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

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Swedish National Council for Nuclear Waste

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for Nuclear Waste Report

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Translated into English by Richard Nord Translation

Project administrator for the English translation of SOU 2011:50: Karolina Brogan

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To the minister and head of the Ministry of the Environment

The Swedish National Council for Nuclear Waste's Review of the Swedish Nuclear Fuel and Waste Management Co's (SKB's) programme for research, development and demonstration of methods for the management and disposal of nuclear waste.

One of the tasks assigned to the Swedish National Council for Nuclear Waste is to assess SKB's research, development and demonstration (RD&D) programmes[1]. The present report contains the Council's assessment of RD&D programme 2010. The review is based on the members' special areas of expertise and the aspects which the Council has addressed previously, in previous reviews and state-of-the-art reports.

On 16 March 2011, SKB submitted its application for licences under the Nuclear Activities Act and the Environmental Code to build facilities for final disposal and encapsulation of spent nuclear fuel. The Council intends to begin its review of the application during the latter half of 2011, and its contents have not influenced the Council's review of the research and development programme.

All Members of the Council – Hannu Hänninen and Ingvar Persson (experts), Holmfridur Bjarnadottir (administrative director) and Peter Andersson (secretary) – stand behind the Council's review. In addition, the following persons have contributed to the review work: Ove Stephansson (geosphere), Per Möller (climate evolution) and Lars Marklund (hydrology). The project administrator has been Öivind Toverud.

Stockholm, June 2011

Swedish National Council for Nuclear Waste

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[1] M 1992:A, Dir.2009:31

Torsten Carlsson
Lena Andersson-Skog
Carl Reinhold Bråkenhielm
Willis Forsling
Mats Harms-Ringdahl
Tuija Hilding-Rydevik
Karin Högdahl
Lennart Johansson
Clas-Otto Wene

/Holmfridur Bjarnadottir, Peter Andersson

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1.1 Premise for the Council's review

The Swedish National Council for Nuclear Waste has reviewed selected portions of SKB's research programme. The premise for the review is the composition of the Council and the special expertise of its members, which means that the review does not provide a comprehensive assessment of the contents of the programme. Instead, attention is focused on areas where the Council possesses special expertise and issues the Council has spotlighted in previous reviews.

The review includes viewpoints on SKB's plan of action, the LILW programme, the nuclear fuel programme, research for assessment of long-term safety and social science research. It has been supplemented with studies performed by consultants in the fields of geosphere, climate evolution and hydrology. These special reports are attached as appendices to the present report.

In order to make it easier for the reader to compare the Council's review with SKB's own presentation of its research and development programme, the report has roughly the same disposition as SKB's presentation. Following is a summary of the questions the Council feels are of particular importance, followed by all of the Council's conclusions. Definitions of terms are given in the respective chapters.

1.2 Questions of particular importance

The Swedish National Council for Nuclear Waste has identified unclear points in SKB's research programme and considers the following issues to be in need of further research:

Responsibility after closure. The Council would like to see a clearer division of responsibilities after the final repository has been closed and approved. This includes formal responsibility for physical protection after closure (see Chapter 2).

The LILW programme. The Council welcomes a more detailed account of the programme for low- and intermediate-level waste (LILW). However, the Council would appreciate further clarification of different parts of the LILW programme, particularly with regard to the consequences of changes in the timetables for the extension and operation of SFR, as well as the composition of the Decommissioning Group. It is therefore the Council's considered opinion that SKB should, before submitting an application for the extension of SFR, submit a supplementary assessment of the consequences of a delay in the extension of SFR and plans for such an eventuality. Further, the Council calls for a more detailed analysis of flows and shipments of different categories of radioactive waste generated by the utilization of different interim storage facilities. The Council would appreciate clarification of the proportion of long-lived waste in SFR, the possibility of recycling decommissioning waste, and the extent to which the waste is intended to be conditioned to reduce its volume. SKB is urged to improve its knowledge of the adsorbency of important corrosion products, as well of the importance of microbial activity and colloidal transport of radionuclides, and to investigate how material composition and pretreatment of concrete can be utilized to prolong the life of the barriers (see Chapter 3).

The safety assessment. The Council repeats its demand from 2007 that SKB should clarify the internal role of the safety assessment as a tool for guiding R&D and technology development. The Council would like SKB to carry out a system analysis as soon as possible to clarify the relationship between the two iterative main processes of safety assessment and construction and the roles of the two key concepts of initial state and *design premises* (see Chapter 5).

Unclear points regarding canister, buffer and backfill. The Council observes that some points pertaining to the canister are still unclear and that SKB should pursue further studies in several areas. Examples are corrosion studies, analyses of creep in the copper canister, and the material properties of the cast iron insert. With regard to buffer and backfill, SKB is urged to examine the importance of a very long period before full water saturation for the long-term quality of the buffer, and the possibility of reducing the amount of pellets in the backfill by fitting the bentonite blocks more closely to the outer contour of the tunnels (see Chapters 4 and 5).

The need for social science research. The Council concludes that there is still a great need for social science research regarding nuclear waste, which should be as free as possible of economic and political interests but still of relevance to Swedish nuclear waste management. The future research should study the consequences of increased competition on the global market for raw materials, the consequences of crucial changes in the ownership of nuclear power, and conditions for societal planning and decision-making.

1.3 Swedish National Council for Nuclear Waste's conclusions

All conclusions from the Council's review follow below. The background and reasons for the Council's review are presented in the respective chapters.

SKB's plan of action (see further Chapter 2)

The following points comprise the Swedish National Council for Nuclear Waste's conclusions:

- It is the Council's considered opinion that SKB should determine what research is needed to explore the option of dry interim storage of the control rods. SKB should also plan for development and demonstration of an interim storage facility.
- It is the Council's considered opinion that SKB should shed light on how international treaties requiring Sweden to provide safeguards against illegal intrusion in the final repository can be enforced after closure, when monitoring is not planned.

- It is the Council's considered opinion that SKB should more clearly combine the milestones described in RD&D Programme 2007 with the flexibility requirement and in RD&D programme 2010 with regard to the LILW programme.
- The Council calls for further study of how extending the operating times of the nuclear power plants would affect Clab.
- The fourth generation of nuclear reactors may be put into operation within 100 years, i.e. in conjunction with the final part of the repository's operating phase. It is the Council's considered opinion that SKB should not restrict itself to examining the consequences of the third generation of nuclear reactors, but also of the fourth generation.
- It is the Council's considered opinion that SKB should give more consideration to the consequences of a trend towards the fourth generation of nuclear power reactors for the main timetable and for its Nuclear Fuel Programme. The question can be asked whether the envisioned repository could be converted to an interim storage facility for nuclear fuel from our light water reactors, so that it could be retrieved and used in the fourth generation of nuclear power reactors.
- It is the Council's considered opinion that SKB should consider what consequences earlier dismantling of other nuclear power plants might have for the extension of SFR.
- It is the Council's considered opinion that the state should assume formal responsibility for physical protection after final closure of the facility.
- It is the Council's considered opinion that the state should assume "ultimate responsibility" for the final disposal of spent nuclear fuel and nuclear waste after final closure of the facility and approval of this closure by the then-responsible authority. This means that the state will at that time assume the obligations and rights of the licensees for the repository and the spent nuclear fuel.

The LILW programme (see further Chapter 3)

- It is the Council's considered opinion that SKB should, before submitting an application for the extension of SFR, submit a supplementary assessment of the consequences of a delay in the extension of SFR and plans for such an eventuality.
- SKB should clarify how large a fraction of the waste in SFR is actually long-lived.
- SKB should describe in greater detail the reasons, including advantages and disadvantages, of assuming in its planning that SFL cannot be put into operation before 2045. They should also promptly investigate the possibilities of an earlier commissioning of SFL.
- SKB should systematically analyze and describe the flows and shipments of different categories of radioactive waste generated by the utilization of different interim storage facilities, including processes for conditioning, closure, etc.
- SKB should describe more clearly the role, composition and working methods of the Decommissioning Group.
- The LILW programme should be supplemented in the next RD&D programme with an account of the possibilities of recycling of decommissioning waste in particular, but also of waste that would otherwise be placed in SFR. SKB should moreover describe how, and to what extent, they intend to condition the waste for the purpose of reducing its volume.
- SKB is urged to improve its knowledge of the adsorbency of important corrosion products and of the importance of microbial activity and colloidal transport of radionuclides.
- SKB is urged to investigate how material composition and pretreatment of concrete can be utilized to prolong the life of the barriers.

The Nuclear Fuel Programme (see further Chapter 4)

The canister

- SKB should develop final testing methods and acceptance criteria for all parts of the canister that take into account material structure, material properties and defects. It must be possible to verify the quality requirements by nondestructive testing methods.

The buffer

- SKB is urged to describe the consequences of failure to fulfil the requirements on the initial state of the buffer with respect to water saturation.

The backfill

- SKB is urged to explain the importance of the density and composition of the backfill for fulfilment of the requirement to limit the upward swelling of the bentonite.
- SKB should explain how the requirement on low hydraulic conductivity of the backfill can be met with bentonite blocks with a lower montmorillonite content than that of the buffer.
- SKB should consider the problems that can arise at closure due to expected future climate change as well as periods of freezing.

The rock

- It is the Council's considered opinion that SKB needs to study the consequences of fracture formation and fracture propagation, and whether this leads to higher water flow around the deposition holes.
- SKB should clarify which method for thermal conductivity and heat capacity they plan to develop.

KBS-3H

- SKB is urged to intensify its development work on the KBS-3H method.

Research for assessment of long-term safety (see further Chapter 5)

The safety assessment

- The Council assumes that the time horizon for the safety assessment of SFR will be extended so that the safety assessment can give a correct picture of the dose risks posed by long-lived nuclides.
- The Council repeats its demand from 2007 that SKB should clarify the internal role of the safety assessment as a tool for guiding R&D and technology development.
- The Council would like SKB to carry out a system analysis as soon as possible to clarify the relationship between the two iterative main processes of Safety Assessment and Construction and the roles of the two key concepts of Initial State and Design Premises.
- The Council observes that studies of the processes aimed at guaranteeing that the initial state is fulfilled are extremely important and finds:
  - that the work of formulating design premises should be incorporated in the RD&D programme and viewed as an essential part of the reporting of the R&D programme for long-term safety.
  - that SKB should, as soon as possible, initiate systematic studies of what the *organization* should look like in order to guarantee that all design premises are complied with and the desired initial state is achieved under the special conditions that prevail for execution of a final repository.
  - that SKB should develop a *measurement programme* that makes it possible to verify changes that occur in the conditions in the buffer, deposition holes and deposition tunnels as the tunnels are sealed.

The canister

- SKB should continue corrosion studies within several different areas. Research is under way, and it is important that the conclusions are scientifically certain and that corrosion data are sufficiently substantiated in order to permit a credible assessment that guarantees long-term safety against corrosion of the canister.
- In creep analysis of the copper canister, more consideration should be given to the creep properties of heterogeneous friction stir welds and geometric discontinuities that exhibit the largest local deformations in copper canisters according to the design analysis.
- The material properties of the cast iron insert (variation in microstructure and mechanical properties) should be further investigated. The variation of ductility and fracture toughness in large castings will be important if the damage tolerance analysis shows that the critical size of the material defect is small.

Buffer and backfill

- The Council urges SKB to present a quality programme that includes the total mineral composition of bentonite.
- The Council urges SKB to conduct repeated freeze-thaw tests on bentonite with a lower montmorillonite content in the same way as for bentonite in the buffer.
- The Council urges SKB to study the importance of a very long period before water saturation for the long-term quality of the bentonite.
- The Council recommends that SKB consider reducing the amount of pellets in the backfill by fitting the bentonite blocks more closely to the outer contour of the tunnels.
- The Council urges SKB to determine transport mechanisms and travel times through the buffer for the most important radionuclides in the event the copper canister should leak.

The geosphere

- It is the Council's considered opinion that SKB should clarify how the flux boundary conditions (surface water runoff) have been used in the models of the importance of the repository site for the regional flow paths.
- The Council proposes that SKB carry out seismic surveys in a dense network in order to create a better 3D picture of the distribution and orientation of important fracture systems in Forsmark.
- The Council proposes that SKB establish a local seismic network in Forsmark.
- The Council proposes that SKB install stationary GPS stations and artificial reflectors for DInSAR in Forsmark and that measurements of possible changes of the surface be performed continuously over a long time.
- The Council proposes that SKB carry out a consequence analysis of the models for mechanical rock failure.

Surface ecosystems

- The Council calls for a more comprehensive account of the contents of the planned research programme concerning terrestrial and aquatic ecosystems.

Other methods

- SKB should investigate whether good physical conditions for disposal in deep boreholes exist in the country, taking into account upgraded knowledge of drilling and deposition technology.

Social science research (see further Chapter 6)

- It is the Council's opinion that SKB has detached its social science research programme from its fundamental final disposal mission in an unsatisfactory manner.

- There is still a great need for social science research around nuclear waste, which should be (1) as free as possible of economic and political interests but still (2) of relevance to Swedish nuclear waste management.
- The future research should study the consequences of increased competition on the global market for raw materials (for example copper), the consequences of crucial changes in the ownership of nuclear power, and conditions for societal planning and decision-making.
- A number of the changed premises that could warrant a far-reaching re-examination of the execution of the nuclear waste programme and SKB's main timetable are associated with different types of societal changes, which could be made the subject of social science research.
- In the light of SKB's evaluation and the Swedish National Council for Nuclear Waste's upcoming review, the Government should (1) study the forms for how independent social science and humanistic research on the nuclear waste issue is to be conducted in the future and (2) in the upcoming research bill, make sure that money from the Nuclear Waste Fund is allocated in the coming decades to social science research.

2 SKB's plan of action

2.1 Background

In RD&D programme 2010, SKB presents its plans for research, development and demonstration during the period 2011 to 2016. The programme is based on SKB's overall plan of action for low- and intermediate-level waste (the LILW programme) and for final disposal of the high-level waste from the Swedish waste (the Nuclear Fuel Programme). It is this plan of action that serves as a basis for SKB's plan for research, development and demonstration. In other words, the plan of action is of fundamental importance for understanding the different parts of the RD&D programme and how SKB has chosen a direction for its research.

2.2 Overall plan of action

2.2.1 Main timetable

A fundamental premise for SKB's plan of action is 50 years' operation of the reactors in Forsmark and Ringhals and 60 years' operation of the reactors in Oskarshamn. In other words, the repository is projected to be closed in about 75 years. This premise determines the main timetable for both the nuclear fuel programme and the LILW programme.

The Swedish National Council for Nuclear Waste has four comments on the main timetable:

The first comment concerns the interim storage of control rods (about 2,500 rods). Today the control rods are stored in pools in Clab, but in the 2010 RD&D programme, SKB maintains that they are instead considering storing them, together with certain core components, in a dry interim storage facility. It is the Council's considered opinion that SKB has not ascertained to a sufficient degree the research that is needed for these plans and would like SKB to present the technical solutions for such a dry interim storage facility.

The second comment concerns the Spent Fuel Repository Project. SKB writes that "initial design is under way along with site activities such as establishment of a site office and further geo-scientific investigations"[1]. The Council would appreciate a more detailed description of the purpose and planned scope of these geoscientific investigations.

The third comment concerns SKB's planned measures for closure and the possibilities of retrieval. SKB states that they have demonstrated that it is possible to retrieve deposited canisters during the operating phase and that retrieval is also possible after closure. There are no formal requirements on retrievability in Sweden, but "the design of the repository is such that if future generations should wish to retrieve the fuel, this is fully possible (albeit resource-consuming)." The Council has no objections to these plans, but would prefer that they had been formulated in the light of the more all-embracing concept of stepwise decision-making presented in earlier RD&D programmes[2].

The fourth comment concerns the statement that "The Spent Fuel Repository is designed in such a manner that its safety is not dependent on post-closure monitoring"[3]. The Council sympathizes with SKB's view of the difficulties of establishing a reliable and long-term monitoring of conditions inside the repository. With reference to its *Nuclear Waste State-of-the-Art Report 2010*[4] , the Council would however like to emphasize that international treaties require Sweden to provide safeguards against illegal intrusion in the final repository.

2.2.2 Assumption of responsibility in the back end of the nuclear fuel cycle – a legal perspective

The reactor owners' long-term responsibility

The reactor owners, as well as other licensees for nuclear activities, are obligated to ensure that spent nuclear fuel and nuclear waste are

[1] RD&D programme 2010, page 47.
[2] See also *Nuclear Waste State-of-the-Art Report 2010*, SOU 2010:6.
[3] Page 48 in RD&D programme 2010.
[4] SOU 2010:6.

managed and disposed of in a safe manner. The obligations persist 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 finally closed[5].

Even if a licence has been revoked or expired, the licensee is still obligated to safely manage and dispose of spent nuclear fuel and nuclear waste and to decommission and dismantle the plant. This responsibility persists until all obligations have been fulfilled[6].

The licence to operate a nuclear power reactor thus entails a long-term commitment for the licensee.

SKB's long-term responsibility

As the licensee for the final repository, SKB has the same long-term responsibilities as other licensees for safe operation of the facility. The Nuclear Activities Act requires a licensee not only to comply with the conditions and regulations issued by the Government or the Swedish Radiation Safety Authority, but also to adopt on their own initiative all measures needed to safely decommission the facility when the activity will no longer be conducted. SKB's long-term responsibility for the final repository thus persists at least until final closure of the repository.

One question that arises in the context is whether the responsibility can also formally be extended until after final closure of the final repository, since operation of a nuclear facility also includes responsibility for maintaining the physical protection of the facility in order to prevent illicit trafficking with nuclear material and sabotage.

Responsibility for the physical protection of a final repository for spent nuclear fuel does not really have an endpoint in time, which is why the Council finds it appropriate that the state assume this responsibility after final closure of the facility.

The state's long-term responsibility

The Swedish parliament, Riksdag has on a number of occasions established that the state has overall responsibility for spent nuclear

[5] Cf. Section 10 of the Nuclear Activities Act.
[6] Cf. Section 14 of the Nuclear Activities Act. See also Gov. Bill 1983/84:60, page 94.

fuel and nuclear waste[7]. According to the Riksdag, long-term responsibility for a final repository for spent nuclear fuel should thus rest with the state. One reason is that supervision of safety at the final repository will probably be necessary for a considerable time after closure of the repository.

One idea put forth by the Government is that a national authority could assume responsibility for the closed final repository. The Government has stated that it is only natural that the state should bear ultimate responsibility for ensuring that the repository functions satisfactorily even in the very long term[8].

The state's ultimate responsibility for safety – international obligations

By ratifying the Nuclear Waste Convention[9] , the Swedish state has undertaken to ensure that primary responsibility for safety in the management of spent nuclear fuel or radioactive waste rests with the licensee of the facility that generated the waste[10]. If there is no such licensee or any other responsible party, this responsibility rests with the state, which has jurisdiction over the spent nuclear fuel or over the radioactive waste. These premises entail that the state bears "ultimate responsibility" for the final disposal of spent nuclear fuel and nuclear waste.

The state's responsibility according to the Nuclear Waste Convention thus has two components:

1. The state has an overall responsibility to ensure that final disposal is implemented.
2. The state has an ultimate responsibility for final disposal in the sense that the state itself is forced to assume the role of both purchaser and financer if the nuclear power industry is not able to perform the task or for another reason refrains from doing so.

The state's ultimate responsibility does not in itself entail any limitation of the nuclear power industry's responsibility under the

[7] See e.g. Gov. Bill 1980/81:90, Appendix 1, p. 319, Gov. Bill 1983/84:60, p. 38, Gov. Bill 1997/98:145, p. 381, Gov. Bill 2005/06:183 and the Parliamentary Committee on Industry and Trade's reports 1988/89:NU31 and 1989/90:NU24.
[8] See Gov. Bill 1997/98:145, p. 381.
[9] The 1997 Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management.
[10] SÖ 1999:60.

Nuclear Activities Act. It is also in view of this that a special financing system has been devised for this purpose.

The Radiation Safety Commission proposes in its report that a legal rule be instituted that regulates the state's ultimate responsibility for the spent nuclear fuel[11]. According to the Commission's proposal, the state is responsible for the obligations and rights that have previously rested with the licensee if there is no licensee or other party that can be held responsible for fulfilling these obligations.

It is the Council's considered opinion that the state should assume "ultimate responsibility" for the final disposal of spent nuclear fuel and nuclear waste after final closure of the facility and approval of this closure by the responsible authorities. This means that the state will at that time assume the obligations and rights of the licensees for the repository and the spent nuclear fuel.

2.3 Flexibility in the face of changed premises

2.3.1 The flexibility requirement

SKB's RD&D programme 2010 contains a section headed "Flexibility in the face of changed premises". The Swedish National Council for Nuclear Waste greets these reflections with satisfaction. They are in line with the Council's *Nuclear Waste state-of-the-art report* 2010[12], and what the Council writes there about stepwise decision-making. However, the Council thinks SKB's flexibility requirement could be linked more clearly to SKB's description of the milestones in RD&D Programme 2007 (and in RD&D programme 2010 as regards the LILW programme, pp. 59–61 in the report).

Initially, SKB says (regarding the premises for the execution of the LILW Programme and the Nuclear Fuel Programme) that the planning premises will in all likelihood change. SKB takes this into account and therefore plans for a certain measure of flexibility in the design of facilities and systems.

The Council concurs with this general assessment. SKB is also investigating in greater detail what the flexibility requirement entails. They observe that the nature of the changes in the premises

[11] SOU 2011:18.
[12] SOU 2010:6.

may be such that they only require "minor modifications of the programmes without major changes in the long-term timetable". Other changes require substantial adjustments of "for example additional facilities or facility sections, changes in the layout of a final repository or longer licensing review processes than previously".[13] SKB draws attention to four such more substantial changes:

1. Extension of existing reactors' operating times
2. New reactors
3. Delayed commissioning of the final repository for high-level waste
4. Delayed commissioning of the final repository for short-lived waste (SFR) from decommissioning of the reactors in Barsebäck and Ringhals.

The Council shares SKB's assessment that the nature of such changes is such that they would require substantial adjustments of the final disposal plans with regard to both high-level and short-lived nuclear waste. The Council will first comment on the four changes taken up by SKB and then address the question of whether there are other changes of a similar magnitude that have not been given sufficient attention by SKB in RD&D-programme 2010.

- *Operating times of the nuclear power reactors.* An extension of existing nuclear power reactors' operating times could affect SKB's plan of action in two different ways. In the first place, such extension could lead to requirements on increased capacity in the repository systems (SFR, SFL, final repository); in the second place, an extended operating time could entail that SKB's facilities (for example Clab) would be utilized for a longer time. An increased power level could lead to an increased disposal requirement. Conversely, a shorter operating time would entail that the nuclear waste programme could be concluded earlier.

The Council calls for further study of how extending the operating times of the nuclear power plants would affect Clab.

[13] RD&D programme 2010, page 49.

– *New nuclear power reactors.* SKB focuses on the consequences of construction of the third generation of nuclear reactors and states: "It should theoretically be possible to use the waste system currently under construction for the additional nuclear waste and spent nuclear fuel from the new reactors as well"[14]. SKB predicts extension of Clab and creation of greater storage capacity – especially if today's reactors are replaced with new ones with a substantially greater aggregate net capacity.

It is the Council's considered opinion that SKB should not have restricted itself to examining the consequences of the third generation of nuclear reactors, but also of the fourth generation. Such reactor technology could be in commercial operation within 100 years – and could be foreseen in conjunction with the final phase of nuclear waste deposition. Such reactor technology differs in decisive ways from the current generation and the third generation of light water reactors. A much larger quantity of energy (up to 50 times as much) can be extracted from the same quantity of fuel, the waste volume could be reduced considerably, and the proportion of radionuclides with a very long half-life could be much lower. Furthermore, these reactors can run on spent nuclear fuel from our light water reactors[15].

It is not the Council's task to assess the desirability of a trend towards the fourth generation of nuclear power reactors. However, it is the Council's task to underscore that such a trend could drastically alter the premises for the final repository project. SKB touches upon this trend in another section and points out the fact that the Swedish Research Council granted SEK 36 million in October 2009 to the research project Genius (Generation IV research).[16]

It is the Council's considered opinion that SKB should have given more thought to the consequences of such a trend for the main timetable and for its Nuclear Fuel Programme. The question can be asked whether the envisioned repository could be converted to an interim storage facility for nuclear fuel from our light water reactors, so that it could be retrieved and used in the fourth generation of nuclear power reactors.

[14] Page 50 in RD&D programme 2010.
[15] See 2011:14 pp. 67–68.
[16] See further RD&D programme 2010 page 389.

- *Extension of Clab.* There are other scenarios that could lead to a considerable extension of the Clab interim storage facility on the Simpevarp Peninsula. We have already mentioned this in connection with the question of an extension of the operating times of the nuclear power reactors. If the nuclear fuel programme is delayed by several decades, an extension of Clab could be necessary – for example by the addition of a third rock cavern. It is the Council's considered opinion that this is a possible scenario, as correctly noted by SKB. At the same time, the Council would appreciate a discussion of how such a development would affect SKB's research, development and demonstration programme during the coming five-year period.
- *Commissioning of the extended SFR* (final repository for short-lived waste). SKB is planning an extension of SFR to be able to receive operational waste from Barsebäck, Ågesta and Studsvik. After an application from SKB in 2013, it should be possible to commence this extension in early 2017. A delay of the SFR extension would entail a corresponding delay of the decommissioning of Barsebäck and Ågesta. However, SKB does not judge that this would have any negative radiological consequences.

The Council concurs in this judgement, but at the same time believes that SKB should – in line with the flexibility requirement – take into account the possible consequences that earlier decommissioning of other nuclear power plants could have on the extension of SFR and the consequences of a delay in the extension of SFR[17].

2.3.2 Extensive unforeseen global changes

Aside from the extensive changes that could warrant a re-evaluation of SKB's main timetable, there are other changes that have not been given sufficient attention by SKB. The Council would particularly like to draw attention to the following examples:

- *Breakthrough for alternative methods.* In a special section on alternative methods, SKB has made the assessment that there are no realistic alternatives to the KBS-3 method (Chap. 27). As far as partitioning and transmutation is concerned, however, the possibility of an important breakthrough within the next few

[17] See the Council's conclusions regarding the LILW programme, section 2.3.1.

decades cannot be ruled out. One might ask what consequences such a breakthrough would have for SKB's planning, main timetable and research programme.

- *Weakening of the legitimacy of the final repository project.* A guiding principle in SKB's work thus far has been to avoid siting a final repository in a municipality that is expressly opposed to it. It is, however, possible that there could be a change in public opinion – for example due to a nuclear power accident or a terrorist attack on any part of the nuclear fuel cycle. Such events could create considerable popular resistance to receiving waste at a selected site[18]. The question is how such an event could affect the establishment process.
- *Need for selection of new site.* SKB's site selection process ended in 2009 in a decision to locate the future final repository at Forsmark in Östhammar Municipality. The site selection was based above all on extensive site investigations, which showed that Forsmark has bedrock that is suitable for a long-term safe final repository. Furthermore, the majority of the inhabitants in the municipality were positively disposed to a Spent Fuel Repository in the municipality. However, the possibility cannot be ruled out that a more thorough investigation will show that Forsmark does not meet the requirements SKB has established for a final repository according to the KBS-3 method. The question is whether Laxemar could in this case be considered as the new site for a final repository for the spent nuclear fuel.
- *Undermining of the nuclear waste project's economic base.* The resources of the Nuclear Waste Fund comprise the economic base of the entire final repository project. The Fund's resources will suffice according to current cost calculations, but the possibility cannot be ruled out that the costs will exceed the assets due to unforeseen expenses. RD&D programme 2010 does not offer any information on SKB's financial planning and how a financial deficit would be handled. A justified question is what might happen in the future if a global economic recession reduces the available resources[19].
- *Assumption of responsibility by the nuclear power companies.* SKB is owned by the owners of the nuclear power plants – E.ON,

[18] Andrén & Strandberg, 2005 pp. 146 and 152.
[19] Andrén & Strandberg, 2005 page 151.

