes the properties which the canisters are expected to have when they are placed in the deposition holes and will not be handled anymore in the final repository. The copper canister is then hot (about 90 °C) and emits ionizing radiation (gamma-radiation) to the environment. The surface will be covered with corrosion products (copper oxides) from contact with air during transport to the final repository. It is this oxidized canister surface that is exposed to bentonite buffer and groundwater and that is gradually converted when the oxygen molecules in the environment have been consumed and the environment becomes anoxic (oxygen-free).

The target state in the deposition holes entails that the buffer is completely water-saturated and free of dissolved oxygen and contributes to exerting an even and constant pressure on the copper canister. The buffer will then be very dense with optimal

[45] For example SOU 2011:50.
[46] For example SOU 2011:14 and SOU 2012:7.

properties as a barrier so that it can protect the canister from corrosive substances in the groundwater. The buffer is also supposed to prevent or hinder transport of the hydrogen that is formed by corrosion of copper in an anoxic environment away from the canister.

Water saturation of the buffer is thus a key process for preserving the canister's ability to maintain its safety functions, but can take a very long time. The Council proposes that SKB supplement its application by investigating and describing the consequences of realizing the target state by watering the bentonite buffer artificially.

By the use of clean and tempered water without the corrosive substances present in the groundwater, a tight barrier with desirable properties can be achieved much faster and more or less simultaneously in all deposition holes. A number of negative processes can thereby be avoided.

Artificial watering of the buffer should be accompanied by a specially developed monitoring programme so the process can be followed in detail.

The Council's assessment of the need for supplementary information:

A description should be provided of the canister's safety functions that include the consequences of creep and corrosion of welded joints.

Creep and creep modelling of the entire canister under different mechanical stresses should be investigated.

Results of corrosion tests in a laboratory environment should be compared with and interpreted on the basis of repository-like conditions.

Formation and transport of hydrogen from copper corrosion in an oxygen-free environment under high external pressure in the final repository should be investigated. The influence of hydrogen on the mechanical properties of the canister should be described.

A description of the cast iron insert's damage tolerance and the reliability of nondestructive testing for detecting small defects should be included.

Specific viewpoints on the buffer

The buffer, consisting of natural bentonite, is first compacted to blocks and pellets before it is emplaced in the deposition holes. Water is added prior to compacting so that the water content increases from about 10 to about 17 weight-percent.

Compaction, which involves compression of the bentonite under high pressure with an increase in density, also causes portions of air (about 21 percent $O_2(g)$) to be entrapped in the blocks. The added water also contains dissolved oxygen, $O_2(aq)$. Since blocks and pellets are lowered down into the deposition holes after compaction, this comprises the bentonite buffer's initial state. Compaction causes voids and pores in the bentonite to be compressed, especially those containing atmospheric oxygen, and the internal pressure in the pores increases radically.

SKB's description of the initial state of the buffer makes it clear that there are quantitative design premises that are related to long-term safety. There are many detailed requirements (for example density and water saturation) that they admit are not fulfilled in the initial state, but are otherwise not discussed. In the Council's opinion, an analysis is lacking of the consequences if some of these requirements are not met for a very long time or ever.

Nor is it certain that the buffer will have the design-basis properties when it has become water-saturated. There are many steps on the way from initial state to target state – such as mineral alteration in the bentonite, density increase due to sorption of water, oxygen consumption through various reactions in the bentonite, influence of bacterial activity etc. – that can affect the buffer's properties.

An account of the reference design and production methods for buffer and deposition holes contains specific data on various dimensions of boreholes and buffer with standard deviations. It is described as very important that buffer blocks and canister be centred in the deposition hole so that the gap between buffer and rock wall does not vary too much.

SKB describes that bentonite blocks should be kept under an airtight hood for several months and that the buffer should be protected from absorbing water and drying out by placing a special buffer protection in the deposition hole. This protection is then removed before the onset of the initial state. If the rock is very dry, which was one of the reasons for choosing Forsmark as the site of the repository, the buffer will be in the deposition hole for a very long time before it becomes water-saturated and will consequently dry out. The canister has a temperature of nearly 100 ^{0}C, and the deposition hole is comparable to a thermos, since dry bentonite has very low thermal conductivity.

One might wonder how the strength of the bentonite blocks is affected by this. Can the bentonite blocks directly beneath the canister (which weighs around 25 tonnes), or at the bottom of the deposition hole in contact with the canister, bear the considerable weight of the blocks above (several tonnes) without breaking apart? What will then happen to the tilt of the canister in the deposition hole? Will it tilt so much that it leans against the rock wall?

