Nuclear waste

– research and technique development

KASAMS's Review of the Swedish Nuclear Fuel and Waste Management Co's (SKB's) RD&D Programme 2001

Stockholm 2003

STATENS OFFENTLIGA UTREDNINGAR

SOU 2002:63

Cover: "Landscape", textile art by Maria Triller
Photo by Tord Lund
Translated into English by Monica Bowen-Schrire, EnergiTek Translations

Printed by XBS Grafisk Service
Stockholm 2003

To the Minister of the Environment

Review statement on the Swedish Nuclear Fuel and Waste Management Co's (SKB's) RD&D Programme 2001 – programme for the research, development and demonstration of methods for the management and disposal of nuclear waste

According to its instructions (1992:72), KASAM – the Swedish National Council for Nuclear Waste – shall present to the Government an independent review of the research, development and demonstration programme (RD&D programme) for the disposal of spent nuclear fuel and other waste-related issues that the Swedish nuclear power companies, through SKB, must submit once every three years.

This report contains KASAM's review statement to the Government on SKB's RD&D Programme 2001.

KASAM's review was primarily conducted through the work of KASAM's Chairperson, Camilla Odhnoff, and members Rolf Sandström, Göran Andersson, Carl Reinhold Bråkenhielm, Britt-Marie Drottz Sjöberg, Willis Forsling, Gert Knutsson, Sören Mattsson and Jimmy Stigh, experts Olof Söderberg, Nils Rydell and Sören Norrby, and secretary, Mats Lindman.

KASAM proposes that the Government decide that the reactor owners, through SKB's RD&D Programme 2001, have complied with the requirements in § 12 of the Act (1984:3) on Nuclear Activities.

Stockholm, June 2002

KASAM – Swedish National Council for Nuclear Waste

Camilla Odhnoff

Rolf Sandström	*Göran Andersson*
Carl Reinhold Bråkenhielm	*Britt-Marie Drottz Sjöberg*
Willis Forsling	*Gert Knutsson*
Sören Mattsson	*Jimmy Stigh*

/Mats Lindman

Innehåll

Summary

This report is KASAM's review statement to the Government on the Swedish Nuclear Fuel and Waste Management Co's (SKB's) RD&D Programme 2001.

KASAM's review was primarily conducted through work by KASAM's members, special adviser, experts and secretary.

In KASAM's opinion, the reactor owners, through RD&D Programme 2001, have complied with the requirements of § 12 of the Act on Nuclear Activities.

In KASAM's opinion, SKB´s research and development programme shows great merit. This applies to both what SKB has done and what it intends to do. The report is well-structured and clear.

RD&D Programme 2001 shows that there is still a considerable need for development work in a number of important technical areas. This applies, for example, to the fabrication and sealing of canisters as well as control methods for these activities.

Within other areas, for example, geology, chemistry, hydrology, biology and rock mechanics, there is also a great need for further research and development work, and for practical demonstrations of technical applications.

In KASAM's opinion, humanities and social science issues, that are of importance for the disposal of nuclear waste, should be accorded greater attention. In Chapter 14, KASAM has presented a proposal for how research in these areas can be organised and financed.

KASAM emphasizes that future RD&D programmes should have a broad scientific basis in order to comply with the requirements of the Act on Nuclear Activities regarding comprehensiveness.

In their review statements on RD&D Programme 2001, the Swedish Nuclear Power Inspectorate (SKI) and the Swedish Radiation Protection Authority (SSI) have proposed that SKB should be required to present a strategy document which should be kept updated. In KASAM's opinion, such a report of current strategic issues should be made available to the public and other parties concerned. KASAM also believes that such a documentation of strategy issues should be subjected to a review process in the same way as the recurrent RD&D programmes.

In KASAM's opinion, SKB's timetable is far too optimistic to guarantee the good quality of all of the work that must be done.

In order to promote further research on alternative methods of managing spent nuclear fuel, such as partitioning and transmutation, KASAM proposes a review of the first paragraph of § 5a and § 6 of the Act on Nuclear Activities.

Safety assessments

SKB's safety assessments have focused on the long-term safety of the repository. In KASAM's opinion, safety assessments should also be conducted for the operational phase of the repository as well as for other disposal components besides the repository, for example, the encapsulation plant and the transportation system. A safety assessment should also be prepared for the possible retrieval of canisters from the repository.

SKB has conducted a systematic development of the safety assessment methodology for the long-term properties of the repository. However, in KASAM's opinion, the methodology needs to be further developed. KASAM particularly emphasises the initial canister defect scenario and the issues relating to the encapsulated fuel as well as the cast iron insert. Defect scenarios also need to be analysed for other barriers, such as the bentonite buffer and the backfill.

Furthermore, KASAM considers that several issues relating to probabilistic risk analysis need to be further investigated. KASAM also points out that it is difficult to calculate the probability of certain processes, for example, human intrusion.

KASAM also emphasises the function of the safety assessment, as a tool for identifying and improving the understanding of processes that are of importance for safety and maintains that the safety assessment should be a tool for guiding site investigations and for the development of engineered barriers.

Fuel

SKB limits itself to keeping track of developments within the research area of cladding damage. In KASAM’s view, this is far too low a level of ambition.

In KASAM’s view, the research programme on fuel dissolution, which from the beginning was general in nature, should focus on the conditions that, according to analyses conducted, will occur inside the canister. The dissolution studies in oxidising (air), reducing (hydrogen gas) and oxygen-free (anoxic, argon) conditions are of this type. However, the programme needs to be linked to the analyses of canister damage and the justification and goals of the various programme points need to be reported. In KASAM’s opinion, the programme is sufficiently important to warrant its own research plan.

In KASAM’s opinion, SKB should devote greater attention, in both theoretical and practical terms, to plutonium chemistry in connection with speciation and colloid formation in order to be able to correctly assess the transport processes from the fuel.

Canister

The controlling mechanism, with respect to the impact of phosphorous on creep ductility, is an open question. In-depth studies of the controlling mechanisms are therefore important. For the extrapolation of creep data to be made to long time-periods with certainty, the mechanisms must be known.

When creep data is available for welded joints, detailed calculations of plastic deformation and creep in the canister must be conducted using the finite element method to supplement the calculations performed for the base metal alone.

In its programme, SKB plans to conduct empirical studies of corrosion processes in the contact areas *copper-cast iron-water* and *cast iron-water* under realistic conditions and, with the ensuing data, perform new calculations of the evolution of a damaged canister. KASAM is satisfied that this work has been planned.

Further basic studies are required, particularly in the case of stress corrosion-induced and microbial-induced corrosion on the copper canister. Furthermore, it is especially important to verify the results obtained so far with long-term experiments under as realistic conditions as possible. It should be possible to conduct such experiments at the Äspö Hard Rock Laboratory and such experiments have also partly already been planned.

In KASAM's view, the requirement on the limitation of initial defects in the copper canisters is far too vaguely formulated. The acceptance criterion for initial defects should be based on the requirement that the best available technology, together with requirements based on a dose/risk limitation, must be used for the engineered barriers in the repository, both for manufacturing and quality control.

Encapsulation

The canister design has been adequately specified in an earlier SKB report. The basis of the principles for the design is good. However, continued flexibility is important with respect to the results from the work on canister fabrication and joining.

To obtain satisfactory results in connection with the casting of the cast-iron insert, simulation programs for the process should be run, so that different insert designs can be tested. During new fabrication trials, it should be shown that the requirements of the performance specification are adequately met.

Considerable work remains to be done on the joining of the copper canister. Further investigations should be conducted with both methods – friction-stir welding and electron beam welding – until at least one of these methods shows satisfactory results. A thorough understanding of the mechanisms that result in defects must be developed.

Buffer

KASAM is positive to SKB's plans to carry out studies of alternative buffer minerals in order to obtain a reference to montmorillonite-rich bentonite.

KASAM believes that there are good reasons why not only general limits for impurities should be set. How combinations of impurities can affect the long-term stability of the buffer, both positively and negatively, should also be investigated.

In KASAM's view, it would be very valuable if SKB, in connection with its studies of other compositions of buffer material, also investigated how a limited illitisation and cementation affects important parameters for the buffer. KASAM underlines the need for further studies on the release, transport and precipitation of dissolved silicon and other substances in the buffer.