Fortum and Vattenfall – but E.ON and Fortum are in turn owned by foreign corporations. One might ask how these foreign economic interests could affect the completion of the final repository project.

- *Requirements from the EU.* In 2010, the European Commission presented a draft directive on the management of radioactive waste. This directive confirms previously stated principles that each country shall decide for itself how to manage its own nuclear waste. At the same time, the directive emphasizes the value of international cooperation in the nuclear waste field. This means that the trend towards international cooperation could result in increasing demands on, for example, Sweden to receive spent nuclear fuel from other countries. It is possible that other countries will be impressed by SKB's positive assessments of the reliability of the Swedish bedrock and ask to be allowed to dispose of their nuclear waste in Sweden.
- *Changes in ethical values.* The aforementioned directive asserts a basic ethical principle, which the Swedish National Council for Nuclear Waste has in various contexts called the responsibility principle. The generation that has enjoyed the benefits of the nuclear energy is also responsible for ensuring a safe final disposal of the spent nuclear fuel. At present there is broad agreement on this responsibility principle. But the possibility cannot be ruled out that this standpoint will be weakened as other environmental issues attract greater concern, for example the climate issue.

The Council would once again like to underscore that the Council deems flexibility and foresight to be crucial in the final disposal process. SKB understandably attaches great weight to this in the introduction to RD&D programme 2010. However, the Council believes that these reflections are worthy of further discussion. One reason for this is that future research, development and demonstration should be considered in the light of the unforeseen circumstances that could have a crucial influence on the execution and timetable of the final repository project.

2.4 Swedish National Council for Nuclear Waste's conclusions regarding SKB's plan of action

The following points comprise the Swedish National Council for Nuclear Waste's conclusions:

- It is the Council's considered opinion that SKB should ascertain what research is needed to explore the option of dry interim storage of the control rods. SKB should also plan for development and demonstration of an interim storage facility.
- It is the Council's considered opinion that SKB should shed light on how international treaties requiring Sweden to provide safeguards against illegal intrusion in the final repository can be enforced after closure, when monitoring is not planned.
- It is the Council's considered opinion that SKB should more clearly combine the milestones described in RD&D Programme 2007 with the flexibility requirement (and in RD&D programme 2010 with regard to the LILW programme).
- The Council calls for further study of how extending the operating times of the nuclear power plants would affect Clab.
- The fourth generation of nuclear reactors may be put into operation within 100 years, i.e. in conjunction with the final part of the repository's operating phase. It is the Council's considered opinion that SKB should not restrict itself to examining the consequences of the third generation of nuclear reactors, but also of the fourth generation.
- It is the Council's considered opinion that SKB should give more consideration to the consequences of a trend towards the fourth generation of nuclear power reactors for the main timetable and for its Nuclear Fuel Programme. The question can be asked whether the envisioned repository could be converted to an interim storage facility for nuclear fuel from our light water reactors, so that it could be retrieved and used in the fourth generation of nuclear power reactors.
- It is the Council's considered opinion that SKB should consider what consequences earlier dismantling of other nuclear power plants might have for the extension of SFR.

- It is the Council's considered opinion that the state should assume formal responsibility for physical protection after final closure of the facility.
- It is the Council's considered opinion that the state should assume "ultimate responsibility" for the final disposal of spent nuclear fuel and nuclear waste after final closure of the facility and approval of this closure by the then-responsible authority. This means that the state will at that time assume the obligations and rights of the licensees for the repository and the spent nuclear fuel.

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3 The LILW programme

3.1 Background

Low- and intermediate-level waste from the nuclear reactors is generated by leakage from the fuel and from radionuclides that are formed when neutrons (which are released in the fuel) irradiate material near the core. Part II of RD&D programme 2010 describes the plans for the future management and disposal of this waste, the LILW programme. This programme also includes management and disposal of radioactive waste from the use of radioactive substances in medical care, research and other industrial activities. This waste will be collected for final disposal in SKB's facilities, after processing and temporary storage in Studsvik. In practice, it could be said that all radioactive waste aside from the spent nuclear fuel itself is classified as low- and intermediate-level waste in SKB's terminology.

Short-lived radioactive waste is disposed of today in SFR in Forsmark[1]. However, this repository is not sufficient for future needs, and SKB assumes that its storage capacity will have to increase from today's 63,000 m^3 to about 200,000 m^3. The design work for this extension is under way. SKB expects to submit an application in 2013 and start trial operation of the new repository in 2020. Long-lived waste is currently interim-stored in Clab and at the different nuclear power plants, which means that this waste will have to be transported to its final repository, SFL, when the latter is finished in around 2045, according to SKB's current plans[2].

The LILW programme has been presented in general terms in previous RD&D programmes, and in somewhat greater detail in a supplement to RD&D programme 2007. The Swedish National Council for Nuclear Waste's comments regarding the LILW

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[1] SFR = Final repository for radioactive operational waste.
[2] SFL = Final repository for long-lived radioactive waste.

programme in RD&D Programme 2007 mainly pertained to decommissioning[3]. In conjunction with the publication of the supplement to RD&D programme 2007, the Council also issued a statement saying in brief that even in the light of SKB's supplement, the Council would like SKB to give a more detailed account of its plans for the management and disposal of low- and intermediate-level waste and the decommissioning of nuclear facilities.

The present RD&D programme 2010 provides the most detailed presentation so far. The question of decommissioning of nuclear reactors and management and disposal of the decommissioning waste ties in with the LILW programme.

3.2 Short-lived low- and intermediate-level waste

3.2.1 What does the term "short-lived waste" mean?

SKB's present facility for the final disposal of radioactive operational waste is characterized in the RD&D programme as "SFR – Final repository for short-lived radioactive waste". The 1983 Government decision gave SKB permission to and build and operate a facility "for final disposal of low- and intermediate-level waste in Forsmark". SKB plans to apply for a licence for extension of SFR for the final disposal of "short-lived decommissioning waste from the existing nuclear power plants" and "short-lived decommissioning waste from Clink" as well as "final storage of large components including whole BWR reactor vessels without highly neutron-activated internals"[4] (BWR = Boiling Water Reactor).

The Council regards it as an important task to contribute to transparency around the waste chain. The added concept of "short-lived" dedramatizes the repository, but the question is whether it contributes to clarifying the repository's content and risks. IAEA defines short-lived waste as waste that does not contain significant levels of radionuclides with half-lives greater than 30 years[5]. SKB uses the limit of 31 years to include one of the most commonly occurring nuclides in the operational waste, namely Cs-137, with a half-life of 30.1 years. (A nuclide is an atomic nucleus with a

[3] Chap. 15 in SOU 2008:70.
[4] Page 70 of RD&D programme 2010.
[5] IAEA 2003.

certain number of protons and neutrons. Thus, a radionuclide is a radioactive atomic nucleus.) However, waste disposed of so far can contain non-negligible amounts of C-14, with a half-life of 5,730 years[6]. This means that the deposited waste can pose a risk for a much longer time than is implied by the term "short-lived". After 5,730 years there are no short-lived nuclides left in the repository, while half of the original C-14 nuclides remain. (C-14 comes from both operational waste from reactors and the Studsvik waste). Final disposal of reactor vessels increases the quantity of C-14 and adds another long-lived nuclide, Mo-93 with a half-life of 3,500 years. RD&D programme 2010 says that these two nuclides "could eventually constitute a significant fraction of the dose contribution from SFR"[7].

It is the Council's considered opinion that the concept of "short-lived" does not help to clarify SFR's nuclide content and risks. Continued measurements may show that this is an incorrect use of the term as defined by the IAEA.

3.2.2 Nuclide content

SFR was put into use in 1988. After 20 years, some uncertainty still exists regarding the radionuclide content of the repository, in which part of the repository the nuclides are, and their chemical state. The work of characterizing the waste[8] is therefore important to get a reliable safety assessment. The Swedish National Council for Nuclear Waste calls for a discussion *from a safety assessment perspective* of the cost-benefit of different measurement programmes.

Of particular interest is the content of C-14, in view of the fact that the carbon atom is a "building block" in different organic compounds. It can therefore readily be internalized in tissue, and the likelihood that the radiation it emits will cause DNA damage will therefore increase. The Council therefore notes with satisfaction the focus given to this issue in research at Lund University, supported by SKB, and thinks that this should continue for the purpose of achieving a better understanding of how C-14 can be disposed of in an environmentally and radiologically safe manner[9].

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[6] Swedish Radiation Safety Authority, 2009.
[7] Page 236 in RD&D programme 2010.
[8] Page 227 in RD&D programme 2010.
[9] Magnusson, Stenström, Aronsson, 2008; Magnusson, Aronsson, Lundgren, Stenström, 2008.

3.2.3 Extension of SFR

The Swedish National Council for Nuclear Waste observes that experience from building and operation of SFR is an important positive factor in the planning of an extension of SFR (referred to below as SFR+) and finds it reasonable that SKB should apply for a licence to build the new facility adjacent to the existing one.

However, the Council fears that the timetable with commissioning of SFR+ in 2020 may turn out to be overly optimistic in view of the complex licensing process. The construction of a final repository for decommissioning waste has been postponed a number of times. According to plans in the late 1990s, SFR+ should have been under construction at this time. A delay of the start of construction of SFR+ will have considerable consequences outside the waste management system. There is a great need for consequence analysis and alternative planning.

Consequence analysis. With present-day plans, a delay of SFR+ will lead to a delay in the dismantling of Barsebäck. A delay of SFR+ will thus have consequences *outside* the nuclear waste management system, while a delay of, for example, the Spent Fuel Repository can be handled *within* the system. The external effects influence who has to bear the costs of a delay. A postponement in the start of construction leads to postponed disbursements from the Nuclear Waste Fund and consequently an increase in the Fund's interest income. The increased interest income compensates the waste system for the increased costs for shutdown operation of the Barsebäck reactors. The community outside the waste system incurs "opportunity costs" for delayed free release of a well-situated shoreline site in a very expansive area.

The net costs for a delayed SFR+ may thus lie outside the waste system, and SKB and its owners may therefore be less interested in controlling these costs.

Alternative planning. Alternative planning for handling the dismantling of the Barsebäck reactors should be aimed at reducing the external consequences of a delay of SFR+. Above all, the alternative planning should lead to an internalization of extra costs in the event of a delay, so that these costs are borne by the waste system.

3.2.4 Initial state, low- and intermediate-level waste

There are a number of parameters that make the scientific research concerning a repository for short-lived low- and intermediate-level waste a great challenge. The time period for short-lived low- and intermediate-level waste (like that for spent nuclear fuel) is reported to be 100,000 years, but the waste is much more complex since it consists of material with completely different properties, for example scrap metal and conditioned wet waste. The scrap metal contains several different metals, above all carbon steel and stainless steel, while the wet waste consists of organic and inorganic material that has been conditioned (solidified) in cement or bitumen.

The waste will be enclosed in vessels and silos of cement or concrete and placed in rock caverns beneath the Baltic Sea. The silo in SFR 1 is surrounded by a bentonite buffer that is placed between the concrete structure and the rock wall.

After closure the repository will become water-filled very quickly (in about 25 years) and the challenges consist in predicting complex chemical and mechanical transformations in different parts of the waste and the long-term function of the engineered barriers. A special complication is the occurrence of the relatively long-lived isotopes C-14 and Mo-93, but the waste also contains a variety of other radionuclides that must be managed and isolated in the repository. The metals in the repository will give rise to a number of different corrosion products, and when they come into contact with groundwater, chemical reactions will occur (e.g. hydrolysis) that lead to new chemical compounds that are specific for different metals (via complexation and precipitation). Organic complexing agents in SFR increase the mobility of many metal ions, and SKB is investigating the possibility of reducing the use of these agents by using inorganic cleaning agents based on carbonate instead. The Swedish National Council for Nuclear Waste is investigating the possibility of using phosphate ions, which have been used in commercial detergents for a long time.

3.2.5 Processes, low- and intermediate-level waste

There are a number of mechanical and chemical processes that will eventually alter the state in the repository. SKB reports and describes many processes in RD&D programme 2010 in an admirable fashion, and the Council will confine itself in this context to commenting on a few of them.

It can be assumed that the repository will freeze and thaw repeatedly during the long period in question. Freezing of the concrete barrier is dealt with relatively thoroughly, while freezing of the waste is not commented on at all[10]. The water in the waste contains a highly composite mix of metal complexes, precipitates and colloidal particles from the waste, as well as ions from the penetrating groundwater. (Colloidal particles are particles that are extremely small, less than a thousandth of a millimetre.) When the waste freezes, it will increase in volume and different impurities will be separated from the water and enriched around the ice that forms (exclusion). When the ice melts again and new groundwater enters the repository, these concentrations of radionuclides could possibly lead to increased transport out of the repository. The Swedish National Council for Nuclear Waste urges SKB to study this phenomenon.

The corrosion that is dealt with in RD&D programme 2010 is mainly corrosion of rebar in concrete, which leads to formation of goethite (FeOOH) or magnetite (Fe3O4), depending on whether the environment is oxic or anoxic (oxygen-free). The same naturally applies to carbon steel and stainless steel in the waste, which, along with other metals in contact with the groundwater, undergoes different types of corrosion, such as galvanic corrosion, pitting, etc. The corrosion products can often adsorb and retain other ions in the repository, which is for the most part favourable. SKB is urged to improve its knowledge of the adsorbency of the most important corrosion products. (Adsorption involves attachment to surfaces.)

Colloid transport can be expected to account for a large portion of the mobility of the radionuclides via adsorption and precipitation. Because the composition of the material is highly complex, there are many opportunities for the formation of colloidal particles with different properties and an ability to attract radionuclides at the pHs, ionic strengths and other conditions that will prevail in repository after the repository has become water-filled and the

[10] Chap. 21.2.3 in RD&D programme 2010.

barriers have been destabilized. The Swedish National Council for Nuclear Waste urges SKB not only to follow the development of knowledge within the area, but also to contribute actively to it.

Microbial activity in the repository will undoubtedly be very high. Due to the complex mixture of organic and inorganic materials there, conditions for bacterial growth should be favourable. The question is what effect the microbial activity has on degradation, transformation and colloid formation in the repository and thereby on the outward transport of colloids. SKB intends to follow developments in this area, which the Council supports.

3.3 Engineered barriers in SFR

The Swedish National Council for Nuclear Waste has contracted Dr. Lars Marklund of Marksmen Consulting in Sörberge to assist the Council with viewpoints concerning hydrology in Chapter 21, "Engineered barriers in SFR", in RD&D programme 2010. Dr. Marklund's conclusions are presented in an appendix to the Council's review report.

3.3.1 Initial state, engineered barriers

The engineered barriers in certain parts of SFR are supposed to retard the outward transport of radionuclides from the repository. There are two different types of engineered barriers: concrete and bentonite. The initial state of the barriers refers to their condition at closure before the repository has filled with water.

3.3.2 Processes, engineered barriers

The concrete barriers will eventually be broken down and destroyed, and it is important to obtain a good idea of how and at what rate this occurs. There are a number of possible mechanisms that occur in this context: frost attack, sulphate attack, salt attack, attack by sea water, acid attacks, leaching, cement-aggregate reactions (i.e. chemical reactions between cement and stones in concrete), and of course rebar corrosion (corrosion of the iron reinforcing bar in the concrete)[11]. Some of these processes are described in RD&D programme 2010, where an account is also given of current research on the chemical and mechanical properties of aged concrete. There are also ample opportunities to influence the properties of the concrete by using optimal types of cement and aggregate in the concrete (gravel and crushed rock).

The Council would appreciate an account of how SKB is working to optimize the type of cement and aggregate that will be used, and how they can be pretreated to achieve maximum strength in the repository. It is important not to become committed to a single type of Portland cement, but to also investigate other cement types available on the market such as low-alkaline Portland cement or slag cement. The latter has also shown good resistance to attack by sea water, while the addition of pozzolans (e.g. silica fume or fly ash) provides good resistance to salt attack. One treatment that can be used to obtain a denser cement is to carry out an extra grinding of the cement mineral to reduce the particle size.

As is evident from RD&D programme 2010, unaerated concrete is particularly susceptible to frost damage in the presence of saline solutions – even at low salinities. The frost damage usually consists of gradual peeling of the concrete's surface layer and can lead to the detachment of large pieces of aggregate.

Some aggregates can react with the cement paste in a way that can ruin the concrete and should be avoided. This includes all minerals consisting of amorphous silicic acid, but the aggregate size also plays a certain role, and in a repository such as this all conditions must be optimized in order to ensure maximum life.

Rebar corrosion is naturally a crucial factor in predicting and optimizing the life of the concrete barriers, warranting a special research programme which is being conducted by SKB via literature studies and experiments, when necessary. The Council supports SKB's ambitions in this area.

As stated by SKB in RD&D Programme 2010, sorption of radionuclides is one of the most important retarding safety functions in SFR. The cement in the concrete barriers naturally plays an important role in this, and due to their high pH, the positively charged complex ions will in particular be retarded by adsorption on the surfaces. The Council takes a positive view of the fact that SKB has initiated a research programme to determine the sorption

[11] Fagerlund, 1987.

coefficients of different radionuclides on concrete, bentonite and sand, as well as studies of complexation of radionuclides with organic degradation products.

Diffusion of radionuclides through aged concrete in particular is another important process in this context, and it is urgent for SKB to acquire a good understanding of this phenomenon. Since many countries store nuclear waste in concrete tanks and silos as their main strategy, it should be possible to learn a great deal by cooperating with them.

In summary, the Council urges SKB to thoroughly examine the possibilities offered by the mineral composition of cement and aggregate and pretreatment (e.g. further grinding) of cement mineral to increase the life of the concrete barriers. In the Council's opinion, research concerning rebar corrosion, sorption and diffusion should continue.

3.4 Long-lived low- and intermediate-level waste

3.4.1 Timetable

The final repository for long-lived low- and intermediate-level waste (SFL) is the repository that will be the last to be completed and commissioned, according to SKB's plans. It is not expected to be able to be put into routine operation until 2045. SKB intends to start the site investigations for SFL in around 2020, after which design and safety assessment will begin. A timetable was presented in the supplement to RD&D Programme 2007 that was published in 2009. The distant time horizon also means that site selection remains, along with detailed design.

It is the Council's considered opinion that SKB should further explain the reasons why they have chosen to wait so long with SFL, including advantages and disadvantages. They should also examine the possibilities of moving SFL forward without compromising safety, and to what extent this could affect the planning and operation of the other repositories.

3.4.2 Interim storage

A large part of the long-lived low- and intermediate-level waste is so-called historic waste that has already been produced and is currently being stored in interim storage facilities at Clab or at the nuclear power plants awaiting completion of SFL. In the future, interim storage may also take place in BFA at the Oskarshamn Nuclear Power Plant, as well as in SFR. Given current plans, the total need of space for interim storage is estimated to be about 10,000 m^3. The interim storage space available today is in principle sufficient for this, but since it is also used for temporary storage of other waste it's availability is uncertain. It is not clear what will be stored where.

It is the Council's considered opinion that SKB should analyze and report the flows and transport of different categories of radioactive waste generated by the utilization of different interim storage facilities, including processes for conditioning, closure, etc. The Council believes that the results of such an analysis comprise one of the factors that should be taken into consideration in the siting of SFL.

3.4.3 Reference inventory

A total of 2,500 control rods from the BWR reactors as well as core components that have been exposed to heavy neutron irradiation will be deposited in SFL. A set of core components weighs on average 70 tonnes and has a deposition volume of 100 m^3 per reactor. According to SKB, the recent decision on extended operating times at the nuclear power plants has changed the waste streams to SFL and thereby also the reference inventory. However, it is not clear what this change entails and how it affects the characterization of the reference inventory. SKB intends to present an updated reference inventory by 2013.

3.4.4 Engineered barriers in SFL

Research projects that have been identified as important for the design of SFL are presented in brief in the RD&D programme. These coincide to a great extent with what has been presented for SFR as well as regards the properties of cementitious material and corrosion of metals. The Council's viewpoints on these plans are presented in Chapter 4.3 of the present report.

3.5 Decommissioning and dismantling of nuclear facilities

3.5.1 Swedish National Council for Nuclear Waste's conclusions 2007

SKB should specify when different facilities can be decommissioned and give reasons for this. The desire for immediate dismantling can be evaluated in relation to the need to have final repositories ready to receive decommissioning waste before the dismantling work is begun. The Swedish National Council for Nuclear Waste therefore believes that there is a need for a systems analysis encompassing all the facilities and activities covered by SKB's account of the LILW programme.

Questions concerning the decision process for decommissioning and disposal of the waste need to be studied. The need for environmental impact assessments of decommissioning of nuclear power plants should be illuminated. The implications of current EU directives and provisions of the Environmental Code need to be clarified prior to decommissioning of nuclear power plants.

The Swedish National Council for Nuclear Waste wishes to emphasize the importance of a transparent decision process with regard to decommissioning and dismantling where the municipalities are invited to participate in the dialogue.

In RD&D programme 2010, SKB gives an account of the plans and strategies for decommissioning and dismantling of the various nuclear facilities in Sweden. However, it is rather difficult to derive the timetable from this account. A system analysis is still lacking.

The formation of the "Decommissioning Group" is a step in the right direction, but the division of responsibilities within this group should be explained more clearly.

3.5.2 Division of responsibilities

Legal responsibility for decommissioning of a nuclear facility rests with the licensee. This includes responsibility for planning, licensing, dismantling, and finally disposal of the waste. A number of different actors, including SKB, are thus responsible for different nuclear facilities in Sweden. There is therefore a need for a coordination of decommissioning and dismantling at the national level, and to achieve this a Decommissioning Group was formed at the beginning of the century for the purpose of focusing on logistics and technology.

The nuclear power companies have assigned SKB the task of participating in the planning and execution of upcoming decommissionings and operating a final repository for decommissioning waste. SKB is expected to develop general methods and procedures for the dismantling work, activity and volume estimates, waste classification and cost estimation. However, it is not clear who is heading the Decommissioning Group. SKB appears to have an important role, but this should be described more clearly. A clearer account of the role, composition and working methods of the Decommissioning Group would also be desirable.

3.5.3 Planning

RD&D programme 2010 gives an account of the plans and strategies for decommissioning and dismantling of the various nuclear facilities in Sweden. Of particular interest are Barsebäck and the R2 reactor, where Studsvik and BKAB are participating in a Technical Advisory Group within NEA that is handling some 40-odd international decommissioning projects.

The planning work is regarded as an iterative process aimed at building up and fostering greater competence among the actors. Experience from the planning work at Barsebäck is being taken into consideration, along with international experience. This should also lead to a better notion of the waste volumes and the nuclide-specific content.

However, it is rather difficult to derive the timetables for all facilities from the text. A clearer overview is needed of all measures, and especially matters that are crucial for achieving a safe decommissioning of the different nuclear facilities, a safe disposal of the waste from decommissioning, and unrestricted release from regulatory control of the sites where the nuclear facilities have been or are situated. SKB also needs to shed more light on what the primary limiting factors are for when the different nuclear power plants can be dismantled. It is important that the relevance of international directives and conventions as well as experience are visible in the continued planning of decommissioning and dismantling.

In previous sections on the extension of SFR, the Swedish National Council for Nuclear Waste underscores the connection between the planning of the Barsebäck plant's decommissioning and the processes for licensing and construction of the extension and would once again like to emphasize this connection. A delay of the extension will have consequences outside the waste system, and this underscores the need for alternative planning to deal with the socioeconomic consequences of a delay.

3.5.4 Management of the decommissioning waste

In the RD&D programme, three possible strategies are mentioned for decommissioning and dismantling of nuclear power plants. With the exception of Barsebäck and Ågesta, the intention is to apply the strategy of "direct dismantling" for the Swedish nuclear power plants. This entails in brief that dismantling and disposal of the waste take place within a relatively short time after shutdown, after which the facility is released from regulatory control. However, both a detailed description of what this entails and a presentation of the reasons, including advantages and disadvantages, for the choice of this method are lacking. What problems can arise when unrestricted release of a facility is planned after dismantling? Conflicts could arise between the desire for direct dismantling and the completion of repositories to receive the waste.

A brief description of the quantity and nature of decommissioning waste from Barsebäck is provided. Studies and/or planning are under way for the other nuclear facilities.

3.5.5 The conservation principle and the sustainability principle

The Swedish National Council for Nuclear Waste would in this context like to refer to the legally binding principles and general rules of consideration of the Environmental Code. According to the Code, the operator of an activity shall conserve raw materials and energy and take advantage of all opportunities for sustainable reuse and recycling, in other words apply the conservation principle and the sustainability principle.

The conservation principle entails that all activities shall be conducted and all measures shall be adopted in such a manner that raw materials and energy are used as efficiently as possible. The ecocycle 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 ecocycle principle can be described as a principle that aims for closed material flows.

In the Council's opinion, these principles have thus far not had any significant practical impact on the management of low- and intermediate-level radioactive waste. In most cases, radioactive waste is disposed of directly without any attempt at recycling. The reason may be that downstream management steps could entail a risk of increased dose to personnel. Economic considerations may also play a role.

In order for it to be possible to reuse radioactive material, it must be released from regulatory control (cleared). This entails measurement to verify that the amount of radioactive substances in the material is below a prescribed level. The Radiation Protection Act is thereby no longer applicable to this material[12]. In order to be recycled, radioactive waste may require an extra treatment step before it can be cleared for unrestricted use. This also applies to reuse in the sense that objects are used again, for example very lightly or only superficially contaminated scrap metal or tools that can be utilized in production once again after treatment and inspection.

The Council cannot see any good reasons for not allowing the conservation and ecocycle principles to be fully applied in conjunction with the treatment of radioactive waste. This is particularly true in the case of very low-level radioactive wastes, such as decommissioning waste, which are deposited in the near-surface repositories at the nuclear power plants and the Studsvik plant. Utilizing incineration or pyrolysis to a greater extent as a way of reducing the volume of deposited waste can, if it can be done without unacceptable atmospheric releases of radioactivity, also be a desirable development.

[12] Hamrefors, 2004.

From the environmental point of view and in the light of the rules in the Environmental Code, it is the Council's considered opinion greater recycling should be possible for the radioactive waste that arises in connection with nuclear activities. The purpose should be to reduce the volume of radioactive waste to be disposed of. This reduces the need for space in the final repositories, and ultimately also the required number of repositories. The latter applies particularly to near-surface repositories for radioactive waste.

In view of this, the Swedish National Council for Nuclear Waste proposes that the LILW programme in RD&D programme 2010 be supplemented in the next RD&D programme by an account of how the conservation and sustainability principles (i.e. recycling) can be applied in the management and final disposal of low- and intermediate-level radioactive waste.

3.6 Swedish National Council for Nuclear Waste's conclusions regarding the LILW programme

The following points comprise the Swedish National Council for Nuclear Waste's conclusions:

- It is the Council's considered opinion that SKB should, before submitting an application for the extension of SFR, submit a supplementary assessment of the consequences of a delay in the extension of SFR and plans for such an eventuality.
- SKB should clarify how large a fraction of the waste in SFR is actually long-lived.
- SKB should describe in greater detail the reasons, including advantages and disadvantages, of assuming in its planning that SFL cannot be put into operation before 2045. They should also promptly investigate the possibilities of an earlier commissioning of SFL.
- SKB should systematically analyze and describe the flows and shipments of different categories of radioactive waste generated by the utilization of different interim storage facilities, including processes for conditioning, closure, etc.
- SKB should describe more clearly the role, composition and working methods of the Decommissioning Group.

- The LILW programme should be supplemented in the next RD&D programme with an account of the possibilities of recycling of decommissioning waste in particular, but also of waste that would otherwise be placed in SFR. SKB should moreover describe how, and to what extent, they intend to condition the waste for the purpose of reducing its volume.
- SKB is urged to improve its knowledge of the adsorbency of important corrosion products and of the importance of microbial activity and colloidal transport of radionuclides.
- SKB is urged to investigate how material composition and pretreatment of concrete can be utilized to prolong the life of the barriers.