A very low or negligible concentration of oxygen in the buffer is also part of the target state for both buffer and copper canister, even though this is not evident from SKB's application. After compaction of the bentonite, oxygen will be present both in air pockets and in the pore water in the blocks. The question is how quickly the oxygen will be consumed in the relatively dry bentonite if there is little or no groundwater influx from the surrounding rock for a long time. How will this affect possible corrosion of the copper canister?

Another consequence of drying out of the buffer is that the canister will not be cooled at the assumed rate by the transmission of heat through the buffer, which also affects the safety function.

Artificial watering of the buffer would eliminate most of the above problems. SKB should explore the possibilities of increasing the rate of water saturation with tempered water free of corrosive substances.

SKB intends to make great efforts to make the bottom of the deposition hole as flat and level as possible. A bottom pad of copper will be used, whose exact position can be adjusted by means of bolts. It is urgent that the buffer, as it dries out, retains its capacity to keep the canister vertical in the deposition hole.

Added to this are the consequences of all the processes that occur when a relatively dry buffer becomes water-saturated after a long time. SKB should therefore describe the advantages and disadvantages of saturating the buffer with water immediately after deposition of the copper canister. This could then be included in a new definition of the initial state,.

The target state could then be achieved considerably faster, especially in dry boreholes.

The Council's assessment of the need for supplementary information:

SKB should investigate how the long-term strength of the bentonite blocks in the deposition holes is affected by a diminishing water content due to drying-out. A particular issue here is the verticality (uprightness) of the copper canisters in the deposition holes.

SKB should investigate how the chemical and physical properties of the buffer are affected by long-term exposure to high temperature in the deposition holes.

SKB should investigate how the interaction between buffer, rock and canister – as well as between buffer and backfill – will function under conditions with a very uneven water supply.

SKB should find out more about how rapidly the oxygen in the air and pore water in the buffer is consumed and what the mechanisms for this are in unsaturated vs. water-saturated bentonite.

SKB should investigate and describe the consequences of artificially saturating the buffer in the deposition holes with water by injecting an optimal amount of water of known composition and temperature. The procedure should be combined with a monitoring system specially developed for the purpose.

Specific viewpoints on the backfill

SKB's RD&D programme 2010 states that "the most important functions of the backfill are to make the mass transport capacity comparable with that of the surrounding rock and to minimize the upward expansion of the buffer." This state must be regarded as the backfill's target state and does not correspond to the properties of the backfill immediately after closure, which by definition can be designated the backfill's initial state.

This are a number of specified design premises for the backfill that are related to long-term safety. These premises apply to the above-defined target state, whereas the initial state does not fulfil many of these requirements.

The same problems exist for the strength of the bentonite blocks in the backfill if the rock is dry as for the buffer in the deposition holes. Once the deposition tunnel has been filled up to the roof, the bottom blocks will have to carry the great weight exerted by the blocks above, and if they dry out their strength will be greatly degraded and the blocks could possibly collapse. Such a scenario would have a great impact on the tightness of the seal against the roof and walls.

The influx of water from the rock into the deposition tunnels can be expected to be very uneven, which means that the swelling of blocks and pellets will vary greatly at different places and in all dimensions. In addition to a considerable risk of local erosion, the density of the buffer, and thereby also its hydraulic conductivity, will vary.

It is not possible to make the same rigorous demands on the flow of water through fractures in the rock in the deposition tunnels as in the deposition holes, and conditions in different tunnels, as well as in different parts of the tunnels, will exhibit relatively great variation. It will probably take a very long time before these conditions are equalized.

One of the backfill's most important tasks is to resist the swelling of the buffer upwards in the deposition holes, so that its density there can be kept at a high level. In order for this to happen, the density in the backfill must probably be high enough, and the only way to ensure this is by ensuring that the bentonite blocks have become water-saturated and swelled. The bentonite in the backfill has a lower concentration of montmorillonite and can therefore be expected to have a poorer swelling capacity. In other words, there will be a fairly sensitive interaction between the water saturation process in the deposition holes and in the backfill, and there are at present no plans for verifying how well this has been fulfilled.

If parts of the deposition tunnels are dry and the bentonite blocks there have dried out and their strength declines, they will most likely have much poorer resistance to vibrations that may occur in conjunction with blasting in adjacent tunnels.