With the help of the existing knowledge on the specific surface area of the main minerals, the cation exchange capacity, the type and concentration of available surface sites, temperature and ion-strength variations, KASAM believes that it should be possible to develop a more sophisticated sorption model, which includes ion-exchange, adsorption and surface precipitation of the most important radionuclides as a function of the concentration of the substances and the pH value of the pore water.

The combination of wetting and temperature differences in the buffer with subsequent heat transport as a function of time and water quality is a challenging area of research. KASAM notes with satisfaction that SKB is studying these issues.

There are remaining uncertainties regarding the understanding of gas transport in the buffer and the relationship between gas flow and swelling pressure. Therefore, KASAM considers that it is positive that SKB is prioritising this area and considers that both experiments and model development are required to investigate the process.

KASAM is positive to the further research on bentonite erosion described in RD&D Programme 2001.

Backfill

KASAM considers that if the different requirements on the backfill are found to be difficult to unite, the function of limiting the swelling of the buffer should be prioritised.

In KASAM’s view, SKB should conduct performance assessments of the *buffer-backfill-geosphere* system in order to clarify advantages and disadvantages of different types of backfill, including only natural clays, mixtures of crushed rock and clay as well as crushed rock alone that is of such a size that it provides maximum resistance to pressing due to the expansion of the bentonite buffer.

Naturally, the assessment must include, as far as possible, the long-term evolution of the three types of backfill in groundwater environments with various salinities.

The areas to be backfilled – deposition tunnels, transport tunnels and shafts and ramps to the surface – may need to be filled with materials with different properties.

SKB should limit the quantity of potassium that the crushed rock can contain in order to be used in the backfill.

Geosphere

KASAM considers that the main direction of the further investigations of the geosphere, as reported in RD&D Programme 2001, is suitable.

In KASAM's opinion, the properties of the rock, according to the results from the site investigations, should be described in the light of the properties of other rock types. The development of the "descriptive rock mechanical models for potential repository sites" stated by SKB should be supplemented by the possibility of conducting comparative assessments of rock types with different properties (both geochemical and hydrogeological properties).

KASAM has no objection to make to the overall description of processes in the geosphere that is presented but recommends that SKB should develop the programme description bearing in mind the effects that can occur as a result of rock stress redistributions in connection with the construction of a deep repository.

With respect to remaining uncertainties concerning the elasticity of the rock and the understanding of thermal movements, KASAM considers that SKB's programme proposal is well justified.

In KASAM's opinion, SKB's assumptions and projects are reasonable for the improvement of knowledge on the issue of time-dependent deformations and for an increased understanding of fracture formation processes.

In KASAM's opinion, the description of the need for a respect distance between a repository and fractures of various lengths should be clarified and the reasons for these distances should be well supported by published research results and empirical evidence.

In KASAM's opinion, SKB's plans for further research on earthquakes and climate evolution are justified and important since there are still uncertainties associated with these issues.

In KASAM's view, SKB should study different methods for injection in fractures in the aim of achieving a permanent limitation of the hydraulic conductivity in the host rock without having a negative impact on the chemical environment in the repository.

KASAM recommends that SKB should present a programme to develop methodology for the classification of the heterogeneity of the rock in connection with the forthcoming site investigations. In KASAM's view, the relationship between the land uplift intensity in different areas and the openness of the fractures and, thereby, the hydraulic conductivity, should be investigated. Furthermore, in KASAM's opinion, the amount of groundwater formed at different depths should be investigated and the groundwater flow on a regional scale should be modelled, taking into account the actual conditions. SKB should also describe the importance of the groundwater transport time in comparison with other hydrogeological and hydrochemical conditions and in comparison with the recipient's properties.

In KASAM's view, it is important for SKB to exploit existing national and international knowledge within the decision aid area, as well as to develop and evaluate decision-support models prior to site selection.

Biosphere

KASAM supports the overall goal of the biosphere programme with the aim of, with a modern knowledge base, describing the most important processes in the biosphere from the radiological standpoint, as well as to provide an adequate scientific support to assess environmental consequences of the construction and operation of a repository. KASAM particularly notices the ambition stated in the RD&D programme to confirm and deepen the knowledge obtained in ongoing projects by promoting increased publication in international journals. KASAM shares SKB's view that it is important to disseminate SKB's knowledge abroad in order to obtain viewpoints and the necessary scientific peer review.

In KASAM's view, a deeper understanding of the hydrological relationships between a deep repository for spent nuclear fuel and different ecosystems is highly desirable. This knowledge is necessary in order be able to make a reliable evaluation of transport paths and transport rates to the biosphere in the calculation models. Such a report should include an evaluation of the issue of the areas to which the surface water or groundwater from the repository can be transported. The report should also contain an analysis of the radionuclide transport from rock to sediment (from geosphere to biosphere).

KASAM notes that the biosphere models should be applied to the turnover of the radionuclides and other substances which, due to their chemical toxicity can have an environmental impact. KASAM also notes that the reporting of results from the biosphere studies should be designed bearing in mind the public's interest in understanding the risks of a deep repository and in being able to compare these with other risks in society.

In KASAM's opinion, the ecosystems proposed for studies in RD&D Programme 2001 are important from the standpoint of radiation protection. In KASAM's view, knowledge of the agricultural lands (including land for the production of energy crops) as ecosystems should be developed in greater depth with special consideration being given to future cultivation of former accumulation bottoms in watercourses, lakes and seas as well as the use of boggy grounds that can contain increased concentrations of radionuclides. In further reporting, it is important that relevant main types of ecosystems are included in order to create the largest possible basis for the selection of ecosystems for further evaluation.

KASAM assumes that an environmental monitoring programme for the repository will be established and that this monitoring will be initiated before the start of construction to obtain comparable data on baseline environmental conditions. In KASAM's opinion, it is important that the continued research and development work should clarify the conditions for the selection of measurable parameters and organisms/species that can act as suitable indicators of an impact on the biosphere in connection with model calculations and monitoring. The report should clearly state how any recommended limits for the different parameters were arrived at. In this context, KASAM notes that there are certain uncertainties as to how the Swedish Radiation Protection Institute's *Regulations on the Protection of Human Health and the Environment in connection with the Final Management of Spent Nuclear Fuel and Nuclear Waste* (SSI FS 1998:1) are to be applied. However, the ongoing FASSET Project and the general recommendations that SSI intends to promulgate in 2003 should hopefully provide some guidance on this subject.

Alternative methods

The Government has assumed that issues concerning *which alternatives are to be described* in a future environmental impact statement, in accordance with Chapter 6 § 7. 4 of the

Environmental Code, will be the focus of in-depth consideration in connection with the stipulated consultation. In KASAM's view, a reiteration is warranted of KASAM's evaluation of the alternatives issue in its review of SKB's RD&D Programme 98 and its review of SKB's RD&D Programme 98 Supplement. The conclusion of KASAM's reasoning is that alternatives to the KBS-3 method, which are to be reported in accordance with the Environmental Code, should be identified from the category of repositories that can be mined within the uppermost kilometre of the bedrock. KASAM has not found any reason to change its opinion on this issue. In KASAM's opinion, a method such as disposal in deep boreholes is not a realistic alternative method, that is required to be described in the environmental impact assessment under the Environmental Code. Possibilities of retrieving the spent nuclear fuel are likely to be non-existent and there could, thereby, also be considerable difficulties in implementing a meaningful demonstration phase for such a repository.

In the light of the above, KASAM shares SKB's opinion that adequate reasons do not exist for implementing the previously described RD&D Programme for *deep boreholes.* Like SKB, KASAM considers that the company should continue to follow developments in the area.

KASAM has no objection to make to SKB's presentation of newly acquired knowledge in the *transmutation field*. In KASAM's opinion, there are good reasons for the current direction of the Swedish nuclear waste programme, namely further development work focusing on direct disposal in accordance with the KBS-3 method.

It is important that SKB is actively tracking developments in the area of partitioning and transmutation. KASAM proposes that the Government should request that SKB in RD&D Programme 2004 should present a more detailed basis for assessing suitable levels of funding for this work.

KASAM shares SKB's opinion, that it is not reasonable for the company to initiate major development projects in the area of partitioning and transmutation at present. However, in KASAM's opinion, SKB should remain open to the possibility that such increased work within the framework of EU-funded research on transmutation, currently discussed, can lead to the need for increased Swedish contributions.

The Act on Nuclear Activities (1984:3) contains two provisions which, in KASAM's opinion, many researchers perceive as a signal from the parliament and the Government that they should not focus on the nuclear field. In this way, society could lose researchers who, in other circumstances, could have made important contributions to resolving the nuclear waste management issue.