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4 The Nuclear Fuel Programme

4.1 Background

SKB has continued its planning for construction and operation of the Spent Fuel Repository, with sights set on the account that SKB will submit in the applications under the Environmental Code and the Nuclear Activities Act. The execution plan for the Spent Fuel Repository has, according to SKB, thereby changed character from being a development matter handled mainly within the RD&D process to being a matter that will be handled within the licensing process. The development of the technology that is needed in different phases of construction and operation will, however, continue to be handled within the RD&D process, according to SKB.

In order to provide a background to how the plans for technology development in different areas are linked to the execution of the final disposal of spent nuclear fuel, SKB summarizes the execution plans for the encapsulation plant and the final repository in Chapter 8 of RD&D Programme 2010. SKB's summary pertains to the period from the start of operation, i.e. the main phases licensing, construction and commissioning. According to SKB, it is during these phases that the technology developed for the components of the KBS-3 system will be put into use, or readied for use when operation begins.

SKB says that technology development has now reached the point where a reference design for the KBS-3 system has been finalized and has been shown to meet the design premises that have been formulated. They also say that technology development has come the farthest for components of crucial importance to long-term safety, such as the design of the canister. They also point out that the design of certain components, including the canister, may need to be modified, at least in details.

4.2 Technology development, canister

4.2.1 Swedish National Council for Nuclear Waste's conclusions 2007

In their review of RD&D programme 2007, the Council concluded that the material and casting process for the nodular iron insert must be optimized so that specified requirements can be met. Otherwise some other type of material must be used. Further, the Council pointed out that quality requirements must be developed with respect to fabrication defects in all parts of the canister, including welds, in order to guarantee reliability during canister fabrication and final disposal. The Council said that these criteria should take into account material structure, material properties and defects in both the copper shell and the cast iron insert, and further that the quality requirements must be verified by methods for nondestructive testing (NDT), such as ultrasonic and radiographic inspection.

The Council's viewpoints appear to have been heeded in RD&D programme 2010. The work of establishing acceptance criteria for the canister is under way, as is the work of establishing the detailed set of requirements for defects and the underlying requirements for nondestructive testing. Technology development is being pursued toward the goal of testing the technology for testing of the canister's components and welds in order to verify that the criteria are fulfilled.

4.2.2 Background

The planned operating times of the nuclear power reactors in Sweden are equivalent to the final disposal of about 6,000 canisters, with a deposition rate of about 150 canisters per year. SKB has chosen reference methods for fabrication of the canister's components and for welding and sealing. The copper tube is fabricated by extrusion (a process where long, straight metal parts are produced by forcing the metal through a die by means of a hydraulic or mechanical press), copper lids and copper bottoms are forged, and the loadbearing insert is cast. Welding of the copper bottom and the lid seal is done by means of friction stir welding (FSW). It must be possible to fabricate and seal the canisters with high reliability. Demonstration series of inserts and other components have been fabricated under production-like conditions and evaluated.

The canister is the most important barrier in the KBS-3 system since it will enclose the spent nuclear fuel and prevent radionuclides from escaping into the surrounding environment. The canister also attenuates ionizing radiation and prevents further uranium fission (criticality).

4.2.3 Fabrication, testing and inspection

It is not yet clear what requirements must be made on fabrication, testing and inspection of the canister's components and the entire system. After RD&D Programme 2007, SKB has continued developing the design premises for the canister, and a compilation of the canister's strength and damage tolerance (design analysis) has been presented in SKB TR-10-28[1]. The canisters must be able to be inspected with high reliability in order to ensure that they meet the established requirements.

4.2.4 Acceptance criteria

Acceptance criteria must be established for the system and its operation. The work of specifying acceptance criteria is under way. Acceptance criteria for the insert are based on damage tolerance analyses and fracture mechanics, but for the copper shell the requirements are based on creep ductility and the thickness of the intact copper barrier. (Ductility is the ability to resist fracturing. Creep entails a slow change in the material structure under the influence of external force and elevated temperature. Thus, creep ductility is the ability of a material to resist cracking even when it is subjected to permanent deformation over time). The thickness of the corrosion barrier is 5 cm, but 3.5 cm has also been proposed as a sufficient corrosion barrier.

Acceptance criteria should be established for different defects, cold working and material structures, especially in the weld metal but also in the copper shell and the cast iron insert. Maximum permissible defects in canister components that are of importance for in-process inspection must be defined.

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[1] Raiko, Sandström, Rydén, Johansson, 2010

4.2.5 The canister's barrier function

Creep and corrosion

The canister's barrier function in the repository is dependent on the corrosion properties of metallic copper and on the strength of the canister. The canister must withstand isostatic loading of 45 MPa (the sum of the swelling pressure in the buffer, the groundwater pressure and the hydrostatic pressure during a glaciation). The strength of the insert and the creep ductility of the copper shell are then important. Shear movement in the rock is of importance for the fracture mechanical properties of the insert as well as the ultimate elongation and fracture toughness of the copper shell (material properties that describe ductility). Shear movement entails a twisting around a plane or a surface, as when a piece of paper is torn apart. It is an intensive deformation that occurs rapidly and can amount to up to 5 cm at high velocity. The size of a critical defect in the insert may, in an unfavourable case, be only 4 mm in depth, which makes the insert very sensitive and will thereby impose high demands on nondestructive testing of the insert.

Plastic deformations in the copper shell (due to movement in e.g. the surrounding the rock) and creep deformations (due to the material's own change over time) generally appear to be small, but large local strains (up to 30 percent) can occur in the most critical locations in the lid welds. A maximum plastic strain in the copper shell can exceed 20 percent, the same order of magnitude as for creep.

Creep of cold-deformed copper contributes to the total deformation after shear movement. The creep properties of the copper shell, and especially in the weld metal, now become dominant, and it is the Council's considered opinion that SKB needs to carefully investigate the consequences of high local strains in the canister.

Copper corrosion has been discussed a great deal during the past year. The equally important creep properties of copper have also been thoroughly investigated, but a validated creep model is still lacking. The creep ductility of copper in particular decreases with increasing cold deformation. (Cold deformation occurs for different reasons, for example during fabrication or due to rock shear). If the integrity of the copper shell can be maintained under different loads in the repository, this must be shown by creep modelling.

Strength

The strength of the insert meets the strength requirements, and the analyses have shown that the insert has high damage tolerance under isostatic loading all the way to collapse. But particularly in conjunction with rock shear, comparatively small defects in the insert can initiate cracking. The technical specifications for the material ductility of the insert (ultimate elongation and fracture toughness) should therefore be developed. The requirements that are made today on the microstructure of the insert permit 20 percent non-nodular graphite (chunky graphite) to be accepted, which is equivalent to several tonnes. It is not acceptable to approve such material in the insert without determining its properties.

It is not yet been determined what material properties are possible to achieve in fabrication, and a wide range of material properties can be expected, even within an insert. The technical fabrication specifications for the insert must be designed in order to keep variations in material structure within acceptable limits in large castings. The presence of material defects is inevitable, and it is important to determine different types of defects in the inserts.

Sealing and nondestructive testing

The welding process should be developed to avoid defects in the weld metal (oxide inclusions, joint line hooking and others) by the use of shielding gas. Repeatability and reliability in the welding process must be high, and automation of the friction welding process is therefore very important. The welding process window must be large enough to avoid different defects, in particular volumetric defects (e.g. pores) that require radiography and microstructural deviations that can occur during welding.

Development of nondestructive testing methods should continue in order to develop the method for testing of the canister's components and welds. Nondestructive testing must guarantee that all defects can be tested in a reliable manner. Ultrasonic testing is the most important method for detecting defects. Testing systems that include several testing methods and procedures are important, together with interpretation and evaluation of the results. Several testing methods complement each other.

Microstructural variation in particular can affect the reliability of quality inspection by ultrasonic testing of the copper shell. Anomalous (locally large) grain size compared with the surrounding material can cause increased and varying sound attenuation, making it more difficult to detect the defects. Ultrasound is sensitive to variations in grain size and texture in the copper shell, and particularly in the weld metal. All nondestructive testing must be based on design premises and strength analyses according to practice at the nuclear power plants. For the time being, SKB designates the testing methods for quality inspection of cast iron inserts and the copper shell as preliminary and is evaluating the reliability of the methods. The reliability of the preliminary testing methods has been studied with respect to artificial defects, but the likelihood of detecting the defects, along with the reliability of the testing, must be described with natural defects from now on.

4.3 Technology development, buffer

4.3.1 Swedish National Council for Nuclear Waste's conclusions 2007

In its review of RD&D Programme 2007, the Council said that mechanical strength and chemical stability must be guaranteed for compacted components in the buffer. Furthermore, the Council pointed out that the most important properties of the buffer material should be specified and limit values should be determined with respect to swelling potential, retention capacity for radionuclides, chemical stability, hydraulic diffusion, resistance to erosion and level of impurities (inorganic as well as organic).

The requirements on installed buffer formulated in RD&D programme 2010 include maximum levels for total sulphur, sulphides and organic carbon, as well as the concentration range of montmorillonite and the density of water-saturated buffer. However, there are no other requirements on the mineral composition of the bentonite, including the use of sodium and potassium bentonite, which affects the buffer's swelling potential and erosion properties.

4.3.2 Reference design and initial state

This chapter describes the reference design of the buffer, requirements on the buffer to achieve the initial state, and technology development planned in the years to come. At the same time, research and development on clay barriers has continued.

The primary functions of the buffer are to protect the canister from flowing water and limit the mechanical stresses on the canister in connection with rock movements. The buffer must therefore have low water permeability (hydraulic conductivity) and constitute an effective barrier to the inflow of corrosive substances from the groundwater, while retarding the dispersal of radionuclides from a damaged canister. It must be chemically and mechanically stable for a very long time and be able to repair possible fractures by swelling in water.

SKB has formulated requirements on the installed buffer entailing that swelling pressure, hydraulic conductivity, stiffness and strength should not be adversely affected by changes in temperature and pressure and rock movements. This means, for example, that the concentration of montmorillonite in the material shall be between 75 and 90 percent by weight, and organic carbon shall be less than one percent by weight. Furthermore, the total sulphur concentration shall not exceed one percent by weight, and the total concentration of reduced sulphur shall not exceed a half percent by weight. The density of the water-saturated buffer shall be between 1.95 and 2.05 kg/cubic decimetre. The temperature in the buffer shall be lower than 100^{0} C. (Aside from this there are no unspecified requirements related to production and operation.)

It is easy to understand the reason for most of the requirements. The concentration of swelling mineral (montmorillonite) must be high enough for the buffer to swell sufficiently in water and achieve a high density and a sufficiently low hydraulic conductivity. The requirements on low concentrations of organic carbon are related to corrosion of the copper canister, and the dimensional requirements are a consequence of the buffer's role as a barrier to the transport of corrosive substances and the dispersal of radionuclides, and as a "shock absorber" in connection with minor rock movements.

The temperature requirement is related to minimizing the risk of chemical transformation to e.g. illite, but will nevertheless lead to other types of chemical transformation, such as cementation.

Thus, SKB does not intend to stipulate any requirements on the contents of the bentonite aside from those enumerated above, which the Council does not consider satisfactory. Bentonite is the generic name of a natural clay which generally contains numerous other minerals which can in this context be classified as impurities but may also have positive effects in satisfying the performance requirements on the buffer. A description of most minerals that occur in and together with montmorillonite and their properties can be found in the Council's review of SKB's RD&D programme 2007[2]. The above report also contains a very detailed examination of the effects which impurities can be expected to have in a water-saturated bentonite[3].

SKB's intensified research on cementation and its effect on the stiffness and strength of the bentonite is a direct consequence of the mineral composition of the bentonite. The requirements on the buffer formulated by SKB could therefore be achieved with greater certainty if the composition were specified. More detailed view-points on this are given in the comments on the section concerning research on buffer and backfill.

It is, of course, possible to stipulate requirements on the density of water-saturated buffer in the repository, but the value of doing so is questionable if it can never be verified. Water saturation is a very complex process that can take several hundred years, during which time a great deal can happen with the bentonite in the buffer. This means that the narrow limits set on density in a water-saturated buffer can be likened more to a goal than a requirement.

4.4 Technology development, backfilling

4.4.1 Swedish National Council for Nuclear Waste's conclusions 2007

In its review of RD&D Programme 2007, the Swedish National Council for Nuclear Waste observed that the final choice of materials and method for backfilling must be ready by the time the application to build a final repository is submitted. Furthermore, the Council pointed out that SKB must also be able to show that

[2] 2008:70 Appendix 2.
[3] 2008:70 pp. 59–67.

the buffer and backfill conform to the initial states assumed by the safety assessment.

RD&D programme 2010 presents a backfilling concept where precompacted bentonite blocks are emplaced individually and bentonite pellets are blown into the space between the blocks and the ceiling and walls in the tunnels. The initial state for hydraulic conductivity is set at a very low level, and it remains to be shown whether this level can be achieved.

4.4.2 Fabrication and installation

The backfilling line includes manufacture, handling and installation of backfill in deposition tunnels and in the uppermost parts of the deposition holes. The plug near the mouth of the tunnel where it opens into the main tunnel is a part of the backfill.

The backfill's barrier function is to limit the water flow into the deposition tunnels, which SKB has summarized in requirements on limited hydraulic conductivity (< 10–10 m/s) and a minimum swelling pressure (> 0.1 MPa). Hydraulic conductivity is thus expected to be as low in the backfill as in the surrounding rock, and the question is whether this is completely realistic. It is unclear how this value stands in proportion to the value stipulated for the total connected hydraulic conductivity of backfill in tunnels, ramps and shafts and in the excavation-damaged zone surrounding them (< 10–8 m/s)[4].

It is further said that the backfill should limit the upward swelling of the bentonite in the deposition hole. The Council proposed a requirement on this in its review of several previous RD&D programmes[5], but it is unclear what this entails with respect to the density and deformation properties of the backfill.

The Council regards with satisfaction the fact that SKB has, in RD&D programme 2010 in the reference design for backfill, now decided on a concept with bentonite blocks and pellets. In its most recent review of RD&D Programme 2007[6], the Council says that SKB should have made a decision on the choice of method and material by the time the application for a final repository is to be submitted. The reference design presented entails that a bentonite

[4] 1*10–10 m/s is equivalent to 3 mm/yr and 1*10–8 m/s is equivalent to 0.3 m/yr.
[5] Most recently in SOU 2008:70.
[6] SOU 2008:70.

clay with a montmorillonite content in the range 45–90 percent will be used, which is a clay of lower quality than in the buffer. It is questionable whether this material will suffice to prevent the buffer from swelling up out of the deposition hole.

It is likely that a lower concentration of swelling mineral in the backfill will have to be compensated for by stricter requirements on other minerals in the bentonite with respect to composition and particle size. A high quartz content in the bentonite should mean a higher average particle size (quartz is a hard mineral), which is favourable, while a high content of more soluble minerals (e.g. calcite, gypsum and siderite) should be avoided.

The very low hydraulic conductivity in the reference design probably requires a clay with a high montmorillonite content, if the requirement is at all possible to achieve in such large spaces as in deposition tunnels, where the counterpressure from the surrounding rock will be much lower than in the deposition hole. This is particularly true because SKB has decided that the tunnels are to be backfilled with 60 percent compacted blocks and 40 percent bentonite pellets. The large quantity of pellets will increase the risk of erosion and piping (formation of channels with flowing water) in the tunnels after closure. The quantity of bentonite pellets could possibly be reduced by modifying the blocks nearest the ceiling and walls so that they fit more tightly against the tunnel perimeter.

The impression is that SKB has underestimated the problems associated with the backfill, and that the requirements made on the backfill in the reference design should be regarded more as goals than as actual requirements. The Council would appreciate an analysis of the consequences if the requirements are not met. The backfilling concept also entails a rather complicated technical procedure with concrete plugs containing low-pH cement. The system still requires a great deal of development work on both materials and design, and the Council will follow the continued work with great interest.

4.5 Technology development, closure

4.5.1 Swedish National Council for Nuclear Waste's conclusions 2007

In its review of RD&D Programme 2007, the Council observed that the final design of the closure should be determined by the properties of the rock with respect to e.g. fractures at different depths and salinity. However, this presumes knowledge of what properties different materials – and mixtures of materials – have and how they can interact to best effect.

Research and development specifically related to technology for repository closure has not yet been carried out and the Council's comments on the previous RD&D programme are still valid.

4.5.2 The final repository's openings

Closure of the repository includes backfilling and sealing of all openings except the already backfilled deposition tunnels, plus closure of investigation holes.

Research and development specifically related to technology for repository closure has not yet been carried out. A requirement on closure entails that it must not adversely affect the function of the other barriers to any appreciable degree and must retain its barrier function for a long time and prevent the formation of water flow paths between the repository area and the ground surface.

In its most recent review of SKB's RD&D Programme 2007[7], the Swedish National Council for Nuclear Waste presented its viewpoints on the requirements defined there. Among other things, the closure must ensure that the backfill in the deposition tunnels is held in place and that the upper parts of shafts and ramp are designed to withstand a period of permafrost. The Council also offered some viewpoints on the material choices that can be made for different parts of the closure and expressed its surprise at fact that the problems that can arise in conjunction with climate change due to the greenhouse effect are not discussed at all. They are not discussed in RD&D programme 2010 either, which can be regarded as even more remarkable, since applications to build a final repository have now been submitted to SSM.

[7] 2008:70 pp. 72–73.

In this RD&D programme 2010, SKB has presented a reference design for closure of the different parts of the final repository which the Council, in its review of RD&D Programme 2007[8], considered to be important for the credibility of the safety assessment's calculations. The closure has been designed so that different types of material will be used in different parts of the closure, which is what the Council proposed in its review.

The Council assumes that SKB will, in its choice of materials for different parts of the repository, ensure that hydraulic conductivity fulfils the tough requirements which SKB has itself set (< 10–8 m/s)[9], even in areas with high flows in water-bearing fractures.

The Council would also like to reiterate its conclusions from its most recent review that SKB needs to consider the problems that can arise during the expected climate change, for example higher levels and flows of groundwater as well as altered water chemistry and higher sea levels – possibly already during the construction period.

Special research is needed on the interfaces between backfill and surrounding rock in order to find solutions that prevent erosion and formation of transport pathways for flowing water.

4.6 Technology development, rock

The Swedish National Council for Nuclear Waste has contracted Professor Ove Stephansson of Steph Rock Consulting in Berlin to assist the Council with viewpoints concerning selected parts in Part III "The Nuclear Fuel Programme" in SKB's RD&D programme 2010. Stephansson's report is presented in an appendix to the Council's review report.

4.6.1 Swedish National Council for Nuclear Waste's conclusions 2007

The Council concluded in its review of RD&D Programme 2007 that improved knowledge is needed of rock stresses at planned repository depth in Forsmark. The Council further pointed out that general studies should be conducted regarding what effect existing and altered rock stresses may have on hydraulic conductivity

[8] SOU 2008:70.
[9] 1*10–8 m/s is equivalent to 0.3 m/yr.

in fractures in different directions and the consequences for the detailed design of the repository. The Council also asked for a better account of the extent and properties of the excavation-damaged zone in conjunction with controlled blasting, along with an explanation of why full-face boring has been abandoned.

The Council notes that according to the account in RD&D programme 2010, SKB does not intend to conduct further rock stress measurements before it is possible to conduct them under ground.

The Council also observes that SKB presents in RD&D programme 2010 the detailed results of experiments performed in the Äspö HRL (The TASS tunnel) to determine the extent and water flow rate of the excavation-damaged zone. SKB also gives its reasons why conventional drill-and-blast is preferable to full-face boring. SKB says that the advantages are high flexibility, mature technology and comparatively low cost, not just for rock excavation itself but also for subsequent work.

4.6.2 Rock stress, thermal conductivity and heat capacity

The rock line includes detailed characterization, design, construction and maintenance of the Spent Fuel Repository's underground openings.

One of the most important remaining uncertainties in the work on rock mechanics in Forsmark is the state of stress in the rock. The stress measurements that have been performed are method-dependent and give varying results. At repository depth, most measurements are rather old, done when reactor 3 was built[10]. However, SKB intends to perform stress measurements continuously during construction of the repository, which is of great urgency.

The thermal conductivity and heat capacity of the rock will also be investigated during construction, and field measurement methods for these measurements will be developed. SKB has tested the Finnish borehole probe TERO in the deep borehole in the Canister Laboratory at Oskarshamn, but RD&D programme 2010 does not explain whether it is this method that will be further developed. The Council would like SKB to clarify this.

[10] e.g. SOU 2008:70; Stephansson, 2011.

4.6.3 Rock excavation

According to SKB, rock excavation for construction of the final repository for spent nuclear fuel will be carried out using conventional drilling and blasting methods. Further reasons for the choice of method will be given in SKB's application for a licence to build the repository (which was not available at the time of writing). Blasting can give rise to blast-induced fractures. Measurements in the fine sealing tunnel in the Äspö HRL show that blast-induced fractures extend between 0.23 and 0.56 metre into the rock, which means that a potentially interconnected zone with elevated water transport capacity can be formed along a blasted tunnel. The Council believes that further hydrogeological investigations should be carried out to determine water transport capacity in the excavation-damaged zone.

4.6.4 Thermal conductivity

The heat conduction properties of the bedrock in the candidate area in Forsmark have been investigated and the propagation of heat in the rock generated by the canisters has been modelled and serves as a basis for the design canister spacing. The results of numerical calculation codes and analytical methods are in good agreement. The models also take into account rock stresses, pore pressure and the hydraulic conductivity of the fractures and faults during the different phases of the repository However, SKB concludes that the propagation and coalescence of fractures that occur in the vicinity of the deposition holes is not important and can be disregarded. This is based on the fact that the area around the holes is under compressive stresses, which would prevent the propagation of fractures.

According to SKB, tensile stresses are required for fracture propagation[11]. Recent modelling[12] has shown that fractures can form in the vicinity of the deposition holes that propagate and coalesce with existing fractures, if the latter are oriented in a direction in relation to the prevailing stress field that is favourable for fracturing. Fracture propagation can also occur when the temperature conditions change (thermal loading), and particularly

[11] Hökmark, Lönnqvist, Fälth, 2010.
[12] Stephansson, 2011.

in conjunction with ice ages. Fracture formation and propagation preferably occur as shear fractures, not tension fractures, and they lead to higher water flow capacity and longer flow paths around the deposition holes[13]. Furthermore, according to Stephansson, the versions of the simulation (3DEC) used by SKB for thermo-hydro-mechanical processes cannot treat fracture formation and fracture propagation in the models. It is the Council's considered opinion that SKB needs to study the consequences of fracture formation and fracture propagation, and whether this leads to higher water flow around the deposition holes.

4.7 KBS-3H

According to SKB, the KBS-3 method permits canisters to be emplaced either vertically (KBS-3V) or horizontally (KBS-3H). Vertical deposition is SKB's reference concept, but SKB is also exploring the possibility of switching to horizontal deposition at a later stage. The account in RD&D programme 2010 includes background, a description of the current situation and a status report on the ongoing work to develop the KBS-3H concept, which is taking place in cooperation with SKB's Finnish counterpart, Posiva.

4.7.1 Swedish National Council for Nuclear Waste's conclusions 2007

In its review of RD&D Programme 2007, the Council considered it urgent that SKB clarify its plans for KBS-3 with horizontal deposition (KBS-3H).

The Council can conclude that SKB has in RD&D programme 2010 fulfilled the Council's request to clarify its plans with KBS-3H.

4.7.2 Extensive development work

The Swedish National Council for Nuclear Waste concludes that a great deal of development work still remains before SKB has enough evidence to decide whether KBS-3H could be a future alternative to KBS-3V.

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13 Stephansson, 2011.

With respect to the rock stress field, horizontal deposition would, according to the Council's consultant Stephansson, be more appropriate than the KBS-3V alternative preferred by SKB[14]. Horizontal deposition in long boreholes oriented parallel to the greatest maximum stress direction would, according to Stephansson, give the lowest stress magnitudes around the borehole, which is more favourable for both the stability and the long-term safety of the repository.

4.8 Swedish National Council for Nuclear Waste's conclusions regarding the Nuclear Fuel Programme

The following points comprise the Swedish National Council for Nuclear Waste's conclusions:

The canister

- SKB should develop final testing methods and acceptance criteria for all parts of the canister that take into account material structure, material properties and defects. It must be possible to verify the quality requirements by nondestructive testing methods.

The buffer

- SKB is urged to describe the consequences of failure to fulfil the requirements on the initial state of the buffer with respect to water saturation.

The backfill

- SKB is urged to explain the importance of the density and composition of the backfill for fulfilment of the requirement to limit the upward swelling of the bentonite.
- SKB should explain how the requirement on low hydraulic conductivity of the backfill can be met with bentonite blocks with a lower montmorillonite content than that of the buffer.
- SKB should consider the problems that can arise at closure due to expected future climate change as well as periods of freezing.

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[14] Stephansson, 2011.

The rock

- It is the Council's considered opinion that SKB needs to study the consequences of fracture formation and fracture propagation, and whether this leads to higher water flow around the deposition holes.
- SKB should clarify which method for thermal conductivity and heat capacity they plan to develop.

KBS-3H

- SKB is urged to intensify its development work on the KBS-3H method.

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5 Research for assessment of long-term safety

5.1 Background

In RD&D programme 2010, SKB presents an overall structure for the research areas that are linked to long-term safety (fuel, canister, buffer and backfill) and safety assessments of final disposal for the Spent Fuel Repository (SR-Site) and the repository for short-lived low- and intermediate-level waste (SFR).

According to SKB, certain research areas are of a general nature and not linked to any specific repository system. These areas are safety assessment, climate evolution, geosphere and surface ecosystems.

SKB observes that future climate change may lead to glaciation and permafrost, and the climate can therefore indirectly affect the barriers in the final repository (and thereby also the outcome of a safety assessment). Further, SKB notes that a large number of processes in the rock – such as fracturing, groundwater flow, water chemistry and earthquakes – influence the outcome of a safety assessment.

SKB presents a prioritization of future research needs that subdivide the area according to process type and the components that make up the final repository system[1]. The greatest research needs for the Spent Fuel Repository are within fuel dissolution, deformation and corrosion of the canister, evolution and transformation in the buffer and backfill, microbial processes in the rock, and DFN development. (DFN is an abbreviation and stands for Discrete Fracture Network.)

[1] RD&D programme 2010, Table 17–1, page 196.

5.2 Safety assessment

5.2.1 Swedish National Council for Nuclear Waste's conclusions 2007

In its review of RD&D Programme 2007, the Council said it was imperative that SKB give a clear account of the judgements underlying site selection. Since long-term safety is the most important factor in site selection, the Council found that the safety arguments underlying site selection must be based on two comprehensive safety assessments (in other words two SR-Sites): one for Forsmark and one for Laxemar. The Council thereby wished to emphasize the importance of making a scientifically correct comparison between the sites prior to final site selection.

SKB's safety assessments should show that the final repository system fulfils the regulatory requirements on long-term safety. The Council also wanted to emphasize the internal role of safety assessment within SKB as a tool for both following up repository safety during construction and operation and providing guidelines for technology development and research. The Council pointed out that SKB therefore needs to ensure and show that feedback and information sharing between different parts of SKB's organization works, for example feedback from safety assessment to research programmes, programmes for detailed characterization and technology development.

The Council now concludes that RD&D programme 2010 has not presented any complete safety assessments since SR-Can. Site selection has not been preceded by reports of comprehensive site-specific safety assessments. The Council regards the safety assessment as a particularly important and integral part of the application that was submitted on 16 March 2011 and will consider the need for comparative safety assessment in its judgement of the application.

The Council's view of what has been done and what must be done with regard to the internal role of the safety assessment as well as the importance of this role for SKB's organization is discussed in detail in sections 5.2.3–5.2.6 of this report (see below).