The risk of bentonite erosion is much higher in the backfill than in the buffer. Since the concentration of montmorillonite is lower, the concentration of the other minerals will become more important for the long-term function of the backfill. SKB should introduce a grinding of the bentonite in the production chain in addition to the homogenization that is planned after drying and before storage in a silo. The extra treatment should take the form of a fine grinding step prior to compaction. It is known from the cement industry that an extra grinding activates the surfaces of the particles so that reactions with water proceed faster and more efficiently.

The Council's assessment of the need for supplementary information:

SKB should investigate how the mechanical stability and capacity to sorb water of the bentonite blocks in the backfill is affected by the fact that conditions will vary in different parts of the deposition tunnels for a long period of time. This is particularly true due to the fact that the blocks in the backfill will have a lower concentration of montmorillonite than those in the deposition holes.

SKB should investigate how blasting and other activities in adjacent tunnels affect blocks and pellets in already backfilled tunnels.

SKB should investigate how the fraction of bentonite pellets in the backfill can be reduced by shaping the contours of the bentonite blocks to fit the roof and walls of the deposition tunnels.

SKB should investigate how buffer and backfill interact during very dry periods and whether the influx of water is very uneven.

SKB should investigate the possibility of activating the surfaces of the mineral particles in the bentonite before compaction in order to speed up the wetting process.

15 Viewpoints on Appendix SR-Drift/Operation – Safety analysis report for operation of the final repository

On page 5 of Appendix SR – Säkerhetsredovisning för slutförvaring av använt kärnbränsle ("Safety analysis report for final disposal of spent nuclear fuel"), SKB observes that: "A preliminary safety analysis report must be compiled before a facility may be built. The preliminary safety analysis report will be presented prior to start of construction. SSM's regulations (SSMFS 2008:1, SSMFS 2008:21, SSMFS 2008:37) do not contain any precise requirements on the level of detail in a preliminary safety analysis report". It can then be assumed that SKB believes that the same thing applies for the document PSAR Drift, hereinafter called SR-Drift (Drift = Operation).

Even though SKB clearly lacks guidance regarding precise requirements on level of detail, SKB should nevertheless have made an effort to achieve a more comprehensive and detailed account than the one presented in SR-Drift. The Swedish National Council for Nuclear Waste observes that:

- the text in SR-Drift is very general. There is no discussion of unforeseen events (for example in Chapter 6, section 6, "Release of radioactivity in the facility")
- quite a few claims, usually a line or so of text, are not followed by a more detailed account of consequence
- reference is made in several chapters to the need for investigations linked to relevant events – no exact time is given, nor the consequence of the event (e.g. Chapter 5 page 47, Chapter 8 pages 18 and 24)
- there are in several chapters references to SKB reports, for example the production/line reports, that are not included in the application to the Land and Environment Court

Use of concrete in the repository is incompletely described, for example concrete in the bottom of the deposition hole is not mentioned (only in TR-11-01 page 198 and TR-10-47 page 38). Use of concrete in the repository (for example in plugs for deposition tunnels, sealing of boreholes etc.) is described in SKB TR-10-47, but no reference is made to this report. The total quantity of concrete in the repository is not specified in SR-Drift. In order to be able to assess the construction and operating phases of the repository, it is necessary for SKB to specify the total quantity of concrete intended to be used during the repository's operating time.

Chapter 3 pages 28–29 contains extensive references to the production reports. Since these reports are not included in the application to the Land and Environment Court, relevant excerpts from these reports should have been presented in SR-Drift to permit assessment of the final repository's requirements on engineered and natural barriers.

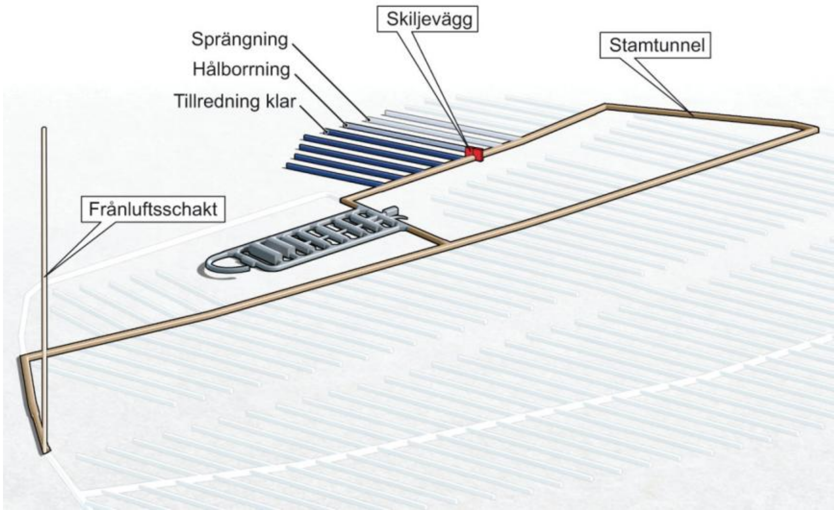
It is evident from chapter 3 section 7.3.5 page 35 "Physical separation" (also chapter 4 page 9) that deposition of canisters will take place sequentially with the rock works in the adjacent deposition tunnel 40 metres away (page 320 in SR-Site gives a distance of 80 metres). In order to be able to have some idea of how blasting of a tunnel affects the barriers in a finished deposition tunnel, SKB should be able to specify the correct distance.