KASAM refers both to the prohibition in § 6 against preparatory measures with the aim of constructing a nuclear reactor in Sweden and to the more decisive stipulation § 5a which prohibits the Government from granting permission for the construction of a new nuclear reactor.

The prohibition in § 5a is probably applicable to the type of facility that would be needed to conduct partitioning and transmutation. Paragraph 6 of the Act on Nuclear Activities allows research to be conducted in the nuclear field although, due to the wording, the exact meaning can hardly be understood without a detailed study of the government bill behind the Act.

KASAM proposes that § 6 should be revoked, partly because its meaning can easily be misunderstood and partly because the justifications that may have existed when the provision was introduced are no longer topical. Furthermore, the Government should investigate how the prohibition in § 5a against granting permission for a new nuclear reactor can be modified. In KASAM's view, the legislation should be formulated in such a way that the Government is not formally prevented from granting permission, in Sweden, for a facility for the partitioning and transmutation *if* further work indicates that such a facility is desirable.

KASAM emphasizes that the deletion of § 6 and a modification of § 5a do not leave the way open for new nuclear power plants to be constructed and operated, since such activities, in any case, require special permission by the Government. The institutions with a political responsibility already have the necessary tools for implementing the energy policy decided in a democratic process.

Decommissioning

KASAM emphasizes the importance of ensuring that the decommissioning issues are accorded attention and is positive to the review of the Financing Act announced by the Government where these issues will be dealt with to some extent.

Other long-lived waste

In KASAM's view, it is important that other long-lived waste (besides spent nuclear fuel) is to be characterised and documented. It is also important to investigate the long-term properties of the concrete that is to be used as a construction material in the repository for such waste. Furthermore, the safety assessment methodology must be developed for the special type of waste as the existing, long-lived waste.

The need for a research programme focusing on aspects of social sciences and the humanities related to the nuclear waste issue

KASAM notes that SKB's local work may be important for local and regional societal conditions. Therefore, it is important that this work should be conducted in close contact with developments on the socio-economic, legal and democratic arenas. KASAM concludes that there is a need to now start a research programme focusing on the social and humanistic aspects of the nuclear waste issues. One possibility is for the Government to initially give KASAM the task of defining research needs and for being responsible for the implementation of such a research programme. Work should be conducted in two stages.

During an initial stage, the Government could give KASAM the task of defining urgent research tasks within the humanities and social sciences that are relevant for the disposal of nuclear waste.

During the second stage, KASAM will identify, after consulting suitable institutions in the research community, qualified researchers who will be asked about their interest in becoming involved in the research tasks that have been identified during the initial stage. Subsequently, KASAM will give researchers the task of conducting projects that KASAM considers to be particularly important, KASAM will administer financing and will agree with researchers on how the results are to be reported.

In KASAM's opinion, a reasonable level of funding for the social science research programme on nuclear waste would be in the order of SEK 10 million per year. This level should be reached after a development period of 2-3 years and would be maintained during the site investigation phase, in other words until the time that SKB obtains permission in accordance with the Environmental Code and the Act on Nuclear Activities to start work on a repository. At this time, it is justified to consider whether the programme should continue along the same lines, whether the direction of work should be changed or whether the programme should be terminated.

Financing should be secured by the Government making resources available to KASAM from the Nuclear Waste Fund.

1 Introduction

1.1 Background

According to § 12 of the Act (1984:3) on Nuclear Activities, the reactor owners must prepare or commission the preparation of a programme for the comprehensive research and development activities and the other measures necessary to safely handle and dispose of nuclear waste generated by nuclear activities and to safely decommission and dismantle facilities that are no longer needed. The programme is to be prepared and submitted to the Swedish Nuclear Power Inspectorate (SKI) once every three years and shall cover a time-period of six years.

The reactor owners have commissioned their jointly-owned company, the Swedish Nuclear Fuel and Waste Management Co. (SKB) to prepare this programme. RD&D Programme 2001 – *Program for research, development and demonstration of methods for the management and disposal of nuclear waste* – was submitted by SKB in September 2001.

KASAM – the Swedish National Council for Nuclear Waste – is an independent scientific committee within the Ministry of the Environment charged with the task of investigating issues relating to nuclear waste and the decommissioning of nuclear facilities as well as providing the Government and certain regulatory authorities with advice on these issues. KASAM's terms of reference include a report of its independent evaluation of the nuclear power companies' research and development programme. This report is KASAM's review statement to the Government on SKB's RD&D Programme 2001.

SKI earlier submitted its review statement to the Government on RD&D Programme 2001 (see SKI Report 02:9, in English). In connection with its evaluation of the Programme, SKI obtained statements from the Swedish Radiation Protection Authority (SSI), see SSI Report 2002:3, in Swedish, and about 40 other reviewing bodies.

1.2 KASAM's review of RD&D programme 2001

KASAM's review was largely conducted through the work of its members, experts and secretary.

The basis of KASAM's review includes KASAM's earlier review statement on RD&D Programme 98 (September 1998) and on RD&D Programme 98 Supplement (*Integrated account of method, site selection and programme prior to the site investigation phase*, December 2000), and the Government's decisions (January 24, 2000 and November 1, 2001) on both of these reports on the RD&D Programme. KASAM has also taken into account the review statements from SKI and SSI and other reviewing bodies on this RD&D Programme.

The following report starts off by presenting KASAM's overall evaluation of RD&D Programme 2001. Comments are then provided to the sections in RD&D Programme 2001 that KASAM has reviewed in detail. Finally, KASAM presents its view on the need for a research programme focusing on aspects of the social sciences and the humanities related to the nuclear waste issue.

2 Overall evaluation

2.1 Background

The focus of SKB's RD&D Programme 2001 is technical/scientific with an emphasis on research and technology development. The programme does not deal with humanistic and social science issues which are important for the disposal of nuclear waste. In the preface to RD&D Programme 2001, SKB states that issues concerning the siting of SKB's facilities will be reported in connection with applications to the authorities and in the accompanying environmental impact statements.

2.2 KASAM's evaluation

In KASAM's opinion, the reactor owners, through RD&D Programme 2001, have complied with the requirements of § 12 of the Act on Nuclear Activities.

In KASAM's view, SKB's research and development programme shows great merit. This applies both to what SKB has done and what it intends to do. The report is well-structured and clear. It contains a systematic review of primarily the authorities' earlier comments and how these comments have been addressed or how SKB intends to address them.

RD&D Programme 2001 shows that there is still a considerable need for development work in a number of important technical areas. This applies, for example, to the fabrication and sealing of canisters as well as control methods for these activities. SKB's canister laboratory in Oskarshamn is an important resource in this field.

Within other areas, for example, geology, chemistry, hydrology, biology and rock mechanics, there is also a great need for further research and development work, and for practical demonstrations of technical applications. The Äspö Hard Rock Laboratory is therefore important both for the scientific understanding of different processes and for practical handling in connection with the deposition and retrieval of canisters etc.

In-depth knowledge of the barriers (canister-buffer-backfill-geosphere) and a deeper understanding of the composition of the biosphere and the biological processes are the basic prerequisites for a safe disposal as well as for the possibility of preparing reliable environmental impact statements and safety assessments in a long-term perspective. The understanding of the risks of deep disposal is thereby facilitated, compared with other risks in society. The safety assessment is the tool with which different issues and parameter values can be linked in order to obtain an overall view of the safety in the disposal system. The safety assessment also needs to be developed.

In KASAM's opinion, SKB's timetable is far too optimistic to guarantee the good quality of all of the work that must be done. The development of technology and control methods for the fabrication and sealing of canisters etc. as well as the development and implementation of site investigations, safety assessments, environmental impact statements and licence applications, with supporting technical documentation, are examples of time-consuming stages for the construction of a deep repository. Furthermore, some of the scientific experiments are of a long-term nature and must therefore be conducted in parallel with the rest of the development work.

In KASAM's opinion, humanities and social science issues, that are of importance for the disposal of nuclear waste, should be accorded greater attention. In Chapter 14, KASAM has presented a proposal for how research in these areas can be organised and financed.

KASAM emphasizes that future RD&D programmes should have a broad scientific basis in order to comply with the requirements of the Act on Nuclear Activities regarding comprehensiveness.