5.2.2 Methodology

Nothing new of importance has happened in the area of method development since RD&D Programme 2007 and SR-Can. SKB intends to continue adapting the SR-Can methodology to the safety assessment for SFR. Standardized waste packages are deposited in the Spent Fuel Repository, but the waste in SFR is more complex. This imposes different demands on the formulation of safety functions. The Council finds the adaptation of the SR-Can methodology to SFR to be a good ambition, but wishes in future safety analysis reports to see a discussion of whether the safety functions that are used are sufficient and necessary to guarantee the repository's safety.

The time horizon for the safety assessment for SFR is not discussed in RD&D programme 2010. The presence of long-lived nuclides in SFR, for example C-14 (see section 4.2 in this report), demonstrates the need to extend the assessment beyond 10,000 years. It takes 40,000 years for the radioactivity of C-14 in the repository to decay to one percent of the original level. The Council assumes that the time horizon will be extended so that the safety assessment gives a correct picture of the dose risks from long-lived nuclides.

5.2.3 The roles of the safety assessment

SKB identifies both *external* and *internal* roles for the safety assessment. In its review of RD&D Programme 2007, the Council concurred with this role division.[2] The objective of the external role is to provide society with a basis for assessing the long-term safety of a final repository. In its review of RD&D Programme 2007, the Council found that that the safety assessment is well developed and documented for this role. However, the Council called for discussion and documentation of the two *internal* roles:

- Management tool for construction and operation (execution phase)
- Management tool for natural science research and technology development (R&D)

In its review of RD&D Programme 2007, the Council focused on the safety assessment as a guide for research and technology development. The criticism levelled by the Council at the lack of transparency in the feedback from safety assessment to R&D programme

[2] SOU 2008:70.

remains: RD&D programme 2010 does not show any more than RD&D Programme 2007 did how this feedback works and will work in the future, and here the Council refers to its review of RD&D programme 2007. In the following, the Council would like to focus on the role of the safety assessment in the execution phase, i.e. the first of the two internal roles.

SKB underscores the importance of the internal role of the safety assessment in the execution phase. SKB states that the "during construction and commissioning /…/ the activity has been divided into two iterative main processes," safety assessment and construction[3]. The Council finds this subdivision reasonable. It reflects the fact that the function of the repository is to produce safety not just for the foreseeable future, but for the unforeseeable future.

The unique feature of the repository as an industrial project is that its productivity will never be able to be measured and verified in physical or economic terms; verification of the repository's productivity can only be done by means of a computer simulation, i.e. the safety assessment. The conclusion is that the *relationship between the two main processes* is of fundamental importance. The Council finds that research and development to understand and handle this relationship is extremely important and should be highlighted as an important part of the RD&D programme. In preparation for a positive decision on SKB's application, a research project aimed at this relationship should be initiated as soon as possible.

SKB introduces two concepts for handling the relationship between the two main processes: *initial state* and *design premises*. The concepts are discussed in the two following sections. The Council intends to return with additional viewpoints on the relationship between the main processes.

5.2.4 The concept of initial state

SKB introduces "Initial State" as the fundamental concept for handling the relationship between the two main processes Construction and Safety Assessment. Throughout the presentation in RD&D programme 2010, the initial state is the point of departure for the safety assessment. The importance of the concept for the

[3] RD&D programme 2010, page 113.

Safety Assessment process is thus clear. The Council calls for an equivalent clear definition of the relationship between initial state and the Construction process. In general, SKB appears to mean that the initial state represents the repository's state at closure. In the case of SFR, the initial state "is defined as the state that exists in SFR at closure" (RD&D programme 2010, page 223). The question is what is meant by "at closure".

It is desirable that the initial state be verified as far as possible by direct measurements. This entails determining the initial variable values of strategically important barrier components independently of results calculated from computer models, which can contain uncertainties related to, for example, the mutual dependence of the barrier components. Verification by measurement "at closure" is, however, complicated by the fact that the process of closure is drawn out in time. It can therefore be tempting to give up the requirement on measurement when the repository is closed. With regard to buffer and backfill, SKB states for example that "The expected initial state of other variables depends on how buffer and backfill evolve after installation and is determined by means of analyses"[4]. Since such analyses could extend far into the future, this does not solve the problem of the time of the initial state. The SKB report *Design premises for a KBS-3V repository* (TR-09-22) proposes design premises that apply to the density of the buffer at water saturation, which in Forsmark would not occur until after several hundred years. This results in an initial state that is drawn out in time, where the initial values of different components and even different variables for these components refer to different points in time.

It is the Council's considered opinion that two reasonable requirements on the concept of "initial state" is that it (1) refers to the state of the repository's components at one and the same time, and (2) that the information on this state is based as far as technically possible on measurements at or close to this point in time. This means that SKB must develop a measurement programme that makes it possible to follow changes that occur in the conditions in the buffer, deposition holes and deposition tunnels as the tunnels are sealed. Given the current development of miniaturized measurement devices and measurement technology, it is deemed that a

[4] RD&D programme 2010, page 277.

measurement programme will not interfere with the barrier function of the components.

The Council concludes that the concepts of initial state and design premises can provide a good basis for handling the relationship between the two main processes of Safety Assessment and Construction. However, a system analysis is required of the relationship between the two concepts as well as of their relationship to the two main processes. The goal of the analysis is to obtain stringent definitions and clear applications that can be used for clear and quality-assured communications between the two main processes. Requirements on design premises as well as organization and project management to realize the initial state are discussed in the following two sections.

5.2.5 Design premises

The Swedish National Council for Nuclear Waste observes that SKB has begun the work of deriving design premises from the results of the safety assessment[5]. These design premises constitute the requirements which the repository's components must fulfil in order for the repository at closure to be in the initial state that is assumed in the safety assessment. Taken together, the design premises constitute a *building code* for the repository.

The work on the building code must continue and should be regarded as a part of the RD&D programme. Due to remaining uncertainties regarding the outcome of research and technology development[6] and the properties of the rock, the building code will have to be continuously updated throughout the execution phase, at the same time as each individual design premise must be realistic, verifiable and simple to interpret throughout the project organization. This, together with the close relationship to the advanced safety assessment, will require further method development beyond that done in TR-09-22[7]. It is the considered opinion of the Council that the work with the building code should be incorporated into and regarded as an essential part of the research and development programme for long-term safety.

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[5] SKB, 2009.
[6] RD&D programme 2010, page 196–197.
[7] SKB, 2009.

5.2.6 Realize the initial state

Construction and commissioning should realize the building code. This will require extensive planning and verification of each link in the chain of activities for rock construction, design of technical components and deposition. The focus will be on organization, project management and the interaction of man-technology-organization. The Council underscores the need for systematic studies of what the organization should look like in order to guarantee compliance with the building code and achievement of the initial state under the special conditions that prevail for the construction of a final repository. The Council believes that such studies should commence as soon as possible so that the knowledge is available prior to a decision on the permissibility of a KBS-3 repository in Forsmark.

5.3 Climate evolution

5.3.1 Swedish National Council for Nuclear Waste's conclusions 2007

In its review of RD&D Programme 2007, the Council pointed out that SKB needs to consider the problems that can arise during the expected climate change, for example higher levels and flows of groundwater as well as altered water chemistry and higher sea levels, probably already during the construction period.

Further, the Council said that SKB's climate research should be developed according to three time scales: the next 100 years, the subsequent 1,000 years and the 100,000 years following that, and that the results must be taken into account in the planning, design and construction of the final repository. The Council pointed out that new knowledge concerning climate change has not always been taken into account.

The Council notes now that SKB has in RD&D programme 2010 responded to the Council's question about sea level rise during the construction period. However, SKB has not complied with the Council's request to develop its climate research in three different time scales. The viewpoint from 2007 remains that SKB does not always take new knowledge about climate change into account.

5.3.2 The current state of research

The Swedish National Council for Nuclear Waste has contracted Professor Per Möller of Lund University to assist the Council with viewpoints on Chapter 19, "Climate evolution," in SKB's RD&D programme 2010. Möller's report is presented in an appendix to the Council's review report. The following comments constitute a selection of viewpoints from Möller.

Möller observes that considerable progress has been made between the 2007 and 2010 RD&D programmes in their presentation and understanding of climate evolution. Möller believes that future glaciation cycles may well entail both greater and smaller ice thickness and that current and future human impact on the atmosphere may have a great impact on the natural climate variations and ultimately lead to considerable deviations in glacial development compared with SKB's reference evolution.

Under the heading "Ice sheet dynamics and glacial hydrology", Möller questions the revision of glacial development in Scandinavia which SKB presents in RD&D programme 2010. Möller says that it has not in any way been irrefutably established that ice-free conditions prevailed in large parts of Scandinavia during the period known as Marine Isotope Stage 3, about 50,000 years ago. Möller also says that geological data, as well substantiated by stratigraphy and chronology as the data presented in six references in the RD&D programme, completely contradict the programme's notions about ice sheet extent during this period.

The current state of research, as Möller sees it, is that there are still two opposing glaciation models where either one or the other is wrong due to the uncertainty of datings of geological successions. Möller stresses that the current state of research is not as clear as SKB would have us believe.

5.4 Canister

5.4.1 Swedish National Council for Nuclear Waste's conclusions 2007

The Council pointed out in its review of SKB's RD&D programme 2007 that continued corrosion studies are needed in different areas: accelerated long-term stress corrosion cracking experiments, general corrosion in chloride- and sulphide-containing water with bentonite, and microbial corrosion. The Council further concluded that mechanisms of copper corrosion in oxygen-free water must be investigated experimentally to determine whether corrosion of copper by hydrogen evolution can take place in pure, deionized, oxygen-free water and in groundwater with bentonite.

SKB has taken recent discussions of preconditions for corrosion of the copper canister in the final repository seriously and has now initiated open experiments at a number of laboratories in Sweden and Finland. The experiments are reported to a reference group including critical researchers, environmental organizations and municipal representatives.

The Council's viewpoints with regard to copper corrosion have thus been well heeded.

5.4.2 Background

The copper canister is the most important barrier in the KBS-3 system, since it expected to be completely watertight and corrosion-resistant. Complete knowledge is needed concerning mechanisms, rates and driving forces for copper corrosion under the conditions that prevail in the final repository. Well substantiated data on different types of copper corrosion in the final repository environment are important for public confidence in the KBS-3 method.

5.4.3 Corrosion

SKB's continued research programme with respect to copper corrosion includes both modelling and experimental studies both in the laboratory and under more repository-like conditions. The research is aimed at investigating whether the copper canister has good enough properties with respect to corrosion and strength in the final repository. According to RD&D programme 2010, the following areas of copper corrosion will be studied:

- Copper corrosion and stress corrosion cracking in the sulphide/water system
- Copper corrosion in compacted bentonite
- Copper corrosion in repository-like environments (LOT and Minican)

- Copper corrosion in oxygen-free water
- Independent experiments to replicate the results of Hultquist et al., 2011[8].

The Council is gratified to see that SKB is taking the copper corrosion research seriously and focusing more on studies of copper corrosion. The studies of copper corrosion under repository-like conditions are aimed at avoiding the problems associated with the interpretation of results of more short-duration and limited laboratory experiments. It is important to obtain in-depth knowledge concerning the evolution of the environment in compacted bentonite and the entire final repository system and how this affects the corrosion rate.

5.4.4 Creep

During its service life, the canister will be mechanically deformed by external loading, including pressure from swelling bentonite. Creep in copper is another mechanism that can damage the copper canister in the final repository. The copper canister's creep properties must be studied by taking into account the properties of friction stir welding and the effects of cold working that can arise locally in the canister for various reasons. Rock shear causes plastic deformation in the copper canister, and the interaction between plastic deformation and creep is very important. SKB has concluded that even if a homogeneous parent metal of copper is not sensitive to artificial stress raisers, this does not apply to weld metal with a very heterogeneous microstructure and actual welding defects.

Experience from different power plants and from laboratory tests of welds have shown that in the case of creep, the deformation is localized to the heterogeneous microstructure of the weld. In the case of creep in the weld, the global deformation may be considerably less than the local deformation, but in some critical area in the weld the local creep deformation may be much higher. The creep properties of the copper canister cannot be determined on the basis of the results that have been obtained from creep testing of a homogeneous copper parent metal. The creep properties

[8] Hultquist et al., 2011.

of a heterogeneous microstructure in the friction stir weld are needed for modelling and analysis.

Development of creep strain in the weld is complicated due to e.g. varying microstructure, residual stresses and degree of cold working, as well as the very long period of time. Information on accumulation of creep deformation, together with knowledge of location and type of creep damage, is critical for evaluating the creep properties of the copper canister and its welds. Large creep deformations can be expected to occur in very local areas of the weld, due to the heterogeneous microstructure of the friction stir weld and the long period of time.

The Swedish National Council for Nuclear Waste regards with satisfaction the fact that SKB has adopted a broader approach in its creep research on copper by investigating different material states, multiaxial stress states as well as the influence of hydrogen on the creep properties of copper and possible hydrogen embrittlement. SKB is also concentrating more on copper corrosion. Studies of creep in welds are as yet too few, and in future SKB will have to study in greater depth the creep properties of friction stir welds and geometric discontinuities that exhibit the highest strains in design analysis[9].

The Swedish National Council for Nuclear Waste regards with satisfaction the fact that SKB has initiated research on creep and the influence of hydrogen on material properties in the cast iron insert.

5.4.5 Residual stresses

Residual stresses from fabrication of canister components have not yet been given the same serious attention. It is the Council's considered opinion that residual stresses, together with local plastic deformation (cold working), are important and must be measured and analyzed carefully, particularly in welds in the canister but also in the cast iron insert. There are also great microstructural variations in the welds that can cause localization of deformation and creep under the external mechanical loads that arise in the components in the final repository. These loads can also cause local deformations that can lead to unexpected damage during operation. Stress corrosion cracking is often caused by residual stresses.

[9] Raiko et al., 2010.

5.5 Buffer and backfill

In such a long-term and technically-scientifically challenging project as building a safe final repository, research activities must play a prominent role.

The copper canister is the only completely tight barrier in the KBS-3 concept, but it must be protected from chemical and mechanical attacks in order to be able to fulfil its purpose. The canister is thus the "king" of the repository, and this metaphor can be continued by regarding the bentonite buffer as the royal guard, which is supposed to protect the king from outside enemies – in this case corrosive substances in the groundwater and movements in the surrounding rock.

The soldiers in the royal guard have often been hand-picked due to their personal attributes, which in the final repository correspond to the properties of the bentonite in the form of chemical stability, swelling capacity, etc. The royal guard's organization is supposed to optimize conditions for protecting the king and corresponds in the repository to the technical design of the barriers, which consist of bentonite blocks, rings and pellets.

5.5.1 Swedish National Council for Nuclear Waste's conclusions 2007

In its review of RD&D Programme 2007, the Council concluded that transport models should be set up for the most important radioactive isotopes (with positive and negative charge) through the bentonite, and that special research efforts are needed for the interfaces between the backfill and the buffer on the one hand and the surrounding rock on the other.

One of most important functions of the backfill is to prevent the buffer from swelling up in the deposition holes. SKB has not explained whether this imposes special requirements on the material composition of the bentonite blocks in the backfill. The spaces between the bentonite blocks and the rock will be filled with pellets, but this increases the risk of erosion. Transport models for the most important radionuclides are still not a priority area.

5.5.2 Processes in buffer and backfill

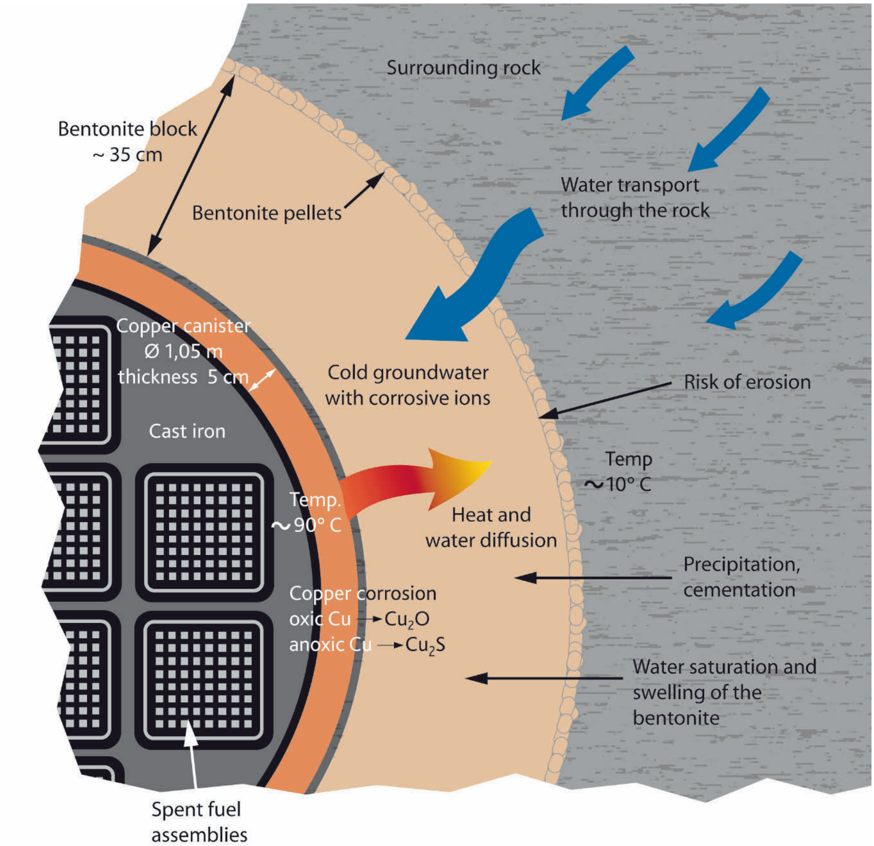
Bentonite blocks and pellets are thus very central components in the buffer and backfill, and it is only natural that they are the subject of independent research programmes. There are a number of processes in buffer and backfill that are crucial for their long-term function, and some of them are described in the following points:

- The buffer becomes water-saturated and swells, whereby further transport of water decreases radically while the buffer density increases, as does the pressure against the canister and the surrounding rock.
- Dissolved oxygen in the buffer and groundwater is consumed by reactions with various impurities in the bentonite.
- Corrosive substances and ions in the groundwater are filtered out on transport through the buffer by adsorption, precipitation and ion exchange.
- Certain minerals in the bentonite are dissolved and transported before once again precipitating, which can affect the mechanical properties of the buffer (cementation).
- Any radionuclides escaping from a damaged canister are adsorbed in the buffer, retarding transport.

Water saturation and water transport

Water saturation of buffer blocks and pellets is a complex process controlled by a number of parameters such as temperature (the temperature gradient in the deposition hole, see Figure 1), density, montmorillonite content, groundwater inflow and time. The time for complete water saturation may vary from a few years to several hundred years, depending on the supply of groundwater. In a relatively dry rock such as that in Forsmark, the buffer in the deposition holes will sometimes stand in direct contact with a relatively warm copper canister for a long time, which can have an adverse effect on its mechanical and chemical properties.

Figure 1 **The engineered barriers. Illustration: Willis Forsling and Jonas Nilsson.**



A water-saturated bentonite may contain many different types of water, such as pore water (in the voids between mineral particles), intercalated (adsorbed) water (between the layers in swelling minerals such as montmorillonite), adsorbed water (on particle surfaces), and chemically bound water (in precipitated minerals). How the relationship between these different types of water is affected by the above-mentioned parameters (temperature, time and water saturation) should be a topic for SKB's research. The quantity of pore water is probably a function of the particle size distribution in the bentonite, which is in turn dependent on the mineral composition. In previous reviews, the Council has urged

SKB to present a quality programme that includes the total mineral composition of bentonite[10].

It is gratifying that SKB plans an extensive research programme on water saturation of the bentonite buffer as a function of the properties of the rock and different buffer parameters such as mineral composition etc.

Water transport under both unsaturated and saturated conditions is of course one of the most important parameters for the long-term function of the buffer and backfill. The hydraulic conductivity of the buffer and backfill must be kept at a very low level during the entire repository period. If complete water saturation takes a very long time, there is a risk that the buffer will dry out and be altered both chemically and mechanically.

The buffer's thermal conductivity decreases when it dries out, further prolonging the time required to reduce the temperature differences between the inner and outer parts of the buffer.

Freezing of bentonite

The long repository time means that it will periodically be very cold and that the bentonite in the backfill will partially freeze. The lower content of swelling minerals in the backfill will lead to a different water distribution in the buffer, i.e. more pore water and less adsorbed water. This will in turn affect the buffer's freezing properties and lead to exclusion of salts and impurities in the backfill. SKB is urged to conduct freeze-thaw tests on bentonite of lower swelling capacity in the same way as corresponding studies of the buffer bentonite.

Mineral transformation and cementation

The Council's most recent state-of-the-art report describes several processes that must be taken into consideration in the modelling of water saturation of buffer and backfill[11]. In addition to montmorillonite, the bentonite contains a number of other minerals, all with different properties with respect to particle size distribution, solubility, hardness, adsorbency etc.[12], and due to the afore-

[10] For example SOU 2008:70.
[11] SOU 2011:14.
[12] See e.g. SOU 2008:70.

mentioned temperature gradient in the deposition hole, heat and hot water will be transported out from the canister, while cold groundwater is sucked in from the surrounding rock. The result will be that ions from the minerals that are more soluble in hot water will diffuse out from the canister, while mineral ions from e.g. calcite and gypsum will be transported into the buffer towards the canister due to the fact that they are more soluble in cold water.

These processes can take place over a relatively long period of time and lead to some mineral redistribution in the buffer (cementation), which can eventually affect its mechanical properties and capacity as a good barrier to the transport of water and ions.

The Council takes a very positive view of the work being pursued within SKB to develop the coupled THM model, but finds that there is a risk that SKB will underestimate the importance of the processes during the saturation phase for the long-term safety of the final repository.

Gas transport and erosion

In the Lasgit experiments in the Äspö HRL, SKB is currently conducting research on gas transport through bentonite as a result of corrosion in a damaged canister. (Lasgit – Large Scale Gas Injection Test). The Council looks forward to the report on the results of Lasgit planned for 2012.

Issues relating to bentonite erosion have come under increasing scrutiny in recent years. In its state-of-the-art report for 2010, the Council described a couple of factors that influence erosion, namely ionic strength and the distribution between calcium and sodium ions in the water (Ca2+/Na+)[13]. But there are other risk factors associated with bentonite erosion.

Piping and erosion in buffer and backfill can easily be caused by continuous inflows of water through fractures in the rock before full water saturation has been reached.

The planned use of a large quantity of pellets in the backfill poses a potential risk, since the water inflow must probably then be extremely low so that more or less unsaturated pellets will not erode or be washed away.

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[13] SOU 2010:6.

SKB is urged to reduce the quantity of pellets in the backfill by designing the bentonite blocks closest to the walls and ceiling so that they fit closely to the outer tunnel contour.

Inhomogeneous swelling

In RD&D programme 2010, SKB provides an essentially insightful description of the mechanical processes that are caused by inhomogeneous swelling of buffer and backfill. An important part of the research programme comprises studies of how upswelling of the buffer and bentonite extrusion into fractures will be limited, and how different processes in buffer and backfill have a long-term effect on strength and brittleness. The Swedish National Council for Nuclear Waste supports the ambition to conduct further research.

Mechanism for transport of water and ions

RD&D programme 2010 describes a number of processes that are important in buffer and backfill: advection, diffusion, osmosis, ion exchange/sorption and montmorillonite transformation. Advection and osmosis are mainly linked to transport of water, while diffusion is primarily a process for transport of water, gas and complex ions. The transport mechanism for complex ions and radionuclides is also dependent on ion exchange reactions and sorption (both adsorption and precipitation), and the Council has in previous reviews urged SKB to set up more sophisticated transport models for important radionuclides. More detailed reasons for this are provided in the Council's review of SKB's RD&D Programme 2007[14], and since the ion charge (positive or negative) will be of great importance for the transport rate through the buffer, that parameter should be included in RD&D programme 2010. Damage to a copper canister that could lead to release of radionuclides will probably occur under oxygen-free conditions, which influences speciation. (Speciation refers to the chemical form of a given substance.)

It is important that the bentonite's affinity for water not be adversely affected by adsorption of potassium ions from concrete

[14] SOU 2008:70.

and feldspars between the siloxane sheets in the montmorillonite[15]. This will happen if the bentonite comes into contact with water at high pHs for a long period of time, which increases the solubility of silicates such as montmorillonite.

Ionizing radiation and radiolysis

The bentonite in the deposition hole will be exposed to high doses of ionizing radiation, which could theoretically adversely affect the montmorillonite and cause its properties to deteriorate. Another possible consequence of the gamma radiation through the canister is that water is decomposed by radiolysis, forming OH radicals, oxygen and hydrogen. According to SKB, the effects of both these processes are negligible. The Council has not altered its assessment, but both of these processes are worrying and are the subject of discussion among people involved in the final disposal issue.

Microbial processes

SKB has devoted large resources over a long period of time to studies of microbial processes in the bentonite buffer in particular. The microbes can reduce sulphate to sulphide ions, but the discussion of their negative effect in RD&D programme 2010 was limited to concerning the boundary area between buffer and copper canister. The activity of the microbes has been considered to be inversely proportional to the density of the buffer, which means there is reason to expect greater bacterial activity in the backfill and the buffer during periods of water saturation.

Radionuclide transport

Most radionuclide transport through the buffer is expected to take place by diffusion in an oxygen-free environment. The transport rate is dependent on water saturation and chemical conditions in the buffer as well as on the speciation of the radionuclides, which leads to different transport mechanisms.

[15] Se SOU 2008:70 App. 3.

Since one of the buffer's most important functions is to prevent (or at least retard) radionuclide transport in the event of damage to the canister, the transport rate and transport mechanisms for the most important radionuclides will be studied and presented in the safety assessment.

The importance of dispersal of radionuclides by adsorption on colloidal particles (particles smaller than 0.001 mm) should not be underestimated either, and the Council takes a positive view of the studies that have been done of the buffer's filtering capacity on inorganic and organic nanoparticles.

5.6 The geosphere

The Swedish National Council for Nuclear Waste has contracted Dr. Lars Marklund of Marksmen Consulting in Sörberge to assist the Council with viewpoints concerning hydrological processes and DFN (discrete fracture network) modelling[16]. Dr. Marklund's report is presented in an appendix to the Council's review report.

The Council has also contracted Professor Ove Stephansson of Steph Rock Consulting in Berlin to assist the Council with viewpoints concerning Chapter 25 "The geosphere" in SKB's RD&D programme 2010. Stephansson's report is also presented in an appendix to the Council's review report.

5.6.1 Swedish National Council for Nuclear Waste's conclusions 2007

In its review of RD&D Programme 2007, the Council concluded that further research and development work is needed on grouting for sealing of fractures, i.e. how and with what material fractures should be sealed. The Council also said that a timetable should be presented for different steps in this programme.

Further, the Council pointed out that additional aspects of changes associated with an open repository should be examined, such as changes in groundwater chemistry, "short-circuiting", i.e. interconnection of different groundwater-conducting zones, and altered rock stress conditions.

[16] See Chapter 25 "The geosphere" in SKB's RD&D programme 2010.

The Council also said that the altered hydrological, hydrogeological and hydrochemical conditions associated with expected climate change should be modelled. Continued modelling should be done of transport and hydrochemistry in the near-surface groundwater and in the transition zone between geosphere and biosphere, taking into account different climate scenarios.

The Council can now conclude that SKB has carried out a fine sealing project and that this research programme is continuing.

The Council can also conclude that extensive hydrogeological modelling studies have been carried out, but due to the complexity of the hydrogeological system there is great uncertainty in the models. According to the Council, the size of groundwater recharge has not been determined with sufficient reliability.

Surface hydrological modelling has been developed with a better understanding of the groundwater in the soil layers and its connections with surface water, atmosphere and groundwater in rock. Surface water modelling has also furnished the biosphere modelling with input data. SKB also intends to study specific hydrological objects that represent the different stages in landscape evolution.