It is said in chapter 3 section 9 page 37 of SR-Drift that

> Concrete and measurable quality requirements to be applied to the barriers in the final repository [...] have not yet been determined, to be done later.

This may have been true when SR-Drift was written. Now concrete requirements must be determined and reported by SKB so that the Council, and subsequently the Land and Environment Court, can form an opinion concerning the quality requirements. Furthermore, SKB should be able to specify how the quality requirements can be measured. See also comments on chap. 8.

Figure 5 Figure 3–1 Repository area at start of trial operation[47]



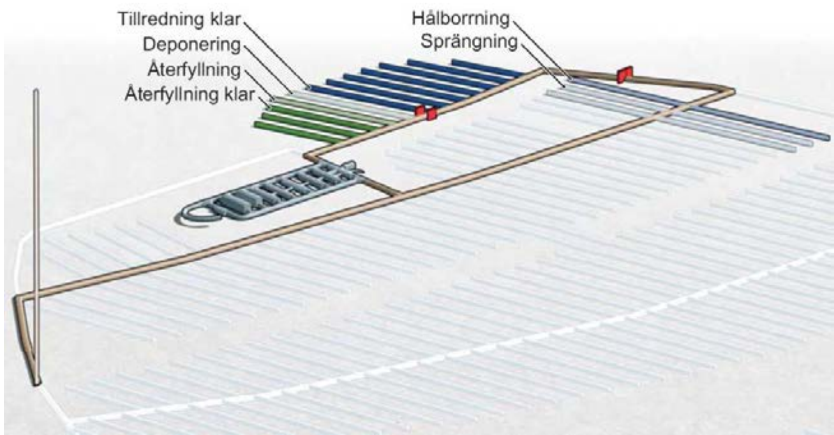
Sprängning = Blasting
Hålborrning = Hole boring
Tillredning klar = Tunnel excavation finished
Skiljevägg = Partition
Stamtunnel = Main tunnel
Frånluftsschakt = Exhaust air shaft

Chapter 5 section 3.1.1 "Trial operation" page 36 gives a very brief description of three sequential deposition tunnels (tunnel excavation finished, hole boring, blasting). Figure 3.1 page 36 shows five tunnels where tunnel excavation is finished, hole boring is taking place in the next tunnel and blasting in the next tunnel (separated by a partition). There is no text describing the deposition and backfilling sequence.

Figure 3–2 on page 37 of the application shows the repository area after a few years' operation. The description of the different tunnels and the deposition sequence is extremely cursory and does not specify any distances.

[47] Appendix SR-Drift, Chapter 5 page 36.

Figure 6 Figure 3–2 The repository area after a few years' operation[48]



Tillredning klar = Tunnel excavation finished
Deponering = Deposition
Återfyllning = Backfilling
Återfyllning klar = Backfilling finished
Hålborrning = Hole boring
Sprängning = Blasting

The first deposition hole is bored about 21 metres in from the main tunnel (mentioned in SR-Site to avoid erosion).

In SR-Site, SKB says that

> Since no deposition hole will be located closer than 20.6 m from the deposition tunnel entrance /SKB 2009b/, this implies that the loss of backfill from deposition tunnels could lead to density reduction of the buffer in at most four to five deposition holes located closest to the tunnel entrance.

The above-quoted, relatively new information regarding the location of the deposition hole in the tunnel definitely belongs in SR-Drift, where all description is very limited.