In their review statements on RD&D Programme 2001, SKI and SSI have proposed that SKB should be required to present a strategy document which should be kept updated. In KASAM's opinion, such a report of current strategic issues should be made available to the public and other parties concerned. KASAM also believes that such a documentation of strategy issues should be subjected to a review process in the same way as the recurrent RD&D programmes, which must satisfy requirements on the comprehensive reporting of SKB's research and investigation work etc.

The Environmental Code stipulates the best available technique. This assumes that alternative possibilities are investigated and evaluated with respect to safety and environmental consequences. In order to promote further research on alternative methods of managing spent nuclear fuel, such as partitioning and transmutation, KASAM proposes a review of the first paragraph of § 5a and § 6 of the Act on Nuclear Activities.

3 Safety assessments

3.1 Background

SKB emphasizes safety assessments and the constant interplay between safety assessment, research and repository design, where the knowledge of the long-term changes in the repository environment is central. SKB's safety assessment report, SR 97, is an application of safety assessment methodology. This report has been reviewed by SKI, SSI, KASAM and a number of other reviewing bodies. The report has also been reviewed by international experts on the initiative of SKI. SKB has also partly taken into account the viewpoints that were expressed in connection with the review of SKB's RD&D Programme 98 Supplement (*Integrated account of method, site selection and programme prior to the site investigation,, phase*) that the Government required SKB to submit.

SSI and SKI have promulgated regulations for disposal with which the results of the safety assessment will be compared. These regulations also contain instructions for how the safety assessment is to be performed.

In previous reviews of SKB's RD&D programmes, KASAM has supported SKB's work within this area. This applies to the use of the THMC (thermal, hydraulic, mechanical and chemical) diagrams where the assumptions for the safety assessment are reported. KASAM has also asserted the importance of different scenario choices. KASAM has also pointed out that the sensitivity analysis for the complex systems must be developed.

Furthermore, KASAM has emphasised that other initial states besides a closed repository should be analysed.

3.2 KASAM's evaluation

The safety assessment chapter (Chapter 3) of RD&D Programme 2001 provides an introduction to a number of different assessments that are dealt with in subsequent chapters. The chapter describes SKB's programme with the aim of developing the methodology for the assessment of the long-term safety of the deep repository. It should be noted that the direction and scope of the safety assessment are dependent upon the initial point of time selected for the description of repository safety. On page 30, SKB states that issues relating to the initial state are dealt with in chapters 3-10. In the introduction to Chapter 3, SKB states that "the time for the initial state may be different for different repository sections". Based on RD&D Programme 2001, it can be seen that the choice of the time for different initial states, which is important for the safety assessment, has been done in such a way that certain safety-related issues fall outside the safety assessment for the repository, even if these may be of importance for disposal. For example, this applies to the following:

- Safety assessments of spent fuel encapsulation
- Safety assessments of the transportation of material from the central interim storage facility for spent nuclear fuel (CLAB) to the encapsulation plant and of the transportation of encapsulated spent fuel to the repository
- Safety assessment of the operational phase of the repository.

The next RD&D programme should clearly state when and where such safety assessments will be conducted.

Furthermore, the RD&D programme lacks a detailed description of safety problems in connection with a possible retrieval of canisters. In Section 12.3.4, a short description of the *Retrieval* project is provided. However, it is not clear from this description which form of safety assessment will be conducted. This should also be specified in the next RD&D programme.

The programme for system description is reported in Section 2.2, the programme for scenario selection is reported in Section 2.3 and the programme for the analysis of selected scenarios is reported in Section 2.4.

On page 32, SKB states that a complete description of all thermal, hydraulic, mechanical and chemical aspects of the disposal system in time and space “would seem to be beyond the realms of possibility.” However, many parts can be modelled in detail and this is an important aspect of the safety assessment. In Section 2.3 on *choice of scenarios*, the modelling chosen by SKB is presented. The scenarios treated are based on the assumption that conditions in the repository change, with the exception of the damaged canister scenario which is an “internal” scenario. Here it is maintained, for example, that the consequences of earthquakes for repository safety will be assessed. It is also stated that “SKB intends to continue the work on scenarios based on human actions”. However, the scenarios to be investigated should be specified and whether these scenarios include intentional or unintentional human intrusion should be stated.

The internal scenario, the damaged canister scenario, must be included in the list of scenarios since it is a prerequisite for analyses of the capability of the other barriers to retain or retard radionuclides released from a canister. However, even in the case of the other engineered barriers, the buffer and the backfill, damage scenarios must be analysed, partly to provide a basis for acceptance criteria.

In KASAM’s opinion, it is essential that the safety assessment assumptions and methodology should be described and justified in a clear manner. The safety assessment is the tool used to show that repository safety (or the safety of other parts of the disposal system) can be achieved and that the requirements specified by the authorities can be met. Therefore, in KASAM's view, it is important that scenarios that are selected should provide a view of the safety at different time-perspectives that are likely to be involved (from 100 to 100,000 years). One basis for the safety assessment should be that safety should be analysed for the time that the spent nuclear fuel is a hazard. The uncertainty in predictions and calculations can increase with time and this must be taken into account. However, to refrain from long-term assessments on account of the difficulty of making them can never be considered to be a reasonable level of ambition. Conducting a safety assessment for a repository for spent nuclear fuel is a major and complex technical/scientific undertaking which also entails philosophical and ethical issues.

Section 2.4 presents and summarises the SR 97 safety assessment. This work includes a method for risk calculations. SKB states that several risk calculation issues must be further investigated. It should be emphasised that certain risk calculations cannot be performed in a simple manner. The risk of the repository being subjected to intentional or unintentional human intrusion is such an example. It should be considered whether or not the RD&D programme should comprise a description of such "non-quantifiable" risks.

KASAM also emphasises the function of the safety assessment and its importance as a tool for identifying and improving the understanding of phenomena and processes in connection with research and the development of the disposal system. This means that the safety assessment should be one (of several) tools for guiding site investigations and for the development of the engineered barriers.

KASAM's earlier comments on SR 97 have largely been taken into account in RD&D Programme 2001. SKB should also take into account KASAM's earlier comments on SR 97, as well as the comments that KASAM has presented here, in SKB's planned new methodology report, which will be partly based on results from site investigations.

Conclusions

SKB’s safety assessments have focused on the long-term safety of the repository. In KASAM’s opinion, safety assessments should also be conducted for the operational phase of the repository as well as for other disposal components besides the repository, for example, the encapsulation plant and the transportation system. A safety assessment should also be prepared for the possible retrieval of canisters from the repository.

SKB has conducted a systematic development of the safety assessment methodology for the long-term properties of the repository. However, in KASAM’s opinion, the methodology needs to be further developed. KASAM particularly emphasises the initial canister defect scenario and the issues relating to the encapsulated fuel as well as the cast iron insert. Defect scenarios also need to be analysed for other barriers, such as the bentonite buffer and the backfill.

Furthermore, KASAM considers that several issues relating to probabilistic risk analysis need to be further investigated. KASAM also points out that it is difficult to calculate the probability of certain processes, for example, human intrusion.

KASAM also emphasises the function of the safety assessment, as a tool for identifying and improving the understanding of processes that are of importance for safety and maintains that the safety assessment should be a tool for guiding site investigations and for the development of engineered barriers.

4 Fuel

4.1 Background

The terminology used in the descriptions of the repository can cause some misunderstanding regarding the research programme for the fuel[1]. The fuel matrix, the uranium oxide pellets, is encapsulated in a tube (*cladding*) made of Zircaloy, which is an alloy of the metals zirconium and tin. The copper canister (with a cast-iron insert), which contains the spent fuel to be deposited in the repository, is called the *canister*. This terminology is used throughout this chapter.

The principle for a KBS-3 type repository is to isolate the spent fuel from the mobile groundwater by enclosing it in a leaktight canister. The repository is safe as long as the canister continues to be leaktight. However, it cannot be assumed in a safety assessment that all canisters will continue to be leaktight forever. Therefore, the safety assessment includes a damaged canister scenario, where one or several canisters become filled with water at some point in time. After this time, radionuclides will be able to leach out of the spent fuel matrix. Many factors determine radionuclide leaching.

- The cladding limits or completely prevents the supply of water to the surface of the spent fuel pellets. This reduces leaching.
- The spent fuel pellets become more or less fragmented as a result of irradiation in the reactor. This increases the contact

[1] This observation applies to the Swedish terminology, where the terms *kapsling* (cladding) and *kapsel* (canister) are similar enough to cause confusion.

surface between the water and the spent fuel and, thereby increases leaching.