The Council notes that according to RD&D programme 2010, SKB has developed site-specific models for groundwater flow during different time periods and in conjunction with changes towards a colder climate, as well as integrated hydrogeological-surface hydrological models for different climate scenarios. The way in which groundwater composition is affected by different climate changes will be described in the SR-Site safety assessment, and the link between hydrogeology and hydrochemistry will be made in a way that resembles the method developed for SR-Can.

5.6.2 Groundwater flow

New modelling tools have been developed and site-specific investigations have been conducted regarding the groundwater flow in Forsmark. The magnitude of the groundwater recharge has not been reliably determined, however. The Council is of the opinion that several independent methods should be used to obtain more reliable values. The groundwater flow modelling (during different time periods) is adapted to site-specific data, and in Forsmark a high-conductive layer has been included in the upper part of the model. With this layer in the models, the effect of the local topography is dampened, but on a larger scale the topography plays a significant role[17].

SKB has conducted a study of the importance of the repository's local properties for the regional flow paths. The top boundary condition that has been used is based on groundwater infiltration, in contrast to previous studies where it is based on the location of the groundwater table. (The top boundary condition is the condition that constitutes the upper part of the simulation model, in this case the ground surface.) The flux boundary condition applied by SKB is often preferable, but this requires the availability of representative infiltration data. (Flux boundary conditions are specific water velocities in the simulation model.) Surface water runoff has been used in the flux boundary conditions, but it is not evident what is meant, and the Council would like this to be clarified.

5.6.3 Integrated modelling

SKB's research programme in hydrogeology is very comprehensive. The models are well developed, but since the hydrogeological system is heterogeneous there are great uncertainties in the model calculations that cover large areas. In general, it can be pointed out that SKB should explain how uncertainties in measurements and conceptualizations are handled.

5.6.4 Reactivation – movements along existing fractures

Displacements in solid rock along existing fractures are related to large-scale geological plate movements (plate tectonics) and readjustment of the Earth's crust after the latest glaciation along post-glacial faults. In the opinion of the Council, in order to evaluate the stability of the bedrock, continuous measurement series should be carried out over long periods of time in order to get a better idea of possible movements in the bedrock.

SKB has performed a consequence analysis of magnitude 6 earthquakes in order to determine shear movements in fractures near the (in the model) seismically active major zones, i.e. the zones where most of the movement takes place during an earthquake. Shear movements entail a twisting around a plane or a surface, as when a

[17] Marklund, 2011.

piece of paper is torn apart. The result shows that movements along fractures situated 200 metres or more from the seismically active zones are small and well below the canister damage criterion.

In order to comply with the canister damage criterion, deposition holes should be rejected if five or more holes are transected by one and the same fracture. However, it is unclear how the flow pattern for surface water is affected if new fractures are opened or if existing fractures are linked with water-bearing systems. This can make other aspects important besides the canister damage criterion in determining how many deposition holes are rejected.

Fractures are potentially water-bearing, and the creation of new fractures or changes in the extent of existing fractures can affect the water's flow pattern via channelling, which can have a negative effect on the repository. It is also unclear to the Council what significance the fractures have in the event of aseismic activity (creep) along the major deformation zones. Aseismic activity is when stress is continuously released by creep in the material, in contrast to when stress builds up and is released in an abrupt movement, resulting in earthquakes.

For understandable reasons, the exact extent and positions of all fractures in Forsmark are not known. The distribution, orientation and frequency of the fractures are important, not just for water flow, but also for models of other processes such as glacial hydrology and rock mechanics. Obtaining a better understanding of the fractures is therefore important. The models and simulations done by SKB are promising[18], but the reliability of the models increases with better knowledge of the distribution and orientation of actual fractures. This knowledge can be obtained with a denser network of seismic profiles (3D seismics). The Council's recommendations are that such an investigation be conducted in the candidate area.

During a five-year period in the 1990s, the Forsmark area was investigated with regard to displacements of the ground surface using the *Differential SAR Interferometry* (DInSAR) method, a satellite radar technique[19]. The investigations could not detect any vertical aseismic movements (vertical "creeps") along geological fracture planes. However, the measurement series is limited and the method is not optimized to detect lateral movements, which could therefore not be ruled out. Small lateral movements can be measured

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[18] Ericsson et al., 2006.
[19] Dehls, 2006.

with high precision by means of continuous stationary GPS measurements.

GPS measurements have been carried out in the Forsmark area since 2005, and according to SKB this measurement programme will continue. The Council considers it of the utmost importance that stationary GPS stations be installed in order to obtain higher precision, and that the measurements be performed continuously over long periods of time. These measurements should be combined with DInSAR or equivalent geodetic methods, and reflectors for these measurements should be installed. (Geodetic methods measure the position of geographic reference points with high accuracy so that any displacements of the positions can be determined.) The Council also finds it urgent that the local seismic network (permanent ground movement detectors) be installed before the start of construction in order to monitor the local occurrence of microearthquakes.

5.6.5 Fracturing

The account in RD&D programme 2010 is contradictory when it comes to fracturing. At the same time as it is said that fracturing near the deposition holes does not have to be taken into account[20], results are reported from rock fracture mechanical modelling showing that fracture formation and fracture propagation can occur at the ends of existing fractures[21]. It is the Council's considered opinion that SKB should clarify the consequences of fracture formation and fracture propagation near the deposition hole.

5.6.6 Time-dependent deformation

Results of studies of time-dependent deformation in solid rock show that there is a stress threshold value. This threshold value is probably too low to be reasonable[22], which means that time-dependent deformation of the rock cannot be entirely ruled out. Like Stephansson, the Council would like the importance of this type of deformation for the long-term safety of the repository to be better illuminated.

[20] Section 25.2.2 in RD&D programme 2010.
[21] Section 25.2.8.
[22] Stephansson, 2011.

5.7 Surface ecosystems

The Swedish National Council for Nuclear Waste has contracted Dr. Lars Marklund of Marksmen Consulting in Sörberge to assist the Council with viewpoints concerning aquatic ecosystems, as well as hydrology and transport[23]. (Aquatic ecosystems are all organisms and their physical environment in a defined area in fresh or salt water. Terrestrial ecosystems only include land areas.) Dr. Marklund's report can be found as an appendix to the Council's review report.

5.7.1 Swedish National Council for Nuclear Waste's conclusions 2007

In its review of RD&D Programme 2007, the Council concluded that a coherent programme for monitoring of the repository area and the surrounding environment must be presented – and promptly implemented – both for the period before and during the construction phase and for the post-closure period.

The Council further pointed out that SKB must show more clearly how the results of the biosphere work are integrated in the safety assessment and the EIA process and what importance the biosphere will have for siting.

In addition, the Council said that SKB should conduct sensitivity analyses of the modelling results regarding the biosphere, and that SKB should prepare a programme for modelling of conditions associated with expected climate change.

The Council now finds that the opinions expressed by the Council in 2007 have to some extent been taken into account.

5.7.2 Terrestrial and aquatic ecosystems

In a brief programme declaration for the continued research on terrestrial and aquatic ecosystems, SKB indicates the direction of this research. Based on the research results of the past few years, SKB has identified uptake and accumulation processes in wetlands as one of the most important topics in this context. Of particular interest is the question of whether future wetlands will be utilized

[23] Cf. Chapter 26 "Surface ecosystems" in SKB's RD&D programme 2010.

for agriculture, and if so to what extent radionuclides may then be transferred to crops, and what this means for the population.

In the aquatic environments, SKB once again finds that carbon flux still needs to be studied, particularly in wetlands bordering on the sea or lakes.

The eco-model systems that are used are complex, which makes it difficult to evaluate and validate the model calculations. It is therefore important that SKB now intends to validate the models with field data from Forsmark. This work should also include sensitivity and uncertainty analyses.

However, it is still unclear whether SKB is referring here to the coherent programme for monitoring which the Council called for in its review of RD&D Programme 2007.

The Council finds the questions brought up in the programmes to be relevant in this context, but at the same time calls for a comprehensive and more detailed description of the different projects. SKB should also explain how they intend to utilize the models they develop in the continued work.

5.8 Other methods

5.8.1 Swedish National Council for Nuclear Waste's conclusions 2007

In its review of RD&D Programme 2007, the Council concluded that it is of great importance for confidence in SKB's work that a coherent and clarifying account be given of alternative methods for the final disposal of spent nuclear fuel. The Council considered that SKB should present such an account not later than in conjunction with the company's licence applications under the Nuclear Activities Act and the Environmental Code, with clarification of its positions on the Deep Boreholes concept.

The Council further pointed out that it is urgent that SKB study alternative methods that can be expected to be technically feasible and that this can be shown in connection with the environmental review.

The Council can now note that SKB has in RD&D programme 2010 stated that there is no justification for pursuing a research programme on Deep Boreholes[24]. The reasons given are that SKB

[24] Cf. page 391 RD&D programme 2010.

- does not feel that anything has emerged that speaks strongly enough on behalf of the method
- for safety-related reasons wants to concentrate its resources on the KBS-3 method
- believes that an equivalent investigation of the Deep Boreholes method would delay the whole project by about 30 years, which is not considered acceptable.

The Council notes that SKB is keeping track of developments in the field and recently published a report where Deep Boreholes is compared in greater detail than previously with the KBS-3 method[25]. The Council considers this to be a step in the right direction, but observes at the same time that alternative methods have not been evaluated as thoroughly.

5.8.2 Partitioning and transmutation (P&T)

Partitioning and transmutation is a possible technology for greatly reducing the amount of long-lived radionuclides to be deposited in a final repository. This is a process that is possible in theory and on the laboratory scale, but the technology has only been tested to a very limited extent on a larger scale. The Swedish National Council for Nuclear Waste described the technology briefly in its Nuclear Waste State-of-the-Art Report 2011[26]. The conclusion there was that this is an interesting method, but due to its complexity it must be developed and run in a European collaboration. Nor does the method eliminate the need for a geological final repository, even though it will not be required for as long a time. It is also deemed unlikely that the method could be used on a large scale for a very long time to come.

The Council notes with satisfaction that SKB is supporting research on partitioning and transmutation at universities and institutes of technology. The Council also supports the goal of the research, to investigate the technology from a “waste perspective” and to judge when and where it is realistic to utilize it to improve and simplify the waste management process.

[25] Grundfelt, 2010.
[26] SOU 2011:14.

5.8.3 Deep Boreholes

The Swedish National Council for Nuclear Waste has previously stressed that the alternative of disposing of the waste in deep boreholes has not been adequately explored by SKB. In response, SKB has published a report entitled "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," in Swedish only) [27]. The report is a compilation of previously published material and material that has been produced by SKB's own experts, and the purpose is to compare the merits of the two methods. The report was presented along with other documents when SKB submitted its licence application. The current RD&D programme presents a summary of studies of disposal in deep boreholes from the UK and North America.

The conclusion in RD&D programme 2010 is, however, the same as before, that disposal in deep boreholes is not a realistic alternative. In SKB's report R-10-13[28], where Deep Boreholes is compared with KBS-3, the assessment that SKB made 10 years ago is reiterated, namely that it would take another 30 years to achieve the same level of knowledge for Deep Boreholes as for the KBS-3 method.

As the Council pointed out in its Nuclear Waste State-of-the-Art Report 2011, there are reports from other researchers that regard Deep Boreholes as a possible alternative for disposal of the waste[29]. It is the Council's considered opinion that further knowledge is needed to be able to evaluate whether Deep Boreholes is a feasible alternative to the KBS-3 method. SKB therefore needs to:

- investigate whether the right physical conditions exist in Sweden
- upgrade knowledge of the groundwater's density stratification so that there is at least a relevant hydrogeological model of normal bedrock Swedish bedrock down to a depth of 5 kilometres
- upgrade knowledge of drilling and deposition technology and the repository's long-term function so that comprehensive

[27] Grundfelt, 2010.
[28] Grundfelt, 2010.
[29] Åhäll, 2011; Brady et al., 2009.

safety-related comparisons can be made in the licensing review process.

5.9 Swedish National Council for Nuclear Waste's conclusions regarding research for assessment of long-term safety

The following points comprise the Swedish National Council for Nuclear Waste's conclusions:

The safety assessment

- The Council assumes that the time horizon for the safety assessment of SFR will be extended so that the safety assessment can give a correct picture of the dose risks posed by long-lived nuclides.
- The Council repeats its demand from 2007 that SKB should clarify the internal role of the safety assessment as a tool for guiding R&D and technology development.
- The Council would like SKB to carry out a system analysis as soon as possible to clarify the relationship between the two iterative main processes of Safety Assessment and Construction and the roles of the two key concepts of Initial State and Design Premises.
- The Council observes that studies of the processes aimed at guaranteeing that the initial state is fulfilled are extremely important and finds:
  - that the work of formulating *design premises* should be incurporated in the RD&D programme and viewed as an essential part of the reporting of the R&D programme for long-term safety
  - that SKB should, as soon as possible, initiate systematic studies of what the *organization* should look like in order to guarantee that all design premises are complied with and the desired initial state is achieved under the special conditions that prevail for execution of a final repository
  - that SKB should develop a *measurement programme* that makes it possible to verify changes that occur in the con-

ditions in the buffer, deposition holes and deposition tunnels as the tunnels are sealed.

The canister

- SKB should continue corrosion studies within several different areas. Research is under way, and it is important that the conclusions are scientifically certain and that corrosion data are sufficiently substantiated in order to permit a credible assessment that guarantees long-term safety against corrosion of the canister.
- In creep analysis of the copper canister, more consideration should be given to the creep properties of heterogeneous friction stir welds and geometric discontinuities that exhibit the largest local deformations in copper canisters according to the design analysis.
- The material properties of the cast iron insert (variation in microstructure and mechanical properties) should be further investigated. The variation of ductility and fracture toughness in large castings will be important if the damage tolerance analysis shows that the critical size of the material defect is small.

Buffer and backfill

- The Council urges SKB to present a quality programme that includes the total mineral composition of bentonite.
- The Council urges SKB to conduct repeated freeze-thaw tests on bentonite with a lower montmorillonite content in the same way as for bentonite in the buffer.
- The Council urges SKB to study the importance of a very long period before full water saturation for the long-term quality of the bentonite.
- The Council recommends that SKB consider reducing the amount of pellets in the backfill by fitting the bentonite blocks more closely to the outer contour of the tunnels.
- The Council urges SKB to determine transport mechanisms and travel times through the buffer for the most important radionuclides in the event the copper canister should leak.

The geosphere

- It is the Council's considered opinion that SKB should clarify how the flux boundary conditions (surface water runoff) have been used in the models of the importance of the repository site for the regional flow paths.
- The Council proposes that SKB carry out seismic surveys in a dense network in order to create a better 3D picture of the distribution and orientation of important fracture systems in Forsmark.
- The Council proposes that SKB establish a local seismic network in Forsmark.
- The Council proposes that SKB install stationary GPS stations and artificial reflectors for DInSAR (satellite radar technology) in Forsmark and that measurements of possible changes of the surface be performed continuously over a long time.
- The Council proposes that SKB carry out a consequence analysis of the models for mechanical rock failure.

Surface ecosystems

- The Council calls for a more comprehensive account of the contents of the planned research programme concerning terrestrial and aquatic ecosystems.

Other methods

- SKB should investigate whether good physical conditions for disposal in deep boreholes exist in the country, taking into account upgraded knowledge of drilling and deposition technology.

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6 Social science research

6.1 Introduction

The importance of research in the social sciences and humanities for the final disposal issue was discussed as early as the late 1980s. The predecessor of the Swedish National Council for Nuclear Waste, KASAM, published its first nuclear waste state-of-the-art report in 1986, where it dealt with SKB's research and development programme from that year. KASAM also made an assessment of then-SKN's (National Board for Spent Nuclear Fuel) research programme, which included social science research.

In its 1989 state-of-the-art report, KASAM returned to the issue of social science research and noted that interdisciplinary programmes with elements of ethics and social science are of central importance and that "there is a great need for expertise unaffiliated with and independent of SKB for follow-up and review of research and studies concerning the final disposal of nuclear waste".[1] In order to secure access to unaffiliated expertise, KASAM proposed that ten or so research positions be created for basic interdisciplinary research on the nuclear waste issue. The proposal was not realized, but the social science and ethical aspects of the nuclear waste issue were explored in a lively series of seminars in the early 1990s.

In 1997, KASAM arranged a seminar on the decision process associated with siting of a final repository, where both social scientists and humanists participated. KASAM and then-SKI's (Swedish Nuclear Power Inspectorate) interest in the social scientific nuclear waste research also stimulated independent university researchers. An example is the anthology concerning municipalities and nuclear waste edited by social scientist Rolf Lidskog.[2] The work of Göran

[1] State-of-the-art report 1989, page 43.
[2] Lidskog, 1998. Svensk kärnavfallspolitik på 1990-talet.

Sundqvist (professor of the sociology of scientific knowledge)[3] is rightfully highlighted in Mats Aldén's and Urban Strandberg's anthology *Kärnavfallets politiska utmaningar,* ("The political challenges of nuclear waste") 2005[4]. The final chapter of this anthology also levels sharp criticism at both SKB and KASAM for expressing (SKB in its RD&D programme 2004 and KASAM in its state-of-the-art report 2004) "a willingness to disregard the societal contexts...ignoring the fact that nuclear waste is an issue with political, economic, social and ideological dimensions".[5] It should however be noted that already in 2002 (in its review of SKB's RD&D programme 2001), KASAM made considerable attempts to bring about a programme for independent research in the social sciences and the humanities related to the nuclear waste issue.[6] The attempt did not meet with success, but instead SKB initiated its social science research programme in 2004. At the time of this writing (April 2011), this social science research programme is approaching its evaluation and possible conclusion. The question is then whether the knowledge generated by SKB's programme has provided SKB and the decision-making bodies (SSM, the environmental court and the Government) with an adequate social scientific basis to make a decision in the final repository question.

6.2 The Council's previous viewpoints

6.2.1 Swedish National Council for Nuclear Waste's conclusions in its review of SKB's RD&D programme 2007

The Council devoted considerable attention to SKB's social science research programme in its review of RD&D programme 2007. Among other things, the Council pointed out that there is a great need for such a programme, but that it should have a broader and more critical orientation. The Council also asserted that the programme should be supplemented in two different ways:

1. by studies of future economic consequences of the handling of the nuclear waste issue, mainly cost-benefit analyses. This is

[3] Sundqvist, 2002. The Bedrock of Opinion. Science, Technology and Society in the Siting of High-level Nuclear Waste.
[4] Andrén & Strandberg (red.), 2005.
[5] See page 143 in Andrén & Strandberg (red.), 2005.
[6] SOU 2002:63 pp. 115–124.

needed in order to judge what societal resources are needed for alternative solutions, and

2. research projects concerning global changes and safety culture (for details see point 2 in section 14.2 of the Council's review SKB's RD&D Programme 2007). This was deemed in the Council's review to be a very urgent research field, since such research can shed light on the social barrier for safety in the final disposal solution.

Neither of these viewpoints was taken into account in SKB's continued work, nor are they addressed in RD&D programme 2010.

6.2.2 Swedish National Council for Nuclear Waste's viewpoints in the Nuclear Waste State-of-the-Art Report 2011.

The Council dealt thoroughly with SKB's social science research programme in its state-of-the-art report from 2011. The Council's general conclusion is that the research activities in the programme are of high quality and have been conducted with high scientific integrity. The knowledge of the nuclear waste issue gained via the programme is judged by the Council to be reliable. However, the Council points out that there are knowledge gaps and that the critical social science perspective on e.g. the alternatives issue could have been given greater attention.[7] The Council also reiterates the need for nuclear waste research in the social sciences that is independent of SKB. Like SKB's scientific committee, we pose the question as to "why state research councils and regulatory authorities have not created their own programmes for funding research projects in such an important field as the social and societal dimensions of the nuclear waste issue."[8] SKB repeats this viewpoint in RD&D programme 2010 and says that "It would benefit the entire research field if other actors than SKB also took the initiative to fund social science research".[9] The Council will return to this question in section 6.4.

[7] SOU 2011:14 page 77.
[8] Berner, Drottz-Sjöberg, Holm, 2009 page 8.
[9] RD&D programme 2010, page 399.

6.3 Current viewpoints

6.3.1 The need for independent social scientific nuclear waste research

Since 1986, the Swedish National Council for Nuclear Waste has in different contexts called attention to the need for independent nuclear waste research, for example in the social sciences and humanities. (By "independent" is meant in this context that the Council strives for independence from economic and political interests and positions based on scientific evidence and on accepted and defined ethical principles). The Council's state-of-the-art report 2010 underscored the need for resources for such research aside from the research programme which SKB has conducted and is now about to evaluate.

The social science research funded by SKB can be characterized as applied sectoral research directly linked to site selection, the democratic process and ethical issues in the work of producing an application.

Now that SKB has submitted its application for a final repository, the nuclear waste issue may be entering a new phase of construction, operation and closure of the repository. If all goes according to plan, this phase will be concluded in 2065. Follow-ups and evaluations of the different projects will be needed during this period, not least to create a transparent and democratically viable process. During this span of time there will also be a need for social science research on the nuclear waste issue to be carried out in a coherent and structured manner.

There is an obvious need for new knowledge concerning the viability and feasibility of the waste system from various aspects. Increased competition in the future on the global market for raw materials such as copper could put pressure on the nuclear waste programme via significantly increased costs. This is an example of a situation that could alter the premises for the final repository programme. Other structural societal conditions that could bring crucial changes include increased international ownership of and influence over the nuclear power companies, or increasing influence by the EU, which could undermine the responsibility principle and confidence in the legitimacy of the final repository. Another crucial premise for a safe final repository is that our generation is able to find a way to pass on reliable and detailed information on the system to future generations. How can society accomplish this?

A vital long-term task and responsibility for the Swedish National Council for Nuclear Waste is to make sure that the further development of the waste programme undergoes continuous evaluation and follow-up. Furthermore, a more general acquisition of knowledge is needed by means of both studies of special questions that may arise in connection with the programme and research on the relationships between technology, politics, economics and society. These are topics that not only have a bearing on the nuclear waste programme, but also reflect a general neglected need for more knowledge on the sociotechnical systems on which society rests.

6.3.2 The orientation and work forms of the societal programme

In RD&D programme 2010, SKB defines the purpose of its social science research programme as being to:

- Broaden the perspective on the societal aspects of the Nuclear Fuel Programme. This will facilitate evaluation and assessment of the programme in a larger context.
- Provide deeper knowledge and a better body of data as a basis for site- and project-related studies and analyses. The results of the social science research will thereby provide a sounder basis for various decisions.
- Contribute with data and analyses to research on the societal aspects of large industrial and infrastructure projects. In this way, experience gained from the nuclear fuel programme can benefit other similar projects.[10]

The Council would like to draw attention to the fact that this statement of purpose differs in one crucial point from the one formulated in RD&D programme 2004. There the social science research programme was related in a clear way to the environmental impact statement appended to the application. The second point was then formulated in the following way:

[10] RD&D programme 2010, page 397.

– The results of the social science research will thereby provide a sounder basis for decisions *and the EIS*.[11]

In the introduction to the chapter on social science research in RD&D-Programme 2004, the close relationship to the EIS was underscored in the following manner:

> An Environmental Impact Statement (EIS) must be appended to the applications for a licence to build the encapsulation plant and the final repository for spent nuclear fuel. The EIS must contain descriptions of the environmental impact and effects of the planned facilities and activities. The EIS must also contain descriptions of projected consequences for the environment, the landscape, human health and society. In order to be able to present a broad and complete account of societal aspects together with the licence application, SKB intends to conduct and fund social science research.[12]

During the course of the programme, the purpose of the societal programme has changed in a decisive way. In RD&D programme 2010, SKB states that “The programme is independent of both the EIS and the licence applications”.[13]

This crucial change in the direction of the programme has not been satisfactorily explained by SKB, either in RD&D programme 2010 or in any other document published by SKB. SKB writes that “the social science research is not primarily municipality-specific but is aimed at gathering new and general knowledge.” This claim can be questioned on two points:

In the first place, several of the completed research projects concern municipality-specific conditions, and *in the second place*, new and general knowledge is also highly relevant to different parts of the application. The Council would once again like to emphasize that several of the changes that could lead to a far-reaching re-examination of the execution of the nuclear waste programme and SKB’s main timetable are associated with different types of societal changes, which could be made the subject of social science research (see section 2.2.2).

It is the Council’s considered opinion – like that of then-SKI in its review of the 2007 RD&D programme – that the detachment of the social science research programme from the rest of SKB’s work with applications is unfortunate. This was pointed out by the

[11] RD&D-Programme 2004, page 301 (the Council’s italics).
[12] RD&D programme 2004, page 301.
[13] RD&D programme 2010, page 398.

Council in RD&D-programme 2004 and was repeated in the Council's review of RD&D programme 2007, where the Council noted that SKB's social science research programme and its results are entering into the planning and licensing process at a very late date. The Council pointed out that it is therefore all the more urgent to link site selection and technical solutions to the results of the social science research, and to show how these results can shed light on the final repository issue and contribute to SKB's application for a licence to build a a final repository for spent nuclear fuel. The Council went on to say that the formulations of the purpose could been clearer and linked to specific knowledge needs in SKB's own work, for example with the Environmental Impact Statement, EIS.[14]

It is noteworthy that in RD&D programme, SKB does not address this question in the section *Conclusions in RD&D 2007 and its review.*[15]

This leads to the question of the societal programme's work forms, and above all to the question of how SKB has distributed the nearly SEK 24 million allocated to the social science research programme.[16] A scientific committee was appointed early in the process. After two preparatory research seminars in 2002 and 2003 with researchers and representatives from municipalities, regulatory authorities and then-KASAM, four general areas of research were identified as being relevant for the waste issue and the municipalities:

- Socioeconomic impact – macroeconomic effects
- Decision processes
- Public opinion and attitudes – psychosocial effects
- Global changes

An initial call for proposals in these research areas was sent out to a number of universities and institutes of technology in the spring of 2004. Additional calls were issued annually between 2005 and 2009. They were then assessed by the scientific committee and resulted in 18 different research projects, whose results are summarized in RD&D programme 2010, Chapters 30–32. Three research seminars were held in 2007, 2008 and 2009.

[14] SOU 2008:70 p. 108.
[15] Page 398 in RD&D programme 2010.
[16] Berner, Drottz-Sjöberg, Holm, 2009.

According to RD&D programme 2010, two main criteria were used by the scientific committee to assess applications. First, the application must be of intradisciplinary relevance and good quality, and second, it must be relevant to SKB's mission. This latter condition is puzzling considering the fact that the social science research programme is supposed to be independent of both EIS and its applications.[17]

It is the Council's considered opinion that the procedure and work forms of SKB's social science research programme have been determined far too little by SKB's mission, namely to take "responsibility for nuclear waste management from the time the waste leaves the nuclear power plants".[18] This is in part due to the fact that the programme was established relatively late in SKB's application preparations. But once the programme was detached and became independent of both the EIS and the applications (above all the application for a licence for final disposal of spent nuclear fuel), the condition that social science research applications must be relevant to SKB's mission was in fact invalidated. The Council is positively disposed to SKB's plans for a general evaluation of the social science research programme[19] but would like to state that a critical and thorough evaluation of procedure and work forms should also be undertaken. Based on SKB's evaluation, the Council finds that there is a need for the Council to conduct an independent and thorough review of the forms and results of the programme in 2012.

6.4 Future forms and tasks of the social science research

SKB will evaluate the social science research programme in 2011. The Council will await the conclusions of this evaluation, and intends after further analysis to return to the question of how the social science research in the field of nuclear waste should be funded and organized.

In the light of SKB's evaluation and the Swedish National Council for Nuclear Waste's own upcoming review, the Council would like to urge the Government to (1) study the forms for how

[17] RD&D programme 2010, page 399.
[18] RD&D programme 2010, page 23.
[19] RD&D programme 2010, page 399.

social science research on the nuclear waste issue is to be conducted in the future and (2) in the upcoming research bill, make sure that money from the Nuclear Waste Fund is allocated in the coming decades to social science research.