In the reference Jonsson et al. 2009b in SR-Site (R-09-40), the conclusion is drawn that the bentonite buffer will likely be subjected to a displacement of less than 0.5 millimetre when

[48] Appendix SR-Drift, Chapter 5 page 37.

blasting is being conducted at a distance of 30 metres with a charge of 4 kg. The question is what explosive effect a charge of 4 kg can create in blasting a tunnel. Another important question which SKB should be able to answer is what happens to a dry backfill during blasting of nearby deposition tunnels in the repository.

In order for the Land and Environment Court to be able to assess the practical execution of deposition of bentonite and canisters in the deposition holes and bentonite blocks and pellets in the deposition tunnels, as well as the plugs in deposition tunnels, SKB should describe this in running text.

Examples of questions/phenomena that should have been mentioned in SR-Drift are whether:

- all deposition holes will be bored and covered with a plate before deposition is begun at the back of the tunnel.
- deposition will take place in all deposition holes before backfilling is commenced (answers to the above questions may possibly be found in other reports).
- It is further worth noting that
- many designs (figures) are preliminary in chapter 5 of SR-Drift, which may be acceptable at this point in the process.
- In chapter 8 “Safety assessment”, page 3, SKB writes in italics that: “*at the present time there are no quantified limit values, acceptance criteria, for the integrity of the barriers or for mechanical stresses in the barriers*” which may have been true when the report was initiated.

Bentonite questions

In SKB TR-10-15, SKB states that homogenization of bentonite (grain size <75μm) shall be done before blocks and rings for deposition holes are fabricated. In order to obtain further homogenization of the bentonite and to obtain much larger contact surfaces for the bentonite grains, grinding of the bentonite could be done. The Council is of the opinion that SKB should be able to describe the advantages and disadvantages of ground bentonite.

Furthermore, SKB should explain whether bentonite for deposition holes and for deposition tunnels is planned to be fabricated in two different lines, so that the risk of mixing bentonite grades is eliminated.

The Council's assessment of the need for supplementary information:

There is absolutely no discussion of unforeseen events. This should be introduced in SR-Drift.

Concrete and measurable quality requirements to be applied to final repository must be established and presented by SKB in order for the court to be able to form an opinion about the quality requirements. Furthermore, SKB should specify how the quality requirements can be measured.

SKB should describe the use and quantity of concrete in the final repository (including concrete in deposition holes).

SKB should present relevant parts of the production reports in SR-Drift in order to provide a basis for assessment of the final repository's requirements on engineered and natural barriers.

SKB should present a detailed logistic description of the deposition sequence, including the distance from main tunnels to deposition holes taking into account e.g. blasting of new deposition tunnels in the dry rock in Forsmark.

Furthermore, SKB should explain whether bentonite for deposition holes and for deposition tunnels is planned to be fabricated in two different lines, so that the risk of mixing bentonite grades is eliminated.

Appendix 1

The term “initial state” in the application documents

01b. Top document – Terms and definitions

Initial state

Properties of the spent nuclear fuel and the engineered barriers when they are finally put in place in the final repository and are not handled further in the final repository.

Properties of underground openings at the time of final deposition, backfilling or closure.

01a. Top document – Pages 32–33

The future state of the system will depend on:

- the initial state
- internal processes that act in the repository system over time, and
- external processes acting on the system.

The initial state includes the state of the engineered barriers after deposition, for example the thickness of the copper on the deposited canisters, the quantity of buffer material in the deposition holes, or the shape of the deposition holes. Conditions in the rock at the time of construction are also included in the initial state.

Appendix SR – Safety analysis report for final disposal of spent nuclear fuel (occurs in 11 places)

Place 1: Page 5

> The properties of the finished technical barriers and the underground openings constitute an important part of the description of the repository’s initial state.
>
> The initial state is one of the points of departure for assessment of post-closure safety in SR-Site.”