- The chemical composition of the penetrating groundwater is important for the leachability of the radioactive substances in the spent fuel.
- The radiation from the spent fuel causes water molecules to break down (radioloysis), releasing oxygen atoms. Leaching increases in the presence of oxygen (oxidising environment).
- The water inside the canister will react with the iron in the cast iron insert of the canister to form free hydrogen gas. The hydrogen gas can react with oxygen atoms, using up oxygen (reducing conditions) to reform water molecules. This reduces leaching.

In order to perform calculations of the release of radionuclides from the fuel, it is necessary to obtain data on these factors. In many cases, these data must be determined through laboratory measurements. The measurements should be made under conditions that, as closely as possible, resemble the conditions inside a canister that has been deposited in the repository. Measurements have been conducted at Studsvik under contract to SKB and at other laboratories that are independent of SKB under increasingly repository-like conditions. In RD&D Programme 2001, SKB reports the results of such measurements, the conclusions that it considers that it can draw from these results as well as programmes for further measurements during the coming six-year period.

4.2 Water and gas transport in the canister cavity

SKB refers to the canister chapter (Chapter 4) in RD&D Programme 2001 and the integrated studies that are being conducted of the evolution of a damaged canister. This is justified with respect to the actual leakage of water into the canister and how this is affected by hydrogen gas generation when the cast-iron insert corrodes. However, the most important corrosion process is the leaching of radionuclides out of the spent fuel. This leaching process is studied within the fuel dissolution programme. However, the programme description does not refer to the conditions that cause corrosion and which result from the transport process inside the canister cavity and near to the spent fuel pellets.

These conditions have been analysed in reference 5-24 of RD&D Programme 2001. This report shows that the cavity will become filled with water and a mixture of gases – hydrogen gas, water vapour and the gas that was originally present in the cavity. If the hole in the canister is in the upper part, for example in the weld between the copper cylinder and the lid, the main leakage will comprise hydrogen gas and water vapour. The radionuclides that will primarily leak out are those that can be transported as gas. If there is a hole in the lower part of the canister, the hydrogen gas will press out water through the hole. In that case, primarily water-soluble radionuclides will leach out of the canister. The water level in the canister cavity will depend on the hydrogen gas pressure and on how high over the canister’s bottom the hole through the canister is located.

4.3 Damage to the cladding

So far, most of the fuel elements have been intact when removed from the reactor. This means that no holes have been found in the Zircaloy cladding. Over a long period of time inside the repository, holes will occur in the cladding since each radionuclide decay that causes an alpha particle to be emitted will result in a helium atom. The pressure inside the cladding will therefore increase until the cladding ruptures, causing gases to leak out.

It is difficult to directly measure irradiated fuel rods. However, it should be possible for SKB to conduct reasonable assessments of the length of time that it takes before the cladding starts to leak as a result of corrosion attack or internal overpressure. Since no radionuclides leak from undamaged fuel rods, the expected time to more extensive cladding damage may be important in analyses of the consequences of early damage to the copper canister.

Damage to the cladding as a result of internal overpressure may take different forms and may be located at different positions. If the hole is small, the corrosion environment inside the cladding will differ from the environment at surfaces which are directly exposed to water in the canister. The water inside the cladding may have different corrosion properties. Figure 4-7 of RD&D Programme 2001 illustrates how differences in corrosion potential can have major consequences for the dissolution process.

Conclusions

SKB limits itself to keeping track of developments within the research area of cladding damage. In KASAM's view, this is far too low a level of ambition.

4.4 Fuel dissolution

The dissolution studies are the most central part of the fuel programme. In the very long term, the protective capabilities of the engineered barriers may become questionable. At that point, the protection of the biosphere could consist of limitations on the release of radionuclides from the spent fuel and in the bedrock's capability to retard and dilute radionuclides on their way to the biosphere. SKB is also placing considerable emphasis on dissolution studies.

Measurements that have so far been conducted and the preliminary conclusions that SKB has drawn are presented in detail and in an informative manner. In its review of RD&D

Programme 98, KASAM stated that the sensitivity of the measurement methods is very important since the concentrations of actinides and fission products are normally very low. In this context, KASAM pointed out that the mass spectrometer used in Studsvik is a low-resolution instrument and that more modern instruments with sector magnets provide a sensitivity that is at least one hundred times greater and detection limits that are at least 10 times lower. It is positive that SKB is now planning to purchase such an instrument.

The programme for further research almost solely focuses on improved equipment and measurement methods. No actual programme of work is reported that states objectives, sub-goals that have now been reached and the strategy for attaining the remaining objectives. As was previously stated in Sections 4.2 and 4.3, SKB has conducted and will continue to conduct analyses of the processes inside a canister when a penetrating hole has occurred in the canister wall. The corrosive environment surrounding the spent fuel rods will change under different stages of water-filling and the condition of the rods can be expected to vary.

Conclusions

In KASAM's view, the research programme on fuel dissolution, which from the beginning was general in nature, should focus on the conditions that, according to analyses conducted, will occur inside the canister. The dissolution studies in oxidising (air), reducing (hydrogen gas) and oxygen-free (anoxic, argon) conditions are of this type. However, the programme needs to be linked to the analyses of canister damage and the justification and goals of the various programme points need to be reported. In KASAM's opinion, the programme is sufficiently important to warrant its own research plan.

4.5 Speciation, colloid formation

Speciation (formation of chemical compounds) and colloid formation of the fuel's degradation products is an important area since it affects, among other things, radionuclide mobility in the repository and in the biological environment. Plutonium chemistry is important in this context and, at the same time, complex and largely unknown as a function of the component-rich environments in the repository and geology.

Conclusions

In KASAM's opinion, SKB should devote greater attention, in both theoretical and practical terms, to plutonium chemistry in connection with speciation and colloid formation in order to be able to correctly assess the transport processes from the fuel.

5 Canister

5.1 Background

The fuel canister can be seen as the most important barrier in the repository since its function is to prevent the mobile groundwater from reaching the radioactive substances in the fuel. The canister comprises two parts – a copper shell and an insert of cast iron. Both contribute to isolating the fuel from the water.

The canister must function as a barrier, without supervision, for a much longer time than has so far been demanded of any industrially manufactured product. Therefore, it is important that SKB can show that the method that it chooses for the fabrication of the canisters results in a very high level of defect-free canisters. SKB must also show that the manufacturing method will not result in such changes in primarily the properties of the copper that could jeopardise the lifetime of the canister as a barrier.

5.2 Temperature and heat transport

The mathematical modelling of heat transport has long been established. When the modeling is conducted with calculation codes, which are based on the finite element method (see box below), high precision results can be obtained in principle. Nevertheless, there are innumerable incorrect heat transport calculations due to the fact that, for example, an unsuitable assumption has been made for a boundary condition. The planned experiments in the Äspö Hard Rock Laboratory conducted to verify the calculated maximum temperature of the canister are therefore important.

Finite element method (example of application)

The heat flux and, therefore, the temperature distribution in a large rock volume which surrounds one or several local heat sources can be calculated using known equation relationships between the quantity of heat emitted by the heat source, the heat capacity and thermal conductivity of the rock and a known or assumed temperature, called a boundary condition, along the outer boundary area of the volume. The computer's capability to process large quantities of data has resulted in the calculation being performed in such a way that the volume is sub-divided into a large number of small-volume elements, known as finite elements.

5.3 Mechanical stresses

After roll-forming or extrusion (pressing through mouthpiece), as well as after welding, residual stresses arise in the material. Since high residual stresses increase the risk of cracking and stress corrosion, especially in welded joints, the magnitude of the stresses should be measured. The magnitude determines whether stress-relief annealing must be performed. The exact maximum level of the residual stresses that can be permitted is not known and should therefore be determined. However, they should be less than a half of the yield stress.

5.4 Deformation of the copper canister

Further studies of the welded joint’s capability to deform, or creep, without cracking are required in order to obtain adequate data, so that it can be shown that the creep properties are satisfactory. This applies both when electron-beam welding and friction-stir welding are used. The creep ductility (see box below) should not be less than 10 per cent, even after a long period of testing.

Creep ductility (a few comments)

At the temperatures of 75-90°C which are expected to occur initially around the canisters, a slow deformation, or creep, occurs in the copper material that SKB plans to use. The copper can withstand a maximum strain before cracking. This maximum deformation is called the *creep ductility* and it may not be exceeded.