6.5 Swedish National Council for Nuclear Waste's conclusions regarding social science research

The following points comprise the Swedish National Council for Nuclear Waste's conclusions:

- It is the Council's opinion that SKB has detached its social science research programme from its fundamental final disposal mission in an unsatisfactory manner.
- There is still a great need for social science research around nuclear waste, which should be (1) as free as possible of economic and political interests but still (2) of relevance to Swedish nuclear waste management.
- The future research should study the consequences of increased competition on the global market for raw materials (for example copper), the consequences of crucial changes in the ownership of nuclear power, and conditions for societal planning and decision-making.
- A number of the changed premises that could warrant a far-reaching re-examination of the execution of the nuclear waste programme and SKB's main timetable are associated with different types of societal changes, which could be made the subject of social science research (see also 2.2.2).
- In the light of SKB's evaluation and the Swedish National Council for Nuclear Waste's upcoming review, the Government should (1) study the forms for how independent social science and humanistic research on the nuclear waste issue is to be conducted in the future and (2) in the upcoming research bill, make sure that money from the Nuclear Waste Fund is allocated in the coming decades to social science research.

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Review of SKB's research programme for geohydrology

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Lars Marklund

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REVIEW OF SKB'S RESEARCH PROGRAMME FOR GEOHYDROLOGY

CONTENTS

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INTRODUCTION

Assignment

The work involves review of specific parts of SKB's research programme (RD&D programme 2010). The pages in RD&D programme 2010 that have been reviewed are: 242-243, 245-248, 329-332, 339-352, 353-360, 366-369 and 372-375.

Client

Swedish National Council for Nuclear Waste, M1992:A
Att: Holmfridur Bjarnadottir
SE-103 33 Stockholm, Sweden

Premises

The subject of the review is the report RD&D programme 2010 and its reference material. The chapter numbers used in this review are the same as those used in RD&D programme 2010.

CONCLUSIONS

SKB's research programme in geohydrology is extensive and in some respects world-leading. SKB uses several sophisticated models that probably offer the best possible representation of reality. But the fact remains that the system to be modelled is very difficult to observe because it is literally buried underground. The system is also highly heterogeneous, which means that the few observations that have been made are not usually representative of a large area. Many of the models used also describe a time sequence that extends thousands of years into the future. Evaluating these model calculations by means of observations is therefore impossible. Great uncertainties thereby characterize the model calculations in SKB's research programme. I would therefore like to see a more concrete plan of action for how to evaluate these uncertainties and how to incorporate the uncertainties in the safety assessment. There does not seem to be any clear strategy for how to handle uncertainty. Uncertainties in the results of both measurements and modelling are handled thoroughly in some respects but not at all in others.

In the following I present some examples of problems which modellers often face and for which SKB should have a clear plan of action.

- Many of SKB's experiments are conducted on a small scale (µm-m). The results of these experiments are used in large-scale transport models (m-km), which usually requires an upscaling of the processes. What is the best way to do this?
- What general conclusions can be drawn from site-specific experiments? How large an area around a test site can be considered to be represented by one test?
- Many of the models that are used are highly complex and include a large number of parameters that must be calibrated. During calibration of the models there is a risk that changes in different parameters will lead to the same end result, a so-called equifinality problem. This means that the model may appear to compute correctly, despite the fact that it gives a false description of reality at the process level. What can be done about this problem?
- There does not appear to be a clear system analysis methodology for how best to determine which processes can be neglected or simplified in the models. Instead it is dependent on the modeller's expertise and the availability of data. Doing this in the best way possible is important not just for the models' performance, but also for the planning of new experiments and for how resources are to be allocated.

There are also other parts of the research programme that should be dealt with more consistently. One example is publication of research results in peer-reviewed scientific articles. Having your research results published in international scientific journals is a kind of quality guarantee. It is therefore desirable that SKB publish as many of its studies as possible. I have full understanding for the fact that it can be difficult to publish within certain areas, but in SKB's case it appears to depend rather on which research group has performed the study.

Another area where I would like to see more rigour and consistency is in the presentation of timetables. In most cases where future plans are presented it is not clear what is to be done immediately and what is further off in time. It would be desirable if the reviewers could be informed of the plans and be allowed to comment on them. Time and resources are always in short supply in the world of research, which is why it is an important part of the review to have a say about the order of priority both within and between different research areas.

21 ENGINEERED BARRIERS IN SFR

21.1.7 Hydrovariables and hydrological boundary conditions

SKB describes how the repository works both under current conditions (drained) and future (water-filled). But they do not present any evidence for their claims. Nor do they present any planned or completed investigations or experiments.

21.2.3 Freezing

The completed work that is presented in RD&D programme 2010 is based solely on literature studies and theoretical arguments; no laboratory experiments have been conducted. Planned studies include how the freezing properties of the concrete change with time and further investigations of the pore size of the concrete. It is not evident whether these studies will be based on new laboratory experiments or theoretical arguments.

21.2.4 Water transport

See 21.1.7

21.2.5 Two-phase flow/gas transport

The analyses of gas transport are based mainly on studies from Grimsel where gas transport has been studied through the concrete silo, the valve and the bentonite/sand barrier. But it would be desirable if SKB would explain how these studies can provide answers about long-term safety. SKB should, for example, study how long-term degradation of the valve and the bentonite/sand barrier affect gas transport.

21.2.14 Advection and mixing

SKB believes that advective transport becomes important when the concrete ages and its chemical and mechanical properties are altered. Consequently, they also believe it is important to study the consequences of this degradation in order to get a better understanding of radionuclide transport out of the repository in the aged concrete. They do not present any concrete plans for studying these consequences, however. No investigations or experiments have been done or are planned.

21.2.15 Colloid formation and transport

See 25.2.18-19

25. THE GEOSPHERE

25.2.3 Groundwater flow

Both SKI and the Swedish National Council for Nuclear Waste were satisfied overall with the studies of groundwater flow in RD&D programme 2007. This included both the development of new modelling tools and the site-specific investigations in Forsmark and Laxemar.

But there were certain shortcomings. Already in its review of RD&D-Programme 2004, the Council proposed that the magnitude of groundwater recharge should be determined by several independent methods. This was not studied in RD&D Programme 2007 and not implicitly in RD&D programme 2010, nor were plans made to do so there. What has been done that touches on this issue is that the amount of groundwater that reaches the tunnel system has been measured in the Äspö HRL by means of flow measurements in channels. Furthermore, the flow rates at repository depth have been estimated in model calculations.

The studies presented in RD&D programme 2010 have mainly adapted groundwater flow modelling to site-specific data. A high-conductive layer has been included in the upper part of the final groundwater model for Forsmark. This is an important development of the model which totally changes the flow pattern. SKB claims that the high-conductive layer dampens the importance of the topography for the groundwater flow pattern at great depth. However, it is important to point out that it is only the importance of the local topography that is limited. The main driver for the groundwater flow at repository depth is still the difference between sea level and the groundwater table in areas further inland.

In SR-Site and for site selection, the site models for Forsmark and Laxemar have been applied for the different periods included in the analysis, as was called for in the review of RD&D programme 2007.

The results of ongoing supraregional simulations were presented in RD&D programme 2010. A follow-up study with a focus on conceptual uncertainties was carried out here. But it is difficult to determine detail exactly what has been done, since the reference (/25-33/) is clearly incorrect. SKB has also carried out a study of the importance of local site characteristics for regional flow paths. In this study, a top boundary condition based on surface water runoff was used. The top boundary condition differs from previous studies in that it is based on groundwater infiltration and not as before on the location of the groundwater table. SKB claims that a so-called "flux boundary condition" is preferable to prescribed levels of the groundwater table. This is often true, but requires representative data for infiltration. SKB says they used surface water runoff, but it is unclear what they mean by that. This should be clarified. A study has been carried out to determine how the heavy salt water located below repository depth prevents flow paths from reaching down to even greater depths. This is an interesting study, and it would be desirable if this study would include conceivable spatial and temporal differences in the extent of the heavy salt water. An important question is how the flow paths from possible repository sites are affected by the heavy salt water.

SKB plans to investigate whether the ventilation air leaving SFR contains significant quantities of water, which could affect the calibration of the flow model. This is a welcome initiative that has been called for in previous reviews. Some improvement is also planned of the current handling of the surface water hydrology within the current version of DarcyTools. However, it is unclear what changes will be made and what the shortcomings of the current version are. This should be specified.

Other further development of DarcyTools and ConnectFlow is also planned for the coming period. However, it is highly remarkable that SKB says that this development will not affect the conclusions in SR-Site. Two questions may be asked: 1) Why focus on model development that is of no importance to SR-Site? 2) If the model development were to lead to significant discoveries, shouldn't these be included in SR-Site?

25.2.10-11 Advection/mixing

SKB has done a great deal of work on the uncertainties in the mixing models. Furthermore, an interesting study has been done of the causes and effects of channelling. This work appears to have been done well and will be significant for the SR-Site safety assessment.

SKB plans to carry out calculations of the evolution of salinity in connection with major climate change over long timespans. This will be an important component of SR-Site and it is therefore important that the work should progress.

SKB plans to install permanent groundwater stations and use new sampling methods in the Äspö HRL. The nature of the new sampling methods is not stipulated. This should be elaborated.

25.2.12-13 Diffusion

SKB has investigated matrix pore water in the Äspö HRL in the Matrix Fluid Chemistry Experiment. At present, however, there are no plans for further extensive analyses of matrix pore water.

SKB's is doing a lot of work on diffusion linked to radionuclide transport, including a number of different experiments with different methodologies. SKB has carried out the tests called for in the review of RD&D programme 2007. However, it should be clarified how the results of these tests will be used in the transport modelling where diffusion proceeds for thousands of years.

25.2.14-15 Reactions with the rock

The use of fracture-filling minerals to gain a better understanding of palaeohydrogeology is an interesting approach. But it appears to be a bit speculative, and some caution should be exercised before drawing too many conclusions from the method. The distribution of redox-sensitive fracture-filling minerals has been studied in Laxemar as well as in Forsmark. The purpose of the experiments has been to evaluate the risk that glacial meltwater will reach repository depth. SKB should further elaborate its arguments for the accuracy of this method, especially its sensitivity to changes of short duration (in the geological sense). Is it possible that the method could miss the presence of oxidizing conditions at repository depth during a number of centuries?

A great deal of work has been done to gain a better understanding of the relationship between Kd values and different geological parameters. However, no methods are presented for upscaling and ways to use the new discoveries in the transport models.

The Greenland Analogue Project is interesting and can hopefully provide important information on penetration of oxygenated water in glacial areas. However, a thorough study should be made of what conclusions from this study that also apply to a repository climate in a future climate.

An LTDE-SD experiment is planned in the Äspö HRL. It is expected to yield site-specific *in situ* K_d values. The results of this experiment only apply to one site, however. SKB should explain how this experiment can provide general knowledge regarding e.g. the difference between in situ K_d values and diffusion values.

25.2.16 Microbial processes

SKB has carried out extensive investigations of sulphate reduction. This is gratifying, since it was something that was called for in the review of RD&D programme 2007. Something that was also called for in that review was a description of microbial activity during periods of permafrost and glaciation. This has not been presented, but SKB plans to do so in SR-Site.

25.2.17 Decomposition of inorganic engineering material

See 25.2.18-19

25.2.18-19 Colloid formation

SKB has investigated the equilibrium concentrations for colloids from bentonite in both deionized water and synthetic Grimsel water. In order to understand how these concentrations relate to the erosion of the buffer, however, this work must be linked to the water flux. This is something that appears not to have been done but that absolutely should be done.

Radionuclide transport with colloids is being modelled in SR-Site. Both reversible sorption on colloids and irreversible sorption on bentonite colloids are being studied within the framework of SR-Site. There are great uncertainties regarding the quantity of colloids formed, how they are transported and how the radionuclides are sorbed to the colloids. SKB should describe how these uncertainties are handled in the transport calculations.

SKB's planned work includes both development of modelling tools for incorporating radionuclide transport with colloids, and studies to gain a better understanding of the specific driving processes behind bentonite erosion and colloid formation. This area is very important and should be prioritized.

25.2.21 Methane ice formation

SKB is conducting a number of investigations to establish the occurrence of methane ice. However, no investigations are presented concerning the effect of methane ice on the repository.

25.3 MODELLING

25.3.1 DFN

SKB has taken into account more parameters in order to narrow the range of outcomes and reduce the number of model variants. This methodology is appropriate and necessary, but SKB should explain how uncertainties in measurements and conceptualizations are handled.

The planned programme for DFN modelling is extensive and includes a number of important points. What would be desirable is a clearer timetable indicating which programme points are imminent and which are further off in time.

25.3.2 Integrated modelling – thermo-hydro-mechanical evolution

SKB's research in this area is described in detail in sections 25.2.4 and 25.2.6-9. I have not examined these sections closely.

SKB plans to further develop the DFN modelling and take into account possible (T)HM-coupled applications. In addition, they plan to carry out brittle-tectonic generic modelling in a relatively homogeneous crystalline rock type. The goal is to simulate typical conceptual fracture patterns that can occur in the Baltic Shield. This is an interesting approach which, despite the difficulty of evaluating it and drawing practical conclusions from it, is nevertheless a method that should be further developed.

25.3.3 Integrated modelling – hydrogeochemical evolution

The code M3 is used for this hydrochemical modelling. The reasonableness of the results is checked by alternative modelling runs, for example geochemical simulations with the code PHREEQC. It is unclear how the PHREEQC modelling is done. There are numerous different possible interpretations, which is why more conceptualizations and models should be compared.

With the aid of models that couple hydrogeology with reactive transport, SKB says it can reproduce the most important hydrochemical trends found in the Laxemar site investigation. This of course indicates that SKB has developed good methods for modelling the system. However, I see two points that need clarification. 1) SKB says nothing about Forsmark. Have they not done the same model description there or have they not succeeded in reproducing the actual conditions? 2) SKB calibrates the hydrogeological models for Forsmark and Laxemar by comparisons between calculated results and chemical field data. Are these the same chemical field data they then claim to be able to recreate in Laxemar? In principle, this means they are validating and calibrating the model with the same data. The model should of course be evaluated against a data series that has not been used for calibration.

SKB advocates the use of streamline simulation, where the geochemical processes are added along flow lines calculated with the hydrogeological models. SKB should then also explain how they intend to take into account temporary differences in the geometry of the streamlines.

25.3.4 Integrated modelling – radionuclide transport

It is good that SKB has studied the question of how results from retention experiments conducted during a limited timespan (months–years) are to be transferred to transport models for long-term safety.

Models that couple hydrogeochemistry and radionuclide transport have been developed and tested, specifically the code Fastreact. This work is reported within the framework of SR-Site. The methodology is based on the use of streamtubes obtained from hydrogeological modelling. SKB should then also explain how they intend to deal with the fact that the streamtubes will change with time, due e.g. to the ongoing process of land uplift.

According to SKB, the integrated transport modelling can handle radionuclide transport with respect to the whole system, i.e. groundwater flow, geochemical reactions and radionuclide transport in both geosphere and biosphere. How this will be done is not described in greater detail, however. If they plan to construct a single model to represent the entire transport system, it will have to handle certain processes in a highly simplified manner. If this is the case, SKB should describe how these simplifications will be done and what they entail for the system being studied. It is, however, more likely that they plan to weigh together the results from several different models. However, it is unclear how the different models will be used in the safety assessment. There should be a clear plan for how the results of the different models will be weighed together. Furthermore, the timetable is unclear (what is meant by “eventually”?).

26 SURFACE ECOSYSTEMS

27.6 Aquatic ecosystems

According to SKB’s analyses, only a small fraction of the carbon that is fixed by primary producers in the lakes is carried further in the food webs to the top consumers. Most of the carbon circulates in the microbial food webs and is returned to the water mass or bound in organic sediments. SKB does not clarify whether these conclusions are based on model calculations or whether they are also supported by measurements. This needs to be clarified.

The flow models that are used in the ecosystem modelling show that a lot of material is accumulated in the lake sediments. Do these results agree with the results from the MIKE-SHE modelling? Are these different models coupled in any way?

Certain radionuclides bind strongly to particles. A large fraction of the radionuclides therefore accumulate in the sediments in the ecosystem models. Two important processes for radionuclide transport in these environments are therefore sedimentation and resuspension. The processes should therefore be quantified by both model calculations and measurements.

SKB plans to validate its model descriptions with existing field data from Forsmark. These models are complex and have great uncertainties in input data as well as in parameters that cannot be measured. Evaluating and validating the model calculations is therefore a difficult task. The spatial heterogeneity is great, it is uncertain how the areas will evolve, and there are parameters that cannot be measured directly. It is important to have a clear plan for how these models are to be evaluated. This plan should also include sensitivity and uncertainty analyses.

Within the framework of the ecosystem modelling, SKB should study how the construction of the repository will affect the nearby aquatic ecosystems. It is remarkable that this has not already been done and does not appear to be planned either.

26.6 Hydrology and transport

The hydrological modelling is done using the calculation tool MIKE SHE, which represents a number of transport pathways in rock, soil layers and the surface water system. Transport of radionuclides bound to particulate matter can be of great importance. Sediment transport is therefore an important process that should be studied more. Sedimentation processes had high priority in RD&D Programme 2007, but in RD&D Programme 2010 they are conspicuous by their absence. No investigations are planned concerning sedimentation processes. This should be explained, either by saying that the question has already been sufficiently studied or that the processes are considered to be irrelevant.

SKB has a sophisticated programme for evaluating the model calculations. The calculation results are supported by a large body of data from hydraulic tests in groundwater monitoring wells, flow measurements in streams and water level measurements in groundwater and surface water, which have been used for comparisons between measurements and calculation results in model calibrations and sensitivity analyses. These models are so complex that there is a risk in the evaluation of the model that changes in different parameters will lead to the same end result, a so-called equifinality problem. This means that the model may appear to compute correctly, despite the fact that it gives a false description of reality at the process level. SKB should present a plan for how such problems can be avoided.

SKB says quite rightly that discharge often takes place in lakes and wetlands, making it particularly important to understand the connection between surface water and groundwater in the saturated and unsaturated zones in the soil in such areas. The conditions around lakes and wetlands have therefore subsequently been subjected to special study by both data evaluation and numerical modelling. Similar studies should be done for watercourses, which are also discharge areas for groundwater and which furthermore interlink different wetlands and lakes.

Detailed studies of specific hydrological objects are being done in the ongoing safety assessment in order to develop and calculate parameter values for the models for the landscape objects in Forsmark. It should also be of interest to study other types of lakes, wetlands and watercourses that may occur in other climate situations.

SKB is funding a research project in connection with the Krycklan catchment study where radionuclide transport associated with wetlands is being studied. This is an exciting and undoubtedly fruitful project, but references are lacking (the only reference is from a master thesis dealing with another area), which makes it difficult to conduct a more thorough review. SKB plans to link newfound knowledge from the Krycklan catchment study to SKB's investigation areas, i.e. to evaluate what results and conclusions might also be valid in Forsmark and Laxemar-Simpevarp. It would also be desirable to conduct similar site-specific studies in e.g. Forsmark in order to verify regional differences.

Researchers at Stockholm University have conducted extensive studies based on data from Forsmark and Laxemar-Simpevarp. It is unclear how the studies will be used in SKB's safety assessment. A plan for this should be prepared and presented.

The process-based modelling of advective-reactive radionuclide transport has so far only been carried out for the water-saturated portion of the soil layers. The continued work will also include the soil's unsaturated zone and key processes such as uptake in plants. In order to gain a better understanding of the process, it is important to learn more about soil layers that are alternately saturated and unsaturated.

SKB plans to continue its work of characterizing the size and location of discharge areas and the processes that drive transport there. They intend to study specific hydrological objects that represent all succession stages in landscape evolution, from marine basins via eutrophic lakes to wetlands and watercourses. This is an incredibly important research area (in my personal opinion the single most important one in the entire safety assessment), which should be given priority.

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LUNDS UNIVERSITET

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Department of Earth and Ecosystem Sciences
Division of Geology
Professor Per Möller

Swedish National Council for Nuclear Waste
Att: administrative director Holmfridur Bjarnadottir
M 1992:A
SE-103 33 Stockholm, Sweden

Postal address: Geocentrum II
Sölvegatan 12
SE-223 62 Lund
SWEDEN
Telephone: direct +46 222 98 88, exchange +46 222 00 00
Telefax: + 46 222 48 30
E-mail: per.moller@geol.lu.se
Website: http://www.cgb.lu.se; http://www.geol.lu.se

Review of "Climate evolution" (Chapter 19) in SKB's RD&D programme 2010

It can initially be observed that considerable progress has been made between RD&D programme 2007 and the present report (RD&D Programme 2010) in the description and understanding of the evolution of the climate during the most recent glacial cycle (the Weichselian).

19.1 Climate evolutions in SKB's safety assessments

In RD&D Programme 2010, future climate evolution scenarios get a much clearer description with the introduction of a so-called "reference evolution" based on the preceding glacial cycle (Weichselian) as a model for a future glacial cycle and its chronology and gradual progression through different climate domains (temperate, periglacial and glacial). At the same time, a very important observation is made: the actual evolution of the climate in time and space during a future glacial cycle is not the most important factor from a safety point of view for a final repository for nuclear waste. What is more important is that the repository meets the safety requirements for the stipulated climate domains, regardless of their chronological sequence. Also positive is the understanding that a future glacial cycle does not have to conform exactly to our current knowledge of the Weichselian period – which is by no means complete. Greater or lesser ice thicknesses than during the Weichselian are important as alternative scenarios, as is the fact that present-day and future anthropogenic impact on the atmosphere may have a great impact on climate variation and ultimately result in considerable aberrations in glacial development compared with the postulated "reference evolution".

19.2 Ice sheet dynamics and glacial hydrology

A thermodynamic ice sheet model was used in RD&D 2007 for a reconstruction of the extent of the Weichselian glaciations over Fennoscandia, mainly based on climate data taken from e.g. ice core archives and sea level change data, in contrast to an "inverse" modelling, which is based on geological "limit values" in the form of known, dated ice advances determined by e.g. ice margin positions and dated stratigraphic sequences. It was noted that the weakness in the modelling according to the first alternative was known, but the lack of good geological data, particularly regarding the Early and Middle Weichselian, made it difficult to construct other scenarios for glacial extent during these periods, since this takes us beyond the dating limit of the 14C method. It is, however, stated in the RD&D programme for the coming year that "SKB plans to study the course of events during specific parts of the most recent glacial cycle in Scandinavia in order to reduce the current uncertainty in the geological interpretations. Datings and correlations of existing interstadial sediment samples and stratigraphies from selected key localities in Sweden are therefore planned."

Pages 209-213 describe how this plan has been implemented, and the text summarizes a large number of reports in this area, an impressive performance which also resulted in a theme section in the international journal Boreas (vol 39, 2010) (references in RD&D 2010: 19-2; 19-3; 19-4; 19-5; 19-6; 19-9). However, the 3rd paragraph on page 209 contains a very peculiar formulation as an introduction to the account: "The average extent of the continental ice sheets during the Quaternary Period was, however, much less than that; *on average, the areas around Forsmark and Oskarshamn were in all probability ice-free*". I might as a specialist be able to understand what this sentence refers to (probably that during a glacial cycle of normally 100,000 years, the areas mentioned are only covered with ice for a small portion of such a period), but it must be very difficult for anyone else to understand what is meant.

A brief summary of glacial evolution over Fennoscandia is provided on pages 210-211, based on the research described in the above references. Special emphasis has been placed on the so-called MIS 3 (Marine Isotope Stage 3), c. 60,000-30,000 years before present. Even before the programme period it was established that contradictory evidence existed for the extent of the ice sheet during this relatively long period of time: (i) the classic picture that most of Fennoscandia was more or less covered with ice during this period, versus (ii) indications that the extent of the ice during the same period was much smaller than previously thought, necessitating a revision of the classic picture. The revision presented here as a fact is that it has been more or less established that ice-free conditions existed in large parts of Fennoscandia – and thus in Sweden during MIS 3. My view is that this picture has not in any way been irrefutably established. For some reason, no reference is made in RD&D 2010 to Houmark-Nielsen's (2010) paper in the above-cited volume of *Boreas*. Geological data, as well substantiated in stratigraphy and chronology as the data presented in the references 19-3/19-4/19-5/19-9/19-22/1925 (see reference list in the RD&D report), completely contradict the notion of these latter references regarding the extent of the ice sheet during MIS 3. Houmark-Nielsen's (2010) palaeoenvironmental reconstructions show two large glacial advances along the Baltic depression up to and over Denmark during this period (*Ristinge advance,* c. 50±5 kyr and *Klintholm advance,* c. 32±4 kyr). The same scenario is revealed in recently completed investigations in Småland (Möller, 2010).

The current state of research, as I see it, is thus that there are still two opposing glaciation models, one of which might be wrong, due to the uncertainty of the datings of geological successions used in both models. These two endmember scenarios give completely different timescales for ice extent during the c. 30,000 years encompassed by MIS 3. Another alternative is that both scenarios are correct in part, i.e. two glacial advances during MIS 3 combined with rapid deglaciation and ice-free conditions in central and northern Scandinavia in between. In such a scenario we have to greatly revise our notion of the dynamics of advance and retreat in different phases of the Fennoscandian ice sheet. I would thus like to emphasize strongly that the current state of research is not as clear as RD&D 2010 would have us believe in this section (and later in Chap. 19.5).

Ideas introduced in RD&D 2007 – that SKB is planning to initiate a project on Greenland (GAP, Greenland Analogue Project) aimed at using the Greenland ice sheet as an analogue for hydrological and geochemical conditions in particular – are further elaborated on under "*Programme*" . The description of plans for future work – including extensive ice sheet modelling linked to basal hydrogeology, combined with simulations of the areas in question in Sweden – are promising (see 19.6).

19.3 Isostatic changes and shoreline displacement

Of fundamental importance here is the previous report TR-06-23 (SR-Can), where a great deal of work has been devoted to predicting future sea level rise, forecast from available land uplift data and modelling. In the interim period up to RD&D 2010, the questions have been expanded and deepened in an excellent manner (ref. 19-15; 19-16). The problem of sea level rise up to 2100, which could ultimately mean a higher groundwater level during the construction period for the final repository, has also been taken into consideration (ref. 19-17).

The proposed programme for refinement of predictions of sea level rise in different scenarios for a warmer climate is excellent.

19.4 Permafrost growth

The ambitious programme proposed in RD&D 2007 for prediction of permafrost growth and its importance for hydrogeological interaction with the final repository during the "periglacial climate domain" has apparently been implemented in an excellent fashion.

19.5 Climate and climate variations

Promised projects aimed at providing a more nuanced picture have been carried out and reported as planned. The results of the cited palaeoclimatic study at Sokli in northern Finland (ref. 19-5 and several other related ones) are naturally spectacular, but the conclusions of this study might be in conflict – as I noted under 19.2 – with other studies in southwestern Scandinavia, which means that the climate scenario for MIS 3 may not be as clear as alleged in RD&D 2010.

Another project with a focus on climate modelling over a 100,000-year cycle for the purpose of describing extremes within which the climate can vary has resulted in a very ambitious and excellent report, as well as international publication. However, the problem remains that the input data for the modelling conflict with the data and interpretation regarding ice extent in SW Scandinavia during MIS 3.

Climate modelling for the early Weichselian and for the Holocene is planned in the programme for the upcoming period, which is excellent. Scandinavia during the early Weichselian had a much smaller ice sheet, with a more northerly/westerly extent, and I don't see any conflicts here in proxy data from southern Scandinavia.

19.6 Greenland Analogue Project (GAP)

The GAP project announced in RD&D 2007, aimed at "better process understanding in order to be able to better create conceptual and numerical models of groundwater flow, groundwater chemistry and hydromechanical factors during glacial periods" by studies in an area of the Greenland ice sheet as an analogue for glaciation in Scandinavia, more specifically the Forsmark area, is an excellent and exciting initiative which has been implemented in the intervening period. The somewhat vaguely described programme in RD&D 2007 has been elaborated into a multinational and diversified project. The questions enumerated on p. 219 are highly relevant to a safety assessment of a planned final repository.