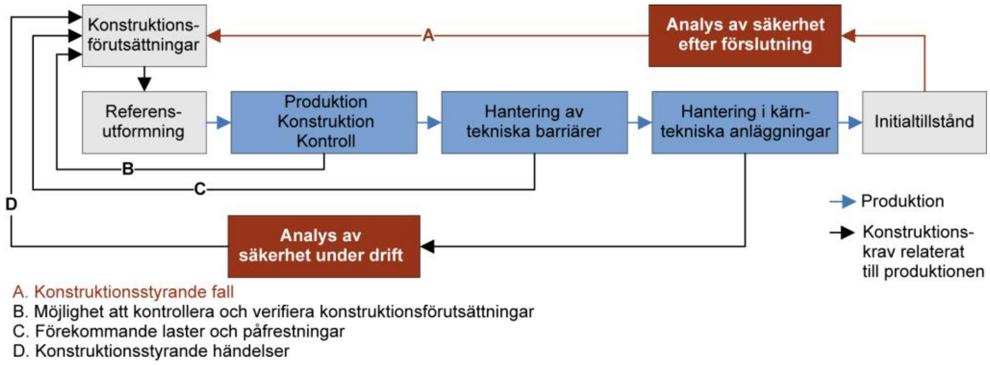
Place 2: Page 7

> Acceptance criteria for the events are, in the case of the canister, related to the safety of the final repository, and in the case of other engineered barriers and underground openings they are related to what is acceptable with regard to the properties in conjunction with the initial state and their importance for post-closure safety.

Place 3: Page 7

Production shall be executed and checked so that the barriers and the underground openings conform in the initial state to the specification given by the reference design. New safety assessments may lead to revised design premises and thereby modified design, production and initial state.

Figure 3–1 The safety assessment's impact on design. Design-basis cases and events are design premises from assessments of post-closure and pre-closure safety



Konstruktionsförutsättningar = Design premises
Analys av säkerhet efter förslutning = Long-term safety assessment
Referensutformning = Reference design
Produktion = Production
Konstruktion = Construction
Inspektion = Inspection
Hantering av tekniska barriärer = Handling of engineered barriers
Hantering av kärntekniska anläggningar = Handling within nuclear facilities
Initialtillstånd = Initial state
Analys av säkerhet under drift = Operational safety assessment
Produktion = Production
Konstruktionskrav relaterat till produktionen = Design requirements related to production
A. Konstruktionsstyrande fall = A. Design-basis cases
B. Möjlighet att kontrollera och verifier konstruktionsförutsättningar = B. Possibility to check and verify design premises
C. Förekommande laster och påfrästningar = C. Occurring loads and stresses
D. Konstruktionsstyrande händelser = D. Design-basis events

Place 5: Page 8

SR-Site with supporting material contains the following:

- Description of the nuclear safety and radiation protection requirements made on a final repository.
- Description of the initial state and how it is achieved.
- An analysis of the evolution of the barriers after the initial state and the final repository's post-closure safety.

- Description of the fact that final disposal can take place in a safe manner for man and the environment in the long term.

Place 6: Page 9

Furthermore, a description is given of production and inspections from delivery until the engineered barriers, the underground openings and other parts have been finished as parts of the final repository. Finally, the properties of the finished repository, i.e. the initial state, are described, along with the expected variations and uncertainties in the properties.

Places 8–11: Page 12

Chapter 5 describes the initial state, i.e. the state immediately after deposition for canisters, buffer, backfill and closure. The initial state of the fuel and the engineered components refers to conditions immediately after deposition. The initial state of the geosphere and the biosphere refers to the natural conditions prior to the start of the rock excavation work. The description is based on the reference design for the KBS-3 repository based on execution methods and inspections described in the production reports /5/, a descriptive model of the site for the final repository and a site-specific design of the repository. The concept of initial state also includes the variation in properties that can be expected with the employed execution methods and executed inspections.

The mission of the Swedish National Council for Nuclear Waste is to advise the Swedish Government in matters concerning nuclear waste and the decommissioning of nuclear facilities. The Council is an independent scientific committee whose members possess expertise in technology, science, ethics and the social sciences.

In February each year, the Swedish National Council for Nuclear Waste publishes a State-of-the-Art Report with the Council's independent assessment of the current state of the art in the nuclear waste field. The purpose is to highlight issues the Council considers important and clarify the Council's viewpoints on these issues.

This year's report—"Nuclear Waste State-of-the-Art Report 2013. Final repository application under review: supplementary information and alternative futures"—consists of two parts.

The first part concerns the viewpoints that have been submitted to the Swedish Radiation Safety Authority and the Land and Environmental Court at Nacka District Court on the Swedish Nuclear Fuel and Waste Management Co's (SKB) application for a licence to build and operate a final repository for spent nuclear fuel. The report describes and elaborates on some of the most important viewpoints from the Council's own statement of opinion. This is followed by a compilation of the most frequently recurring viewpoints in the statements of other referral bodies.

The second part of the report discusses the importance of technology development for the management of spent nuclear fuel, in particular the possibility of recycling the spent fuel.

The report can be downloaded at www.karnavfallsradet.se/en and can also be ordered by emailing to karnavfallsradet@gov.se.

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