The possible explanation of the positive impact of phosphorous on the creep strength of pure copper is that the phosphorous atoms interact in a favourable way with dislocations in the material, even if no-one has yet managed to directly prove this. It has been shown empirically that sulphur can be enriched in the grain boundaries (see box below). A well-known fact for many types of material is that increased sulphur concentrations and a large grain size increase the risk of low creep ductility. The grain boundaries weaken and increased stresses occur over the boundaries.

Grain boundary

Metals comprise small crystals or grains where the atoms occur in regular patterns. The grain boundary is the interface between one grain and the next. The size of the grain (grain size) is an important factor for the mechanical properties of the material.

Conclusions

The controlling mechanism, with respect to the impact of phosphorous on creep ductility, is an open question. In-depth studies of the controlling mechanisms are therefore important. For the extrapolation of creep data to be made to long time-periods with certainty, the mechanisms must be known.

When creep data is available for welded joints, detailed calculations of plastic deformation and creep in the canister must be conducted using the finite element method to supplement the calculations performed for the base metal alone.

5.5 Corrosion of the cast-iron insert

On page 88 of RD&D Programme 2001, SKB writes:

> If there is a penetrating breach in the copper shell, water can run into the gap between the canister insert and the copper shell and further into the insert, where it can cause anaerobic corrosion with hydrogen gas and magnetite as corrosion products.

KASAM states this is only one of several possible corrosion processes. During the first one or two hundred years, the copper shell will deform, be compressed, by the swelling pressure of the bentonite buffer, until it can be supported by the cast-iron insert.

The corrosion process will change when the gap has narrowed. The evolution will then be determined by the corrosion processes in the contact areas *copper-cast iron-water* and *cast iron-water*. The processes with the growth of a corrosion layer on the surface of the cast-iron, the deformation of the copper and the cracking must be described.

Conclusions

In its programme, SKB plans to conduct empirical studies of corrosion processes in the contact areas *copper-cast iron-water* and *cast iron-water* under realistic conditions and, with the ensuing data, perform new calculations of the evolution of a damaged canister. KASAM is satisfied that this work has been planned.

5.6 Corrosion of the copper canister

Comprehensive laboratory data are available for both general and local corrosion. Furthermore, intensive modeling work has been conducted. A large number of mechanisms may be active and the models are based on a series of assumptions. In certain cases, for example, stress corrosion, it has not always been possible to support these assumptions in detail.

So far, very limited studies have been conducted for weld joints. Since their microstructures are different from the base metal, experiments must be conducted also for welded joints. These experiments should include production-type welds.

Conclusions

Further basic studies are required, particularly in the case of stress corrosion-induced and microbial-induced corrosion on the copper canister. Furthermore, it is especially important to verify the results obtained so far with long-term experiments under as realistic conditions as possible. It should be possible to conduct such experiments at the Äspö Hard Rock Laboratory and such experiments have also partly already been planned.

5.7 Initial defects

SKB refers to RD&D Programme 98 on the issue of the design basis for the canister. The requirements specified include:

- Lifetime. The canister must be able to withstand all known corrosion processes so that it can be assessed to remain intact in the deep repository for no less than 100,000 years.
- Initial defects. Methods for fabrication, sealing and control must guarantee than only a few canisters can contain defects which could result in water penetrating earlier than expected.

In KASAM's view, the requirement on the limitation of initial defects in the copper canisters is far too vaguely formulated. It is important to delay the leakage of water. However, the time is not the only decisive factor for the consequences.

For good reasons, SKB has not investigated the size and form that initial defects can be allowed to have without the specified dose or release limits being exceeded. This cannot be determined since, in a multi-barrier system, there is no unambiguous relationship between initial defects in the canisters and radiation doses to a critical group. This is evident from figures 2-3, 2-4 and 2-5 on pages 40-42 of RD&D Programme 2001. These figures show the result of calculations performed with the assumption that, already from the start, there is a hole or crack through the copper with a 1 mm^2 cross-section. The maximum annual dose varies by several orders of magnitude when repeated calculations are conducted with different data for the groundwater flow, the chemical processes in the rock and biosphere conditions. The maximum dose therefore varies considerably between the three study sites: Aberg, Beberg and Ceberg.

The acceptance criterion for initial defects should be based on the requirement that the best available technique, together with requirements based on a dose/risk limitation, will be used for the engineered barriers in the repository, both for fabrication and for quality control. Canisters fabricated in the ongoing development programme are investigated with available methods for non-destructive testing. The sensitivity of the methods is checked by uncovering parts of the canisters, where defects have been observed or are suspected to occur, for visual inspection (investigation through a microscope).

There will be relationships between a shape, size and detectability of a defect. Defects above a certain size are detected with adequate reliability, while minor defects risk being overlooked. This threshold size can be used as the acceptance criterion for initial defects, on condition that estimated releases from canisters with initial defects of that size are well within the stipulated limits.

Conclusions

In KASAM's view, the requirement on the limitation of initial defects in the copper canisters is far too vaguely formulated. The acceptance criterion for initial defects should be based on the requirement that the best available technique, together with requirements based on a dose/risk limitation, must be used for the engineered barriers in the repository, both for manufacturing and quality control.

6 Encapsulation

6.1 Background

RD&D Programme 2001 covers issues relating to the design, manufacturing, sealing and quality assurance of the canisters that are to isolate the spent nuclear fuel in the deep repository. Issues concerning the encapsulation relate to the issues of the durability of the canister which were discussed in the previous chapter.

6.2 Canister design

In its review of RD&D Programme 98, KASAM stated that, from the manufacturing and handling standpoint, a copper canister with a thickness of 30 mm was clearly preferable to a canister with a thickness of 50 mm. This applies providing that no new results are obtained concerning localised corrosion which would exclude this possibility.

A 30 mm thickness makes it easier to attain the required fine grain size, reduces the risk of cracks in the weld and improves the precision of the non-destructive testing. The mechanical integrity in connection with canister transportation needs to be verified.

Conclusions

The canister design has been adequately specified in an earlier SKB report. The basis of the principles for the design is good. However, continued flexibility is important with respect to the results from the work on canister fabrication and joining.

6.3 Canister fabrication

KASAM agrees that extrusion or pierce and draw processing is preferable to rolling and roll-forming, which would also require longitudinal welds. The former process can be expected to result in a smaller grain size and less residual stresses. Further work on documenting the fineness and long-term stability of the microstructure for the selected fabrication method is of central importance.

Since satisfactory mechanical properties of the cast-iron insert have not yet been obtained, the choice of spheroidal graphite iron (nodular iron) and the casting process must be thoroughly analysed. As SKB points out, the materials strength properties of the cast-iron insert must be improved through better control of the casting process by the use of another type of nodular iron. The presence of defects should also be characterised.

Conclusions

To obtain satisfactory results in connection with the casting of the cast-iron insert, simulation programs for the process should be run, so that different insert designs can be tested. During new fabrication trials, it should be shown that the requirements of the performance specification are adequately met.

6.4 Welding method

Considerable work remains to be done on the joining of the copper canister. Since the copper canister is perhaps the most important barrier in the KBS-3 system, the single critical factor is that macro defects should not form in connection with welding. It is particularly important to avoid surface defects that can increase the risk of, for example, stress corrosion.

Of the two welding methods that are now being studied, friction-stir welding appears to be more promising that electron-beam welding. Further investigations should be conducted with both methods, until at least one of these methods shows satisfactory results. A thorough understanding of the mechanisms that result in defects must be developed.

A quality assurance methodology must be developed that, in a convincing manner, can result in a very small number of macro defects.

Conclusions

Considerable work remains to be done on the joining of the copper canister. Further investigations should be conducted with both methods – friction-stir welding and electron beam welding – until at least one of these methods shows satisfactory results. A thorough understanding of the mechanisms that result in defects must be developed.

6.5 Testing

A battery of testing methods – X-ray, ultrasound, eddy-current, leaktightness control etc. – are required in order to verify that the completed canister is free from macro defects, especially those that penetrate the canister wall. Further extensive studies in this area are of central importance in order to obtain a detailed basis for the advantages and limitations of individual methods.

7 Buffer

7.1 Background

The buffer surrounding the canisters is a component with several functions in the multibarrier system. It must:

- keep the canister in place and remove residual heat from the fuel,
- limit the transport of corrosive substances to the copper canister from the surroundings and leaking substances from the canister, including colloidal particles, as well as
- be able to release gas which can form in the canister if water leaks in.