The only results obtained thus far appear to be reports from various meetings and symposia. The project is planned to be finished in 2013. It would have been interesting to get a more detailed picture of the project management and organization for this large number of participants.

Reference cited in the text:
Möller, P., 2010: Subtill sediments on the Småland peneplain – their age, and implications for south-Swedish glacial stratigraphy and glacial dynamics. *LUNDQUA Report 40,* 16 pp. Lund University, Department of Earth and Ecosystem Sciences, Division of Geology/Quaternary Sciences. (Final report to SGU for R&D project at SGU)

Viewpoints on selected parts of SKB's RD&D Programme 2010

Professor Ove Stephansson

Steph Rock Consulting

Berlin

March 2011

Contents

Summary

This report offers viewpoints on all parts of RD&D programme 2010 except Part IV “Social science research”. The structure of the individual parts of RD&D 2010 bears great similarities to the account in the RD&D programmes of recent years, aside from the sequence and the headings of the individual chapters and sections. SKB provides a more detailed description of the LILW programme in RD&D 2010, compared with previous RD&D programmes.

Part I Overall plan of action

SKB is currently changing its organization from previously having been a purchasing organization with a few experts in certain special technical fields to becoming an organization that operates and manages nuclear facilities. RD&D programme 2010 does not clearly explain this change at SKB and what the current and future organization of its operations looks like.

Thermal expansion of the rock and stress increases at deposition level can lead to fracturing and associated seismic activity around the final repository. With what we know today, the possibility of seismic activity being generated by the final repository at the same time as nuclear power reactors are in operation on the ground surface cannot be ruled out. If in the future another final repository is built below the one now planned as, described by SKB as a possibility, the heat from the first repository would spread downward and be added to the heat from the deeper repository, leading to a higher rock temperature and thermal stresses on the lower repository level. The heat emitted by the lower repository will also raise the temperature in the upper repository. The increased volume of high-temperature rock will also increase the probability of greater seismicity in the area.

Part II The LILW programme

According to current plans, an extension of SFR will be served by an additional access tunnel situated next to the existing one. In conjunction with the excavation of the new tunnel, SKB should try to make passages through the Singö Zone for all tunnels that are more watertight than the present-day construction and operating tunnels to the existing facility.

In conjunction with the planning and design of the extension of SFR, SKB should intensify its work of investigating and determining the backfilling of the different rock vaults and settle on a method for closure of the facility.

Part III The Nuclear Fuel Programme

RD&D programme 2010 does not specify any step before or during integrated testing, for example a major heater test performed in the principal rock type at repository level under relevant stress state. It is of utmost importance to get an idea early in the project of the response of the rock mass to the boring of deposition holes, the response of the buffer to the dry conditions that are expected to prevail at repository depth and the spalling failures that can occur as a consequence of the thermal load.

SKB has the ambitious objective of being able to simulate all activities at the Spent Fuel Repository. This objective is commensurate with the demands made by regulatory authorities and the public on the long-term safety of the repository and on the traceability of information on the activity during construction and operation.

The Spent Fuel Repository will be one of the first major underground projects in Sweden where the new Eurocode and its Observational Method will be applied. Bearing this in mind, SKB bears

an extra responsibility for ensuring that the method and its applications are implemented correctly among concerned consultants and contractors as well as SKB's personnel.

Regarding the work on rock mechanics, SKB quite rightly points out that one of the most important remaining uncertainties in the site model for Forsmark concerns the mechanical stress state. SKB has presented a model of the rock stresses that is essentially based on measurement data from the overcoring method and which for the deposition level in the final repository is largely based on old measurement data from the time of construction of the reactor building for Forsmark 3. SKB has chosen to rely more on the overcoring and an equivalent high-stress model for Forsmark. The magnitude and orientation of the stress field in Forsmark is better suited for a repository according to the KBS-3H method than a KBS-3V repository.
Radar surveys with the GPR method have proved to be a good method for continuous recording of the EDZ in tunnels. The method has been used in the fine sealing tunnel in the Äspö HRL, and the results indicate that blasting will probably create a continuous transmissive zone with a depth of about 0.5 m along the tunnel wall. The zone with EDZ will enhance the groundwater flow in the walls of the tunnels.

Part IV Research for assessment of long-term safety
SKB has developed a new calculation model that makes it possible to bound the pressure increase for a given temperature in a system of frozen bentonite. The pressure from the freezing of the bentonite in the buffer can damage the rock around the deposition hole. SKB has estimated the maximum pressure at the lowest possible temperature to be 26 MPa. The pressure increase as a result of freezing considerably exceeds the tensile strength of the intact rock in Forsmark. The damage that can occur is completely dependent on the initial state of stress in the rock mass, where a higher stress (according to SKB's stress model) counteracts fracturing and fracture propagation. With current knowledge of the spalling failures caused by the thermal load (which occur with certainty in the stress model presented by SKB) and the swelling pressure from the buffer, it is difficult to estimate how the situation with earlier fracturing and stress relief has disturbed the rock around the deposition holes when permafrost forms and freezing generates swelling pressure. Growth of the excavation-damaged zone is most likely.

SKB argues that the possibility of fracture propagation and coalescence of already existing fractures in the near-field around the deposition holes cannot be completely disregarded, in part because the area around the holes is subjected to compressive stresses. SKB says that tensile stresses are required at the fracture tips in order for propagation to occur. But this is not true. Recent modelling with the fracture mechanical code FRACOD has shown that fracture initiation, fracture propagation and coalescence of already formed fractures take place in the near-field of the deposition holes for favourably located fractures with respect to the stress field of a typical fracture network model from Forsmark. The fracture propagation takes place under the thermal load, and particularly in conjunction with glaciation (Backers and Stephansson, 2010). Fracture initiation and propagation tend to occur as shear fractures (Mode II) and not as tension fractures, and the result can lead to instability, longer flow paths and increased flow around the deposition holes.
The greatest uncertainty when it comes to assessing the risk of spalling failure is heat transport in the deposition holes, and in particular the influence of the degree of water saturation of the rock. This assessment is verified by the CAPS field experiment, where the test holes in wet rock resulted in more spalling failures compared with dry boreholes. This means that SKB must develop design criteria for deposition in rock with differing degrees of water saturation and determine the thermal parameters as a function of the water content.

1. General observations

This report offers viewpoints on all parts of RD&D programme 2010 (RD&D 2010) except Part IV, "Social science research". The structure of the individual parts of RD&D 2010 bears great similarities to the account in the RD&D programmes of recent years, aside from the sequence and the headings of the individual chapters and sections. SKB provides a more detailed description of the LILW programme in RD&D 2010, compared with previous programmes.

During the month of March 2011, SKB plans to submit an application under the Nuclear Activities Act for a licence to build the Spent Fuel Repository and an application under the Environmental Code for the KBS-3 system. The site investigations for the Spent Fuel Repository have been completed, and in June 2009 SKB selected Forsmark as the site of the final repository. SKB expects to start the work of building the Spent Fuel Repository and the encapsulation plant in 2015-2016 and to begin trial operation of the repository and Clink in 2025. With the current planning horizon, the repository is expected to be closed in about 75 years. Since the planning premises will almost certainly change over the years, SKB has included some flexibility in its planning, for example the possibility that the repository may be extended with an additional deposition level beneath the planned one.

The publication of RD&D 2010 and the application for a licence to build the Spent Fuel Repository are close to each other in time. For this reason, SKB has chosen to present certain results from investigations and studies in the coming application instead of reporting results and conclusions in RD&D 2010. This includes the choice of method for rock excavation in the facility. This does not mean so much in practice, since both RD&D 2010 and the application will be reviewed by the regulatory authorities, but it makes it more difficult to assess the overall state of knowledge in SKB.

SKB is currently changing its organization from previously having been a purchasing organization with a few experts in certain special technical fields to becoming an organization that operates and manages nuclear facilities. This change at SKB and what the current and future organization of its operations looks like is not evident from RD&D 2010. The question of whether SKB has necessary and sufficient competence to operate and manage the various nuclear facilities and their different systems cannot be answered on the basis of the RD&D programme.

The total scientific and technical content of SKB's work as it is reported in RD&D 2010 is very extensive and shows that SKB is a major scientific producer and user in a wide variety of technical and scientific disciplines. SKB also has a strong international position in the sector and is participating actively in a large number of national and international projects and studies of a high scientific standard. SKB has also understood the value of publishing its own results in international scientific media over the years. Many examples of this can be seen in the more than 700 references provided in RD&D 2010.

2. Important technical and scientific comments

Part I Overall plan of action

1.4 Competence and organization

In this section, SKB explains how the work organization for the project has changed from being a typical management organization with a number of experts who have led and managed the work to now being a broader executive organization that runs its own facilities for disposal of the Swedish nuclear waste. The RD&D programme does not have any organization charts showing how SKB has organized its new activities, and in particular how the organization is being built up until such time as the Spent Fuel Repository, the extension of SFR and Clink are put into operation.

2.1 Main timetable

In Figure 2-1, SKB shows the overall timetable for the entire nuclear waste programme as well as when SKB plans to submit applications and other statutory reports. The timetable does not show when SKB intends to submit updated safety assessments after trial operation and routine operation for both the Nuclear Fuel Programme and the LILW programme. When it comes to the extension of SFR, SKB shows a detailed timetable for the PSAR and the SAR up to the start of routine operation in Figure 5-2.

3.2 New nuclear power reactors

In this section of the RD&D programme, SKB describes possible and conceivable changes in the nuclear power stock and the consequences of these changes for SKB's facilities in the future. If new reactors are phased into the current system, the operating time for nuclear power will increase to about 130 years, assuming that the new reactors are utilized for 60 years. SKB reports two possible examples of how the nuclear waste can be managed in the event of an expansion of the programme.

In the first example it is assumed that the replacement reactors have the same net capacity as today's system and that this requires a final repository of roughly the same size as the one planned in Forsmark. SKB is then prepared to investigate the possibility of building an additional level in the planned final repository after the latter has been filled and closed. Such a solution has two effects on the stability of the rock in the final repository area. The first effect is that the heat from the first canisters deposited in the planned repository will result in a maximum temperature and stress increase during the stated operating time of ca 130 years. In the event SKB plans to build an additional final repository beneath the planned one, this will change the premises for the planning and design of both final repositories. This is commented on further under section 15.3 of this review.

Thermal expansion of the rock and stress increases at deposition level can lead to fracturing and associated seismic activity around the final repository. With what we know today, the possibility of seismic activity being generated by the final repository at the same time as the nuclear power reactors are in operation on the ground surface cannot be ruled out. The second effect of building another final repository below the one now planned is that the heat from the first repository would spread downward and be added to the heat from the deeper repository, leading to a higher rock temperature and thermal stresses on the lower repository level. The heat emitted by the lower repository will also raise the temperature in the upper repository. The increased volume of high-temperature rock will also increase the probability of greater seismicity in the deposition area.

Temperature changes in the rock mass will change the state of stress, which could lead to deformations in existing fractures and faults in and around the final repository. The altered stress state could generate earthquakes. As a result of the increased interest in geothermal energy in rock as a source of heating, more and more ground source heating projects are being planned, tested and put into operation, particularly in areas with high geothermal energy in the Earth's crust, for example the old spreading zone in the Rhine valley of Germany, Iceland and other volcanic areas and Australia with sediment-covered granite areas like Cooper basin in South Australia. In all cases, a change in the temperature conditions in the well areas due to the injection or withdrawal of water will cause an increase in seismicity. A certain portion of the increased seismicity is also ascribed to the altered pressure conditions in the fractures and fault systems affected by the injection and withdrawal of water. A change in the temperature or pressure conditions changes the stress field, and this change generates earthquakes.

Up to now, SKB has not reported on the risk of seismicity in the repository area caused by the thermal load in the final repository and how this seismicity and its magnitudes can be expected to change over time. The need to investigate this is even greater if SKB plans to build another repository beneath the planned Nuclear Fuel Repository in Forsmark. If SKB's theory of high rock stresses in Forsmark is confirmed and the planned stress measurements in the access tunnel, shafts and central area show that this is the case, this could lead to rock engineering problems in building another final repository beneath the planned one. The elevated stress field at greater depth, together with the thermal stresses, also increases the chances that earthquakes will be generated.

Part II The LILW programme

5.4 Technology development for the final repository for short-lived radioactive waste

SKB has completed an initial layout and presented a general structure for production of design basis documents (Figure 5-5) for the extension of SFR. The design of the extension in terms of the number of rock vaults and their location has not yet been finalized. According to the current plans, an extension will be served by an additional access tunnel situated next to the existing one (Figure 5-6). The new access tunnel connects to the rock vaults, which are located southeast of the existing facility. In conjunction with the excavation of the new tunnel, SKB should try to make passages through the Singö Zone for all tunnels that are more watertight than the present-day passages for the construction and operating tunnels to the existing facility, see further section 21.1.

SFR has now been in operation since 1988. In conjunction with the extension, it is assumed that the operating systems for the old and new facilities will be coordinated and that many of the fittings and fixtures in the old facility will be replaced and that shared functions and equipment will be coordinated, for example ventilation and drainage.

In conjunction with the planning and design of the new facility, SKB should intensify its work of investigating and determining the backfilling of the different rock vaults and settle on a method for closure of the facility. This information should serve as a basis for the upcoming safety assessment prior to the licensing of the facility. According to SKB's plans, construction of the extension will begin in early 2017.

Part III The Nuclear Fuel Programme

8.2 Main phases and timetable

The Nuclear Fuel Programme consists of two parts, the Spent Fuel Repository and the encapsulation plant Clink, and both construction projects are users of the technology development taking place in the KBS-3 system. The Nuclear Fuel Programme in SKB is the purchaser of the facilities. There is no organization chart here showing how SKB has organized the execution of the two facilities and how coordination will take place organizationally between the two programmes during construction and operation.

In 2006, SKB submitted an application for a licence to build the encapsulation plant, and since the application is under review by the regulatory authorities the description in RD&D programme 2010 is also somewhat limited. The timetable presented for the Nuclear Fuel Programme's two facilities is illustrative and clear.

8.3 Encapsulation

In section 8.3.2, which deals with the construction of Clink, SKB describes how Clab will continue to be operated throughout the construction of the encapsulation plant, and that valuable experience will be gained from the extension of Clab2. The operation of Clab1 continued throughout the extension of Clab2. An important component in the monitoring of Clab1 and its condition during the blasting work for Clab2 was the seismic monitoring system that was built up and used to check the function and effects of the blasting work on the function of the existing facility and possible excavation damage. Extensive rock excavation directly above the existing rock caverns in Clab will be required for the construction of Clink. For monitoring of the function and condition of the existing facility, a similar seismic system system is recommended during the excavation work for Clink.

8.4 Final repository

The final repository presented by SKB and illustrated in Figures 8-4 and 8-5 is the result of a series of site descriptions and facility designs which have led up to the site-adapted final repository solution presented. The animation and the exploded drawings that show the fully built final repository (Figures 8-4 and 8-5) and the exploded drawings that show the facility at different stages of construction (Figures 8-6, 7 and 8) are of good quality and convey an accurate picture of how the facility gradually emerges until the time the central area is excavated.

In section 8.4.2, "Construction", SKB describes how investigations will be conducted for the first deposition area, how a deposition tunnel will be driven and how the first deposition holes will be bored. The purpose of finishing parts of the first deposition area while the central area is being excavated is to gather geoscientific information as a basis for a safety analysis report prior to trial operation. The finished area after integrated testing is used later for deposition. RD&D programme 2010 does not specify any step before or during integrated testing, for example a major heater test performed in the principal rock type at repository depth under the relevant stress state. It is of the utmost importance to get an idea early in the project of the response of the rock mass to the boring of the deposition hole, the response of the buffer to the dry conditions that are assumed to prevail in the repository and the spalling failures that can occur as a consequence of the thermal load.

In the Finnish nuclear waste programme, various geoscientific tests are being conducted in niches blasted out from the access tunnel in the deepest parts of the access tunnel to ONKALO and in rock that mimics conditions in the future repository. The results of the heat test that is in the process of being started will lead to modifications of the deposition method, technology and material that need to be taken into account in the safety analysis report prior to trial operation.

In section 8.4.4, "Work methodology during construction and commissioning," SKB describes the main processes Safety Assessment and Construction. The safety assessment provides the control with requirements and restrictions required to build a safe facility. The headings "Inspection" and "Inspection programme" are lacking in the part of the Main Processes that concerns Construction.

SKB should present a compilation of all critical tests and possibly long-term tests that need to be carried out within the different geoscientific disciplines for the safety analysis report prior to trial operation.

9.2 Control and reporting

Chapter 9 of the RD&D programme provides an overview of technology development for the Spent Fuel Repository. After a brief description of the premises of technology development, where the objective is to find solutions that are adapted to an industrial process, SKB describes the delivery control model, which is a methodology developed in the Nuclear Fuel Programme for control of technology development. In the delivery control model, technology development is divided into the following phases: concept phase, design phase, implementation phase and administration phase. A description of the individual phases is provided in the RD&D programme. During the implementation phase and/or the initial part of the administration phase, the inspection programmes for systems, components and processes that will be used during the administration phase should be established. In the work of developing the delivery control model, SKB has omitted the establishment of inspection programmes with recurrent inspections. This is a shortcoming which SKB should rectify.

9.3 Technology development needs

In section 9.3.6, "The closure line," SKB describes in general terms what technology development is needed for closure of the Spent Fuel Repository when all spent fuel has been deposited. SKB points out the importance of proper design of rock excavation in the access tunnel to ensure an expedient closure. Here SKB can learn from the shortcomings in the tunnelling of the access in ONKALO in Finland. During the initial 100 m or so of the tunnelling in ONKALO, the contractor used an obsolete drilling rig with old alignment instruments, resulting in overbreak and a very uneven tunnel contour. When a modern drilling rig was brought in for the tunnelling work, there was a considerable improvement of the tunnel contour. It is of the utmost importance for the Spent Fuel Repository and safety that machinery, equipment and personnel have been optimized when the rock works begin.

In the area of rock excavation equipment, SKB asserts that such equipment needs to be further developed, but that the machines that are available today for rock excavation and grouting of the accesses have the potential to meet the requirements. SKB needs to better specify what additional requirements will be made on the machines that will be used for rock excavation at deposition level in the Spent Fuel Repository.

SKB goes on to say that documentation of where and how the tunnels have been built in the Spent Fuel Repository will be important for safety analysis reporting. This information is also of the greatest importance for an account of safeguards for the final repository.

SKB mentions in section 9.3.7, “The rock line,” that application of the Observational Method will be particularly important in determining the positions of the deposition holes in the deposition tunnels. This is a correct conclusion. In section 9.3.8, “Production system and logistics,” SKB says that production systems that are used today in the mining industry are of particular interest to SKB due to the great similarities between the final repository and a mine. This conclusion is correct, and the fact that Sweden still has strong technology development in the mining industry can undoubtedly be of help to SKB.

In RD&D programme 2010, SKB presents a preliminary structure for the production system for the final repository (Figure 9-2). The subdivision into headings and subheadings presented is not logical or convincing and needs further work.

SKB has the ambitious objective of being able to simulate all activities at the repository and has during 2009 surveyed existing software that could satisfy SKB’s requirements. This objective is commensurate with the demands made by regulatory authorities and the public on the long-term safety of the Spent Fuel Repository and on the traceability of information on the activity during construction and subsequent operation.

For more than a decade, Posiva and SKB have jointly pursued development work on horizontal deposition, KBS-3H. In section 9.3.9, SKB states that horizontal deposition according to the KBS-3H method can constitute an alternative to vertical deposition. At the beginning of Chapter 16 in RD&D programme 2010, SKB mentions that vertical deposition according to KBS-3V comprises the reference design, but that SKB is also exploring the possibility of switching to horizontal deposition according to KBS-3H at a later stage. This can be interpreted as meaning that the KBS-3H method should not be regarded as an alternative deposition method such as e.g. Deep Boreholes.

In section 27.2, SKB presents the current state of knowledge with regard to Deep Boreholes as an alternative method to the KBS-3 method. SKB repeats its assessment from previous RD&D programmes that that disposal in deep boreholes is not a realistic method for final disposal of spent nuclear fuel. SKB is nevertheless following the development of technology for drilling and disposal in deep boreholes. SKB will also carry out a comparative study of disposal in deep boreholes and the KBS-3 method, which is positive news.

12.2 Current situation and programme for technology development, buffer

In this section, SKB describes a reference design for the buffer (Figure 12-1). The total length of the parts of the deposition hole encompassed by the buffer is 6.7 m. According to the criterion for FPI (Full Perimeter Intersection) and EFPC (Extended Full Perimeter Criterion) with regard to individual fractures in the rock mass around the deposition hole, the deposition hole is disqualified if one and the same fracture intersects five or more deposition holes. A paper recently published by A. Hedin (2010) in the journal "Mathematical Geosciences" describes an analytical and semi-analytical solution to the stereological problem of through going fractures in the deposition holes for a KBS-3V repository. In the paper, Hedin points out the possibility that in the event one or more through going fractures intersect the deposition hole, the borehole can be made deeper so that the through fractures end up outside the area encompassed by the canister's position in the deposition hole. Such a digression from the reference design entails a change in the length of the buffer. In the continued discussions of technology and method development for the buffer, SKB should investigate and confirm that the proposed methodology with deeper deposition holes is a feasible and safe method for deposition.

13.2 Current situation and programme – backfilling

SKB has decided that the reference design for backfilling will consist of precompacted bentonite blocks and bentonite pellets. The bentonite blocks are stacked on top of each other and rest on a bed of compacted bentonite pellets. The expected dry environment in the deposition tunnels should make it possible to design a stable stable floor levelling on which the blocks can be stacked by machine. The proposed solution requires careful blasting of the tunnel floor. The proposed technical design using blasting is, however, much better than the wire sawing of the tunnel floor proposed in RD&D Programme 2007 to obtain a flat base for stacking of the bentonite blocks. Wire sawing has been proposed as a method for bevelling the uppermost part of the deposition hole, see section 15.5. Wire sawing requires big and heavy equipment with a plentiful supply of water during sawing. Furthermore, special equipment is required to remove the sawn-out blocks. The RD&D programme does not explain whether SKB has considered using slot drilling, which was used experimentally in Äspö to make the bevel.

14.2 Current situation and programme for technology development, closure

In this section, SKB describes the reference design for closure of main and transport tunnels as well as the central area (Figure 14-1) and for closure of ramp and shafts (Figure 14-2). It is not evident from the description of the proposed closure materials and their use in different parts of the facility which conceptual models, calculation methods and material properties have been used to arrive at the reference design of the closure of the different parts of the Spent Fuel Repository.

15.3 Methodology for underground design

SKB has chosen to carry out the rock works for the Spent Fuel Repository in accordance with Eurocode EN 1997-1 (2004) – the Observational Method. The method is new, and Sweden is currently in the process of formulating directions and educating Swedish rock engineers about the new method. The Spent Fuel Repository will be one of the first major underground projects in Sweden where the method will be applied. In view of this, SKB bears an extra responsibility for ensuring that the method and its applications are implemented correctly by concerned consultants and contractors as well as SKB's own personnel.

SKB has reported the results of phase D2 of the final repository (SKB, 2009). If SKB intends to expand the final repository in the future with an additional deposition level beneath the one planned now at the 460 m level, the detailed design work must be redone to take into account the higher thermal load in the case with two deposition levels.

15.4 Tools for detailed characterization

In the section that deals with development of technology and methods for geology and geophysics, SKB points out the importance of developing methods and instruments for detecting long fractures in the near-field of the deposition holes and tunnels. The long fractures have a greater probability of being deformed than the short fractures, and a shear movement along long fractures may generate seismicity and damage the canister. In its development work it is also important for SKB to consider the possibility that fracture propagation may occur from the tips of the long fractures, and that the lengthened fractures may then come into contact with the deposition holes and thereby damage the canister and alter the groundwater flow in the near-field. Characterize the geometry and properties of the fractures – especially the long ones – and characterizing the short fractures around the deposition holes will therefore be an important task for SKB in the continued development work.

Regarding the work on rock mechanics, SKB points out that one of the most important remaining uncertainties in the site model for Forsmark concerns the mechanical stress state. SKB has presented a model of the rock stresses that is essentially based on measurement data from the overcoring method and which for the deposition level in the final repository is largely based on old measurement data from the time of construction of the reactor building for Forsmark 3. During the site investigations in Forsmark, SKB could only get reliable measurement results with the overcoring method down to about 200 m depth in the boreholes. With the hydraulic methods they managed to measure down to greater depths in the boreholes, but the greatest and smallest rock stresses that were measured with these methods are only about half as big as the results from overcoring. SKB has chosen to rely more on the overcoring and an equivalent high-stress model for Forsmark. In the final phase of the site investigations, SKB stopped all stress measurements and instead decided to determine the stresses during the tunnelling works and the blasting of the central area.

In conjunction with the tunnelling works in ONKALO, Finland, Posiva has developed a measurement method involving large-scale overcoring at several points in the tunnel walls and then integrating the point-by-point measurement data and from this calculating the stress state for a large volume of rock around the tunnel. The method, called LSG-LVDT (Long Strain Gauges – Linear Variable Differential Transformer) also takes into account the geometry of the tunnel in determining the stress state for the site. The method is promising and should be able to provide reliable results in the less fractured parts of the rock below a depth of about 125 m in Forsmark, provided there is little blast damage. SKB also mentions another new method called SLITS (SLim borehole Thermal Spalling), which enables the orientation of the principal stresses in the horizontal and vertical planes to be determined. According to SKB's plans, continued measurements will be made using both the overcoring and hydraulic methods during the tunnelling works for the access to the Spent Fuel Repository.

When it comes to the thermal properties of rock, SKB intends to continue its development of the field methods for determination of thermal conductivity and heat capacity. While the site investigations were in progress, SKB tested the Finnish borehole probe TERO in the deep borehole at the Canister Laboratory in Oskarshamn with relatively good results. Testing of the borehole probe in Finland has yielded good results. It is not evident from the text of the RD&D report which field method SKB intends to further develop and subsequently use, which is regrettable.

With regard to SKB's plans for technology development for monitoring, the RD&D report mentions that SKB has begun to examine the premises for installing a local seismic network in Forsmark. The purpose is that the network should record both natural seismicity and induced seismicity caused by blasting. Such a system is installed today in Olkiluoto. A local seismic network should also be planned in such a way that it can be used to monitor safeguards and seismicity at the Spent Fuel Repository, with a view to the existing nuclear power plants in the area. The system should also be designed so that it can detect the seismicity from potential thermally induced micro- and macroearthquakes caused by the nuclear fuel.

In recent years, SKB has devoted great research efforts to grouting for sealing of rock. The need for grouting at repository depth in Forsmark is deemed to be small, with the exception of water-bearing fractures that intersect the tunnels. Two different grouting materials have been used in the research: a cementitious grout and silica sol. It remains for SKB to show that the developed grouting materials in the rock fractures can withstand the thermal load without cracking or otherwise losing their functionality as sealing materials.

15.5.2 Rock excavation

SKB says that conventional drill-and-blast will be used as a method for rock excavation in the Spent Fuel Repository. SKB will explain the reason for this choice in the application for a licence to build the repository. However, the regulatory authorities assume that SKB will keep careful track of technology development with regard to tunnel boring methods (TBM) in the event TBM proves to be a better and cheaper method for tunnelling at the repository level.

GPR (ground-penetrating radar) measurements have proved to be a possible method for determining the EDZ and its depth around the tunnel openings. In RD&D programme 2010, SKB presents the measured cross-sectional area (Figure 15-3) and the depth of the dispersion zone in the fine sealing tunnel in the Äspö HRL (Figure 15-4). The depth of the dispersion zone that is presented in the figure reflects the relative fracture frequency in the tunnel wall, and the depth of the zone provides a measure of the depth to which the fracture frequency is elevated. The depth of the dispersion zone shown in Figure 15-4 can be interpreted as meaning that along the stretch of tunnel 36 to 44 m, the depth of the dispersion zone, and thereby the depth of the zone with elevated fracture frequency, varies between 0.23 and 0.56 m into the rock wall, which can be interpreted as meaning that the potential for an interconnected zone with elevated transmissivity is great. The regulatory authorities are still of the opinion that SKB should conduct a large geohydrological field test to determine the transmissivity of the excavation-disturbed zone (EDZ).

15.5.4 Deposition holes

SKB intends to continue to further develop the method of reverse raise boring of deposition holes. Tests have given positive results. In RD&D programme 2007, SKB described the option of bevelling (called chamfering in RD&D 2007) the uppermost part of the deposition hole to make it easier for the deposition machine to lower the canister into the deposition hole. Bevelling also entails that the tunnel height and the excavated rock volume can be reduced. SKB reports in RD&D programme 2010 how bevelling of the deposition hole can be done by means of wire sawing. The proposed alternative methods to wire sawing are stitch drilling or slot drilling.

16.1 Current situation and programme KBS-3H – horizontal deposition

In section 16.1.1, “Design of a KBS-3H repository,” SKB presents the technology development that has taken place since RD&D programme 2007. Since the rock at repository depth will in all probability have a low permeability, SKB has chosen to introduce a technique that permits drainage, artificial watering and air evacuation (Dawe) as a reference design. Compartment plugs of compacted bentonite are placed between the supercontainers for the purpose of facilitating wetting of the supercontainers and creating a more favourable temperature field in the deposition hole. One of the most important issues for long-term safety is the stability of the the deposition holes, and particularly the risk of piping and erosion of the buffer and the distance blocks.

Provided that the deposition holes are oriented parallel to the maximum principal stress (N120° to 150°), the intermediate and minimum principal stresses will be the determining factors for initiation and propagation of spalling failures around the deposition holes. In SKB’s stress model, presented in the results from the site investigations for Forsmark (SKB TR-08-05), a magnitude of 23 MPa is reported for the intermediate and 13 MPa for the minimum (vertical) principal stress. These values are based on stress measurements employing the overcoring method. In all probability, these magnitudes will entail that the drifts will remain stable during drilling and deposition but that the thermal load, in combination with the swelling pressure from the bentonite (initially and during the permafrost stage), plus the hydraulic pressure from the glaciation stage, will lead to spalling failure in the intact rock around the deposition drifts and propagation of existing fractures in the near-field. These conclusions can be drawn from the fracture mechanics modelling performed by Backers and Stephansson (2010) on behalf of SSM. The extent of spalling failures with depth and sectorally around the deposition drifts will in part be counteracted by the swelling pressure from the buffer.

SKB calculated the dimensions of spalling failures on the basis of field tests performed in the APSE project in the Äspö HRL and investigations of spalling failure in the URL in Canada. SKB then estimated the permeability increase that could conceivably take place in the spalling failures. This estimate was subsequently used in the safety assessment for determination of radionuclide transport. Field and laboratory tests are as yet lacking to shed light on the permeability increase resulting from spalling failures around the deposition drifts.

The rock stress measurements in Forsmark have shown that the direction of the maximum horizontal principal stress is roughly in agreement for the different methods that have been used: hydraulic methods (124°), spalling failure (136°) and overcoring (145° ± 15°) and that the NW-SE orientation also agrees with the dominant horizontal principal stress direction in Fennoscandia. Since the site selected for the final repository is characterized by a relatively large area with only two different rock masses with similar properties and a limited number of major deformation zones, a relatively homogeneous and uniform stress field can be expected in the repository area.

However, aberrations in both the magnitude and orientation of the stress field can be expected around the major deformation zones. Since the major deformation zones will be assigned a respect distance (100 m) that prohibits deposition in the vicinity of the zones, it can probably be assumed that the stress field is homogeneous in terms of both magnitude and orientation in the areas where deposition may take place. A homogeneous stress field in the Spent Fuel Repository is a big advantage, since the deposition tunnels for a KBS-3V repository and the deposition drifts for a KBS-3H repository will be oriented so that they coincide with the direction of the maximum horizontal principal stress. In the case of vertical deposition, the maximum and intermediate horizontal principal stresses will always determine the tangential stress around the deposition hole.

16.1.3 Long-term safety, KBS-3H – horizontal deposition

In this section, SKB mentions that theoretical studies have been made of spalling of the deposition drifts, and the results show that the reported stress model for Forsmark will not lead to spalling. SKB has not cited any reference for the theoretical study.

The same results are reported by Backers and Stephansson (2010) in a fracture mechanics analysis of vertical deposition in Forsmark and using SKB's stress model and rock parameters.

As soon as the thermal load from the canisters enters the rock mass, spalling takes place in the drift wall. This spalling is partially counteracted by the swelling pressure from the buffer.

In summary, current knowledge of the stress situation in Forsmark suggests that regardless of whether the stress magnitudes are in agreement with the results from the overcoring or the hydraulic measurements, horizontal deposition according to KBS-3H is more favourable with respect to stability and long-term safety than vertical deposition. Horizontal deposition in long drifts oriented parallel to the maximum horizontal stress provides the lowest stress magnitudes around the drifts. This is favourable for stability and the long-term safety of the Spent Fuel Repository.

Part IV Research for assessment of long-term safety

21.1 Initial state of engineered barriers in SFR

The support elements, rock bolts and shotcrete, are crucial for the long-term stability of SFR. SKB carries out regular tests – extraction tests on the rock bolts and adhesion tests on the shotcrete – in order to check the condition of the bolts and the shotcrete during operation. In order to test the condition of the rock bolts, SKB had a number of test bolts installed when the facility was built 20 years ago, and a given number of these bolts have so far been tested with regard to corrosion and loadbearing capacity.

Prior to the planned extension of SFR, SKB needs to establish a new inspection programme that takes into account the increased life of the facility and how testing of existing grouted bolts will in the future ensure the long-term stability of the bolts in the existing facility and the planned addition.

Testing of the shotcrete can largely follow current procedures and is not dependent on choice of location in the facility. The equipment used for adhesion testing is special, however, and the availability of the test equipment for a long time to come should be ensured by SKB. In conjunction with the regularly recurring inspections of the rock and concrete structures in SFR, it has been noted that rebar located close to the surface in the concrete structures rusts due to the relatively high humidity in the facility, especially in the summertime. Continued measurements of the degree of water saturation of the concrete are therefore warranted.

Water seepage into SFR has been measured and checked regularly ever since the start of operation. Over the years it has been found the water seepage is declining over time. A considerable portion of the seepage to the facility comes from the passage of the access tunnels through the Singö Zone. The seeping water runs in an open ditch from the passage of the Singö Zone along the tunnel wall down to the pump sump at the bottom of the lower construction tunnel, which is the deepest part of the facility. The running water raises the humidity in the facility, which affects the degree of water saturation of the concrete, which can in turn increase rebar corrosion and cause the function of the barriers in the facility to deteriorate. According to the reported plans for the extension of SFR, SKB intends to drive a new access tunnel just south of the two existing tunnels. In conjunction with the planned tunnelling, SKB should consider improving the sealing of all tunnel passages through the Singö Zone in order to reduce the water flow and thereby improve the climate in the facility.

24.2.4 Freezing of buffer and backfill

If the density of the buffer and backfill decreases due to e.g. erosion and the water freezes in conjunction with permafrost, this will lead to a pressure increase that could damage the canister and the rock. SKB has conducted a study that makes it possible to bound the pressure increase for a given temperature in a system of frozen bentonite. The study showed that the resultant pressure does not damage the canister. However, the pressure caused by freezing of the bentonite in the buffer could damage the rock around the deposition hole. SKB has estimated the maximum pressure at the lowest possible temperature in the case with an extreme permafrost scenario to be 26 MPa. The pressure increase due to freezing exceeds the tensile strength of the intact rock, which has been determined by indirect tensile tests to be in the range 8.4–20.9 MPa for fracture domain FFM01 and 12.8–16.6 for fracture domain FFM06. The pressure increase can lead to some limited fracturing and fracture propagation around the deposition holes. The extent of the damage is completely dependent on the initial state of stress in the rock mass, where a higher stress (according to SKB's stress model) counteracts fracturing and fracture propagation. Furthermore, with current knowledge of the spalling failures caused by the thermal load (which occur with certainty in the stress model presented by SKB) and the swelling pressure from the buffer, it is difficult to estimate how the situation with earlier fracturing and stress relief has disturbed the rock around the deposition holes when the permafrost forms and freezing generates swelling pressure.

24.2.5 Water transport under unsaturated conditions for buffer and backfill

SKB has carried out model calculations of the wetting process for different hydraulic conditions in the rock mass around the deposition holes (SKB TR-10-11). Assuming extremely low hydraulic conductivity in the rock mass, $5x10^{-13}$ m/s, and no fracture to conduct water into the deposition hole, which is a probable situation for the tight rock at deposition depth in Forsmark, the calculations show that it will take 1,200 years to achieve full water saturation. At this point the maximum temperature of the canister has been passed and the buffer has dried and probably shrunk and cracked. Moreover, the thermal conductivity of the buffer and the pellets nearest the rock wall in the deposition hole has changed and additional space has probably been created between the buffer and the rock, making it more difficult for heat to be conducted from the canister to the rock. In this section, SKB mentions that further dehydration scenarios in very dry rock will be constructed. The described dehydration of the buffer reduces or eliminates the strengthening effect which the buffer is expected to have to counteract thermally induced spalling of the rock in the deposition hole.

It is of the utmost importance for long-term safety that the model calculations of the various dehydration scenarios also include the thermo-hydro-mechanical processes in the rock, and especially initiation and propagation of spalling failure.

24.2.9 Mechanical processes in buffer and backfill

Following horizontal deposition according to the KBS-3H concept, the metal shell on the supercontainer will corrode. SKB says that the transformation from iron to magnetite entails a volume increase that gives rise to increased pressure against the canister and the rock. It is not clear from the text what pressure increase the transformation will give rise to.

25.2.2 Heat transport

In conjunction with the site investigations and reporting of their results, SKB presented a stochastic method for determining the thermal properties of the rock types and the rock mass for each of the sites Laxemar and Forsmark. Along with analytical and semi-analytical methods for determining the propagation of heat in the rock from the canisters in time and space, SKB has developed a thermal design method for determining the centre-to-centre spacing between the deposition tunnels and the deposition holes. The method, which is described in SKB R-09-04 (where it is called "thermal dimensioning"), enables SKB to take into account the spatial correlation of the thermal conductivity properties of the rock for the different rock domains in the design work and to make use of the available rock volume for the given boundary condition that the buffer temperature may not exceed 100°C for any canister at any point in the canister. The total uncertainty in the calculation method amounts to 3.8–6.3 °C. The results of an extensive series of calculations of the thermal properties and the numerical modelling (explicit finite difference method) of the thermal process have been reported in a series of nomograms for given input data for the initial heat output of the canister, the tunnel spacing, the air gap between canister and buffer and the heat capacity of the rock.

The calculation results from the application of 3DEC and the Code Bright calculation codes have been verified as far as possible with analytic methods and have proved to give very good agreement, which greatly contributes to the reliability of the method for designing the thermal part of the canister spacing for given parameter values.

The complete analysis of canister spacing also includes taking into account the thermo-mechanical and hydro-mechanical evolution of the response of the rock mass to the additional heat load from the canisters. This means that the rock stresses, the pore pressure and the transmissivity of the fractures and faults during the different phases of the Spent Fuel Repository must be taken into account. SKB has given an account of this in the THM report, SKB TR-10-23. The report provides a summary of the results of the thermal evolution of the final repository (Chapter 5) and an approach to evaluating the modelling results (Chapter 3). In the report, SKB argues that fracture propagation and coalescence of already existing fractures in the near-field of the deposition holes can be completely disregarded, in part because the area around the holes is subjected to compressive stresses, while the authors of the report claim, with the support of a study by Damjanac and Fairhurst (2010), that tensile stresses at the fracture tips are required for propagation to take place. But this is not true. Recent modelling with the fracture mechanical code FRACOD has shown that fracture initiation, fracture propagation and coalescence of already formed fractures take place in the near-field of the deposition holes for favourably located fractures with respect to the stress field of a typical fracture network model from Forsmark (Backers and Stephansson, 2010). The fracture propagation takes place under the thermal load, and particularly in conjunction with glaciation. Fracture initiation and propagation tend to occur as shear fractures (Mode II) and not as tension fractures, and the result can lead to longer flow paths and increased flow around the deposition holes.

SKB uses 3DEC models for modelling of the coupled THM processes on different scales in the Spent Fuel Repository. The used version of 3DEC cannot treat fracture initiation and fracture propagation in the models.

SKB has calculated the total stresses from the stress field in Forsmark in accordance with SKB’s stress model and the thermal stresses for three different cross-sections through the repository (A, B and C according to Figure 6-16 in the THM report). In the case of the centrally located profile B, an increase in compressive stresses of about 15 MPa is generated at repository depth about 100 years after deposition. On the ground surface, tensile stresses on the order of 4-5 MPa are obtained. The transition from tensile to compressive stresses takes place about 150 m below the ground surface. In view of the fact that the uppermost 125 m in Forsmark has considerable bedding planes, this means that the intact rock beneath the bedding planes down to repository level (total about 335 m) will transmit the thermal stresses. The smaller thickness of the intact rock entails some increase of the tensile stresses in the uppermost part of the intact rock above the Spent Fuel Repository. A 3DEC simulation of the influence of lower-strength rock for the uppermost 125 m in the central profile B needs to be done to study the influence of the bedding planes on the global stress picture around the repository.

SKB's analyses of the hydro-mechanical coupling use a continuous yield limit model according to Itasca, which is originally based on the Barton-Bandis fracture model and Barton's empirical model for the relationship between mechanical and hydraulic aperture in fractures or faults. The relationship between depth and effective normal stress and between depth and relative transmissivity in the rock mass around the repository (Figures 6-18 – 6-22 in the THM report) demonstrates the necessity of studying the coupled hydromechanical processes of the flow around the repository. This conclusion is in line with the conclusions expressed by SKB in the "Programme" part of section 25.2.3, "Groundwater flow" (page 332).

In Chapter 8 of the THM report, SKB reports the results of the transmissivity changes resulting from shear along a number of assumed fractures in the near-field of the repository. It remains for SKB to show how the flow in the near-field around deposition tunnels and deposition holes changes with the application of prepared and presented hydraulic DFN models. Furthermore, SKB should further develop the material model for the stress-induced transmission models.

25.2.5 Movements in intact rock

In the section "Conclusions in RD&D 2007 and its review," SKB describes the development work done during the site investigations to improve the methods for determining the rock stresses. The measurements in Laxemar, where the magnitudes corresponded to normal conditions for Fennoscandia, yielded reliable results. In the case of Forsmark, an overall compilation of experience and possible explanations of the problems that arose during the measurements is still lacking.

The Swedish National Council for Nuclear Waste's review of RD&D Programme 2007 (SOU 2008:70) levelled sharp criticism at the absence of reliable measurement results at repository level and the great contrasts in the measurement results between overcoring and the hydraulic methods. SKB rightly asserts that both methods provide a fairly concordant picture of the direction of the maximum principal stress down to the level of the Spent Fuel Repository. Regarded from a rock mechanics perspective, however, the stress magnitudes measured for the two methods exhibit great differences and not "certain differences", as SKB writes.

According to SKB, the results of the APSE experiments in the Äspö HRL show that small counterforces are needed from the rubber bladder to prevent spalling failures in the walls of the deposition holes. SKB got a similar result in the CAPS field experiment, where the counterforce was exerted by LECA pellets in the 0.5 m diameter boreholes. Both rubber and LECA pellets are characterized by relatively high friction in their contact with rock. It is therefore of the utmost importance that SKB test their confinement effect for bentonite and other materials with similar friction properties. In order to get a good idea of the confinement effect of the LECA pellets on spalling failure, one or more of the heat tests in CAPS should have been done in boreholes without LECA pellets.

The greatest uncertainty when it comes to assessing the risk of spalling failure is heat transport in the deposition holes, and in particular the influence of the degree of water saturation of the rock. This assessment is verified by the Caps field test, where the test holes that had been bored and heated up in wet rock resulted in more spalling failures compared with dry boreholes. This means that SKB must develop specific design criteria for deposition in rock with different degrees of water saturation. The thermal properties of water-saturated rock samples were tested during the site investigations in Laxemar and Forsmark. The results of the CAPS field experiment shows that testing of thermal properties needs to be done at different water contents.

25.2.6 Thermal movement

The preliminary results regarding the thermomechanical evolution of the Prototype Repository appear to show that the tangential forces are not sufficient to cause spalling failure. In order to bring about spalling failure in the APSE experiments, the drift was oriented so that the maximum horizontal principal stress was perpendicular to the tunnel axis. In addition, the floor of the drift was designed so that the stresses were further concentrated around the trial hole. In the Prototype Repository, the experiments have not been oriented or designed to optimize or study the rock mechanics aspects in connection with deposition. It is therefore quite logical that there is no spalling failure in the Prototype Repository.

25.2.7 Reactivation – movements along existing fractures

SKB has conducted three large studies of different mechanical and geophysical effects in the Earth's crust from large glaciations, and in particular the Weichselian glaciation (SKB TR-05-04, SKB R-06-95 and SKB TR-09-15). The results of these studies have contributed greatly to an understanding of the mechanical aspects and the processes, and the studies are of great importance for assessing the stress situation in the Fennoscandian Shield, and especially on the repository site.

The results of the study presented in 2009 (SKB TR-09-15) have been used directly to determine the effects of large earthquakes on a KBS-3 repository during the deglaciation stage of future glaciations. SKB has used the finite element code ABAQUS for modelling of the mechanical effects in the Earth's crust, while the discrete element method and the code 3DEC have been used for the subsequent analysis of the effects of large earthquakes. The question can be posed whether SKB has considered using the same calculation code to analyze the effects of great earthquakes that could occur during the deglaciation stage of future glaciations.

In conjunction with SKB's presentation of SR-Can, the method for analyzing the impact of large earthquakes from earthquake zones in the repository area on so-called "target fractures" in the immediate vicinity of the repository was presented. Since then the method has been further developed, and a long series of detailed analyses have been conducted and have contributed to a better understanding of the possibilities of generating displacements along existing fractures. In its work, SKB uses a fracture model with circular fractures where the maximum displacement is assumed to occur in the centre of the fracture, with zero displacement at the tip (equation 5-3 in TR-08-11). In view of the fact that fracture propagation can very well be initiated at the tip of the fracture in certain stress situations, the fracture model loses credibility, and SKB should try to find better models to describe the possible and probable courses of displacement in the target fractures. In the programme in the section on reactivation and movements along existing fractures, SKB describes in brief the current situation with regard to the national digital seismic network. It is of the utmost importance that the seismic data gathered during the ten years the network has been in operation be fully analyzed and that focal plane mechanisms be studied for the purpose of learning more about the state of stress in Fennoscandia. In this work, deeper cooperation is recommended with the research group for the World Stress Map Project at the German Research Centre for Geosciences in Germany. Dr. Oliver Heidbach is in charge of the project.

The Pärvie fault is one of the most famous and studied postglacial faults in the world today, and SKB's work has greatly contributed to making this so. Knowledge of the fault and its genesis is of extremely great importance for the assessment and calculation of the risks of large-scale movements of deformation zones during the postglacial period in the repository area, as well as of the long-term safety of the repository. The seismic network around the fault proposed in RD&D programme 2010 and the application of modern satellite radar technology for determination of the movements of the fault, as well as the drilling of deep cored boreholes within the framework of the Postglacial Fault Drilling Project, are all well justified and urgent research efforts on the Pärvie fault.

25.2.8 Fracturing

In section 25.2.2, "Heat transport," SKB's view that new fracture formation in the the near-field of the deposition holes does not have to be taken into account is commented on, and at the same time the results of a fracture mechanics modelling are presented showing that fracturing and fracture propagation can occur from the tips of existing fractures.

The state of knowledge regarding fracturing in the excavation-disturbed zone (EDZ) is commented on in section 15.5.2. From now on, questions concerning the extent and properties of the excavation-damaged zone will be addressed within the framework of the Rock Line's activities and investigation programme, which is logical.

The Prototype Repository in Äspö, which will be opened in 2011, is expected to provide answers regarding whether new fracture formation has occurred around the deposition hole as a result of the heat load and the swelling pressure from the buffer. The new calculations and modelling which SKB plans to carry out with the guidance of the results from the opening of the Prototype Repository are well founded and comprise an important part of the evaluation of the experiment and the reliability and mode of action of the KBS-3V method in general.

25.2.9 Time-dependent deformations

SKB has had a study done concerning concerning the occurrence of microfractures, subcritical fracturing and creep in rock. The study has addressed the general question of whether a lower limit exists below which crystalline rock ceases to exhibit deformations at given loads. In short, is there a creep limit for rock? The authors of the study have reviewed the literature on short-term creep of rock, numerical models and evidence from plate tectonic processes and observations of rock stresses in quarries and arrive at the conclusion that a stress threshold equivalent to a significant fraction of the fracture-initiated stress does exist and amounts to 40-60 percent of the uniaxial compressive strength. This would mean that the assumed yield limit for crystalline hard rock would be about 50-100 MPa, which can scarcely be possible as a yield limit for rock. This lower limit is much too high. The second argument which SKB chose to cite is based on an assumption of exponential extrapolation of creep tests performed during a relatively short period of time and then linearly extrapolated to a final zero strength. From the results of the study, SKB draws the conclusion that time-dependent deformation processes can be dismissed when it comes to long-term safety. SKB's conclusion is not sufficiently scientifically founded, and the question of the importance of time-dependent deformations for long-term safety is still insufficiently illuminated in RD&D programme 2010.

25.3.1 Modelling – DFN

When it comes to the state of knowledge regarding geological and hydrological DFN models, the scientific community is waiting for a breakthrough regarding the grounds for discrete fracture models and their geoscientific application. In the initial stage of the site investigations, an attempt was made to cover the geological and hydrogeological properties with one and the same DFN model. This proved to be impossible, and later during the account of the results from the site investigations, SKB presented separate geological and hydrogeological fracture network models. In the research programme for the next three years, SKB will continue to improve the DFN models and introduce a more integrated perspective on the information, giving more consideration to the geological, hydrological and rock mechanical aspects of the rock. In order to achieve this, SKB presents a 6-point programme for research in the coming years. The work in the programme is more in the nature of a polishing of the DFN methods rather than a thorough and novel approach. Furthermore, SKB's objective for having a DFN model can be discussed. It may be a way forward in the development work, but it doesn't have to be a requirement or an end in itself in the current stage of the Nuclear Fuel Programme.

25.3.2 Integrated modelling – THM evolution

Through the years, SKB has made considerable progress when it comes to method and code development for the thermo-hydro-mechanical evolution of the Spent Fuel Repository's engineered barriers and several of the important processes in the geosphere. This development and the applications have mainly involved the calculation code ABAQUS. SKB has moreover been an active partner in the international research project DECOVALEX, whose purpose is to develop and apply calculation programs for THM processes in geological material and to model well-defined field and laboratory experiments of importance for spent fuel repositories. In the current phase of the project, SKB has been administrative principal and has also made the results from the APSE project at the Äspö HRL available for the modelling work. In the section dealing with newfound knowledge since RD&D 2007, SKB summarizes its efforts in the DECOVALEX project and says something about the results reported by the seven modelling teams that have worked with the simulation of the experiments in the APSE project. The results of SKB's participation in the project have been positive and helped SKB to to get several of the scientific problems in the APSE project elucidated and analyzed with several different approaches, conceptual models and calculation codes.

In the section headed "Conclusions in RD&D 2007 and its review," SKB describes how the regulatory authorities have commented that the change of transmissivity in the near-field as a result of fracture propagation from the tips of existing fractures should be studied. Fracture propagation can be caused by rock excavation, thermal loading, the swelling pressure from the buffer during the thermal phase, and permafrost, as well as the increased pressure gradient in conjunction with deglaciation. SKI expressed the opinion that the 3DEC code needs to be modified to be able to create T-M models for the near-field. SKB has chosen not to respond to the criticism expressed by the regulatory authorities in RD&D 2010. In the THM report, SKB TR-10-23, SKB argues that the effects of propagation of existing fractures in the near-field can be neglected in comparison with the uncertainties that can be related to the properties of the tunnel EDZ and the spalling failures in the deposition holes. SKB still has to show that this is the case, see also the comments in section 25.2.2.

In the programme for the coming 3-year period, SKB describes a number of new and interesting pathways of development when it comes to integrated modelling and in particular the link to the modelling needs that will be required for application of the Observational Method. SKB has also heeded the viewpoints of the regulatory authorities regarding the need to develop new modelling tools and constitutive relationships for the stress dependence of transmissivity and the strength of the deformation zones. SKB's intention to initiate generic brittle-tectonic modelling is welcomed and can be seen as a continuation of the modelling work that has dealt with large-scale stress evolution and fault stability during a glacial cycle.

3. Editorial comments

9.3 Technology development needs

In section 9.3.1, "Overall needs," SKB presents a bulleted list of overall needs for measures with regard to technology development. In the fourth point, SKB writes: "Integrated production adaptation needs to be done with regard to rock extraction, inspection programme, deposition and backfilling." It is not clear what SKB means by "inspection programme" in this enumeration of needed measures.

4. Acknowledgements

I would like to thank Öivind Toverud for his valuable editorial and factual comments on the contents of the first Swedish version of the report.

5. References

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Committee terms of reference

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

Dir. 1992:72

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

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

Dir. 2009:31

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.

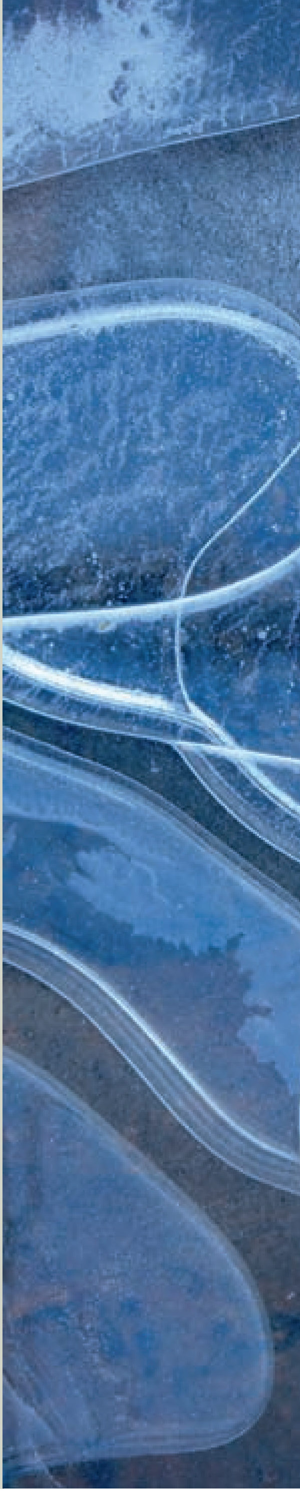
(Ministry of the Environment)

The Swedish National Council for Nuclear Waste (Kärnavfallsrådet) is an independent scientific committee attached to the Ministry of the Environment. The members of the Council possess expertise in technology, science, ethics and the social sciences.

One of the Council's tasks is to assess SKB's research, development and demonstration programmes. The present report contains the Council's assessment of RD&D programme 2010. The review is based on the members' special areas of expertise and the aspects which the Council has addressed previously, in previous reviews and state-of-the-art reports.

The Council's review includes viewpoints on SKB's plan of action, the LILW programme, the Nuclear Fuel Programme, research for assessment of long-term safety, and social science research. It has been supplemented with studies performed by consultants in the fields of geosphere, climate evolution and hydrology. These special reports are attached as appendices to the present report.

The report can be downloaded at www.karnavfallsradet.se and can also be ordered by emailing to karnavfallsradet@environment.ministry.se.



Fritzes
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