In order for this to be achieved, the buffer must swell so that it fills the available space when it is saturated with groundwater and so that it retains its leaktightness in the future.

SKB has chosen Na bentonite (MX-80) – a clay which swells when saturated with water – as the reference material for the buffer. An important aspect is water saturation as a function of time, temperature and groundwater salinity. Another is the chemical changes in the bentonite which are caused by the groundwater in the repository having another chemical composition than the groundwater at the site where the bentonite is extracted.

Bentonite

The term bentonite was used for the first time by Knight (1898) to designate a special high colloidal plastic clay that was found in an area in Wyoming. The clay has the unique property of swelling to many times its original volume when placed in water and of forming tixotropic gels with water, with quite small quantities of clay. Hewitt (1917) later showed that the clay was formed "in situ" through the conversion of vulcanic ash. Ross and Shannon (1926) subsequently confirmed this and established that such clays mainly consist of montmorillonite and that they are generally high-colloidal and plastic. The term bentonite is used by many mineralogists and geologists nowadays and has no connection with the physical properties of the clay.

(More detailed information on the role of bentonite as an engineered barrier in a repository for spent nuclear fuel is provided in Chapter 5 of KASAM's *Nuclear waste state-of-the-art reports 2001*, SOU 2001:35.)

Clays contain clay minerals that comprise layer silicates with high adsorption properties, high cation (positively charged ions) exchange properties, high resistance to diffusion, low permeability, large specific surface area and good swelling properties. These properties are important for the environment in general and in contexts where the durability of material is important and are of decisive importance with respect to the use of clays as engineered barriers.

The specific properties of the clays are highly dependent on their mineralogical composition. The quantity and type of mineral they contain are essential in determining their suitability as an engineered barrier.

Important and measurable parameters include the cation exchange capacity (CEC), specific surface area, diffusion coefficients for different types of ions and hydraulic conductivity. These, and other requirements on the buffer, are discussed in both RD&D Programme 98 and in RD&D Programme 2001. Additional parameters discussed are gas conductivity, swelling pressure, deformability, thermal conductivity and chemical stability.

7.2 Swellability

The clay minerals most used in technical contexts are kaolinite, smectite, montmorillonite (of the smectite type), vermiculite, illite and chlorite (see box below).

Examples of clay minerals

The term kaolinite stands for a number of different clay minerals which contain 1:1 layers, namely a tetrahedric silicate layer and an octahedric aluminium layer. These clay minerals have a large number of industrial applications as components in paints, paper, plastic, rubber etc.

Montmorillonites consist of units that contain two tetrahedric silicate layers and one octahedric aluminium layer, namely minerals of the 2:1 type. Some of the silicon in the tetrahedric layer is replaced by aluminium, giving the entire structure a negative net charge, which is compensated for by cations between the layers. If these ions comprise Na^{+} or Ca^{2+}, they can leach out and water molecules can penetrate between the clay layers and cause swelling. On the other hand, it is very difficult for potassium ions between the layers to leach out and thereby give the clay non-swelling properties such as in *illite*.

Chlorites are similar to montmorillonites in that they are 2:1 minerals, but have a somewhat different structure.

If the cations between the layers consist of Mg^{2+} (magnesium ions), these can leach out and cause a swelling clay, called *vermiculite*.

Perhaps the most salient property of clays is the change in volume when water or another polar solvent is added. Of the clay minerals mentioned above, smectite and vermiculite are classified as swelling and the others as non-swelling. Swellability is strongly linked to the cation exchange capacity (CEC) and the density and distribution of surface charges. Another important factor is the type of cation between the layers.

With respect to the swelling clay minerals, there is both an outer and inner surface area, due to the fact that the surfaces between the layers can be used. This is clear when, for example, montmorillonite (of the smectite type) is compared with the non-swelling clay minerals. The specific surface measured in m^2 per gram is, for example, 600-800 for montmorillonite of the smectite type but less than 100 for illite. The exchange capacity for cations, measured in milliequivalents per 100 grams, is in relation to the specific surface. It is 80-150 for montmorillonite and 10-40 for illite. Therefore, for many reasons, it is important to use swelling clay minerals in the buffer.

On page 98 of RD&D Programme 2001, SKB indicates that it is planning to study alternative buffer minerals.

Even if it is not realistic to study alternative materials to the same extent as MX-80, it is very valuable to better describe the importance of different parameters and, thereby, achieve a basic specification for the buffer material.

Conclusions

KASAM is positive to SKB’s plans to carry out studies of alternative buffer minerals in order to obtain a reference to montmorillonite-rich bentonite

7.3 Chemical stability

The chemical stability under the conditions expected in the repository are a very important factor when assessing the long-term evolution.

On page 102 of RD&D Programme 2001, there is a brief section on impurity levels. The uncertainties in the impurity levels are expected to be small and of no importance for the function of the buffer.

In KASAM's *Nuclear waste state-of-the-art reports 2001*, there is a description of how typical impurities in the bentonite can be expected to react in the repository (Chapter 5). A combination of small quantities of pyrite (FeS_2) and calcite ($CaCO_3$), which are common, could have a largely favourable impact by reducing oxygen gas and buffering the pH value in the bentonite.

Thereby, there is reason to not only determine general limits for impurities but to also investigate how combinations of impurities can affect long-term stability, both positively and negatively.

The conversion from Na-bentonite to Ca-bentonite must be considered to be unavoidable upon contact with groundwater and it is thereby important that the properties of Ca-bentonite with respect to quality parameters should be well known and predictable.

The conversion of montmorillonite to illite (see box in Section 7.2), otherwise known as illitisation is a further threat to long-term stability. The reactions that affect illitisation have been studied in depth. The main factors that control the process are the temperature and the access to potassium ions. Other important factors are time, water content, flow and pressure.

Illitisation can occur at temperatures above 80°C and mechanisms which involve the conversion of layer after layer in a solid phase and/or dissolution/reprecipitation of silicon-aluminium compounds have been discussed. The latter mechanism can also cause cementation in the buffer material. The extent of this process and the composition of the reprecipitated silicon-aluminium compounds will be highly dependent on whether the conditions in the bentonite are acidic or basic. Furthermore, at least during the first hundred years, there will be a considerable thermal gradient in the buffer which will affect these reactions.

Therefore, it would be very valuable if SKB, in connection with its studies of other compositions of buffer material, also investigated how a limited illitisation and cementation affect important parameters for the buffer.

Aluminium and iron precipitate as very low-soluble oxides or oxide hydroxides at neutral pH values, while other cations and silica, $Si(OH)_4$, are fairly soluble. These can then be transported quite far from the weathering zone. Silica, which has a lower solubility at high temperatures, can also precipitate onto the hottest part of the buffer, namely near to the canister surface. The ratio of Si/Al can therefore drop from 2:1, as in montmorillonite, to almost 1:1, as in kaolinite.

There is uncertainty surrounding the release, transport and precipitation of dissolved silicon and other substances in the buffer, which indicates the need for further studies in this area.

Conclusions

KASAM believes that there are good reasons why general limits for impurities should not simply be set. How combinations of impurities can affect the long-term stability of the buffer, both positively and negatively, should also be investigated.

In KASAM's view, it would be very valuable if SKB, in connection with its studies of other compositions of buffer material, also investigated how a limited illitisation and cementation affects important parameters for the buffer.

KASAM underlines the need for further studies on the release, transport and precipitation of dissolved silicon and other substances in the buffer.

7.4 Sorption

As stated on page 125 (RD&D Programme 2001), KASAM, in its review of SR 97, considered that knowledge of the adsorption properties of the bentonite had not been optimally utilised and that the sorption models for radionuclides that are used are relatively primitive.

Conclusions

With the help of the existing knowledge on the specific surface area of the main minerals, the cation exchange capacity, the type and concentration of available surface sites, temperature and ion-strength variations, KASAM believes that it should be possible to develop a more sophisticated sorption model, which includes ion-exchange, adsorption and surface precipitation of the most important radionuclides as a function of the concentration of the substances and the pH value of the pore water.

7.5 The early development

The initial water saturation of the bentonite in the repository will probably not be evenly distributed throughout the buffer volume. According to the discussion on page 105 (RD&D Programme 2001), calculations have shown that the mechanical integrity of the canister is not affected by uneven wetting. However, this conclusion is based on a number of assumptions about the increased water ratio during the manufacturing of the bentonite blocks and that the outer gap is filled with water. In addition to this, there is the fact that a temperature gradient in the buffer occurs as a result of radiation heat from the fuel.

Conclusions

The combination of wetting and temperature differences in the buffer with subsequent heat transport as a function of time and water quality is a challenging area of research. KASAM notes with satisfaction that SKB is studying these issues.

7.6 Gas conductivity

On page 96 (RD&D Programme 2001), SKB refers to experiments which indicate that MX-80 bentonite can "open up" and release large quantities of gas which may have been formed in connection with the corrosion of the iron insert in a damaged canister. It is then assumed that all damage arising through this process must heal and that the buffer material must regain its original qualities. The entire process is described in a very simplified manner and there are a number of parameters that have a major impact on the process, such as the degree of water saturation and swelling pressure. The solubility of gas in the pore water are also dependent on the partial pressure of the gas and also varies with temperature and ion strength.

Conclusions

There are remaining uncertainties regarding the understanding of gas transport in the buffer and the relationship between gas flow and swelling pressure. Therefore, KASAM considers that it is positive that SKB is prioritising this area and that both experiments and model development are required to investigate the process.

7.7 Erosion

There are a number of short-term reactions which, in turn, affect the long-term processes, including water saturation at different ion strengths and the groundwater composition.

In general, a high concentration of highly-charged cations lead to the flocking of clay mineral particles, which affect the swelling negatively and increase the hydraulic conductivity. Acidic conditions tend to cause flocking, while basic conditions generally lead to disperging.

Conclusions

KASAM is positive to the further research on bentonite erosion described in RD&D Programme 2001.

8 Backfill

8.1 Background

Deposition tunnels, transport tunnels, shafts and ramps from the ground surface as well as boreholes must be refilled, no later than when a possible surveillance period after deposition has been completed. SKB reports its requirements on the backfill of the tunnels at repository level. Where applicable, the requirements apply to the openings towards the ground surface.

The requirements on the backfill are that

- it should have a density that minimises the upward expansion of the buffer,
- it should have a hydraulic conductivity that is comparable to that of the surrounding rock
- it should have a swelling pressure against the roof that can resist block breakout and retain a swelling capacity that can seal off possible effects of channelling and creep movements and
- it may not have a negative impact on the repository barriers.

For a long time, KASAM focused on the backfill of the deposition tunnels as a problem for disposal. In its review of RD&D Programme 95, KASAM indicated the difficulties of backfilling the tunnels with a mixture of bentonite and aggregate (crushed rock). KASAM revisited this issue in its review on RD&D Programme 98, where KASAM highlighted the significance of the backfill for repository performance and pointed out the difficulty of controlling the quality of the backfill afterwards, if the backfill consists of a mixture of crushed rock and bentonite.

8.2 Composition of the backfill

In order to satisfy the requirements, SKB intends to use a backfill comprising a mixture of crushed rock and bentonite. The mixture is determined by the groundwater salinity and is expected to be between 85/15 % and 70/30 %.

In KASAM’s view, the buffer is a more important barrier than the backfill. The barrier function of the buffer is dependent on its density. As long as the initial density remains, the buffer provides very valuable protection for the copper canister against impurities and microbes in the groundwater and a significant barrier to the radionuclide transport from the canister to the surrounding rock. One condition for this is that the swelling of the buffer should be sufficiently limited.

The requirement that hydraulic conductivity should be comparable with that of the rock is justified by the fact that the deposition tunnels can otherwise comprise conductive pathways which affect water turnover in the repository. The water turnover at a depth of five hundred metres is primarily determined by the pressure difference, the gradient, which drives the groundwater and by the hydraulic conductivity of the fractures that open into the tunnel system. A backfill that is more porous than the rock’s fracture system redistributes the groundwater flow. However, this does not have to be a disadvantage to safety if radionuclides, which are released from the buffer, are largely transported into the backfill. In the backfill they are distributed over a larger water volume and exposed to a larger sorption surface area than if they are transported in a rock fracture. A porous backfill can also have advantages in terms of buffer saturation with the groundwater during the initial stage after closure.

SKB does not hide the difficulties that mixing bentonite with crushed rock entails. SKB will therefore investigate whether the bentonite can form colloidal particles in the repository environment.

In its programme, SKB also includes studies of the possibility of using other natural clays as backfill material and will continue its inventory of alternative backfill material.

Conclusions

KASAM considers that if the different requirements on the backfill are found to be difficult to unite, the function of limiting the swelling of the buffer should be prioritised.

In KASAM's view, SKB should conduct performance assessments of the *buffer-backfill-geosphere* system in order to clarify advantages and disadvantages of different types of backfill, including only natural clays, mixtures of crushed rock and clay as well as crushed rock alone that is of such a size distribution that it provides maximum resistance to pressing due to the expansion of the bentonite buffer.

Naturally, the assessment must include, as far as possible, the long-term evolution of the three types of backfill in groundwater environments with various salinities.

The areas to be backfilled – deposition tunnels, transport tunnels and shafts and ramps to the surface – may need to be filled with materials with different properties.

8.3 Weathering

It is not evident from RD&D Programme 2001 whether SKB will focus on issues relating to the weathering of crushed rock in the backfill material. In KASAM's opinion, these issues should be investigated.

Furthermore, RD&D Programme 2001 does not state whether there are any requirements on the size distribution of the crushed rock particles. The extent to which crushed rock particles and bentonite can be mixed and packed depends on the size of the crushed rock particles. Bentonite particles are very small, less than 0.002 mm, at least after disperging, while the crushed rock particles should be of varying size on the scale of mm to dm.

The dissolution rates (weathering) of different minerals included in the crushed rock vary considerably and, furthermore, depend on the sizes of the particles. It will probably be necessary to sieve and remove the largest and smallest particles in the crushed rock in order to achieve an adequately dense mixture and to avoid too rapid dissolution.

Potassium feldspar, which can generate potassium ions during weathering, should be avoided since it can contribute to illitisation. The weathering rate increases at low pH and higher temperatures. High water salinity can also contribute to potassium ion release through ion-exchange.

Conclusions

SKB should limit the quantity of potassium that the crushed rock can contain in order to be used in the backfill.

8.4 Sorption properties

The backfill can be a dominant transport pathway for radionuclides from the buffer to the bedrock which, as has been stated, does not have to be a disadvantage. So far, SKB has estimated sorption coefficients for radionuclides in the backfill by weighing together distribution coefficients for bentonite and rock in proportion to the fraction in the backfill. The crushed rock from the sites, which will now be investigated could be used for empirical determination during representative conditions of sorption and diffusion in the backfill material at different groundwater salinities and for the development of models for extrapolation in time.

9 Geosphere

9.1 Background

In the case of geological disposal of spent nuclear fuel, the bedrock is the ultimate barrier to the biosphere. Mechanical stability of the rock and control over fractures and groundwater conditions are important factors when constructing a deep repository.

9.2 General

The chapter on the geosphere (Chapter 8) in RD&D Programme 2001 does not deal with site-specific timetables for the construction of a deep repository. However, SKB has indicated that considerable resources and expertise will be utilised in connection with the site investigations. The basis for planning these investigations will be the KBS-3 method.

SKB has endeavoured to cover all issues that in some way may be connected to a deep repository. Although this is positive, at the same time, issues must be prioritised. A deep repository in accordance with the KBS-3 method will consist of several barriers (canister, buffer, backfill and bedrock). Based on SKB's proposed sites for investigation, it will be located at a depth of about 500 metres in the crystalline bedrock of the Baltic Shield.

The geological data that will be collected in connection with the site investigations will be decisive for the future performance of the repository. SKB points out that a methodological treatment of all of this information will be important. In order to forecast a future evolution of the crystalline bedrock in 100,000 years, knowledge of the Baltic Shield and its geological history is of decisive importance.

The tectonics (see box below), and particularly the fracture tectonics, is very important for a deep repository in crystalline bedrock. Since fractures cannot be dated on their own, fracture formation in rock types of different ages should be studied instead. An analysis of when, where and how the fractures, that we now see in the bedrock, are formed is needed, not only from the standpoint of a site investigation. The reactivation process, namely movements along existing fractures, must be studied and understood in order for a safe deep repository to be constructed.

Tectonics

In this context, tectonics is the deformation of the bedrock due to movements in the bedrock. Deformation can be either plastic or brittle. In the case of *plastic deformation*, the rock behaves like a viscous mass, in which folding or foliation occurs. In the case of *brittle deformation*, the rock is harder and, for example, fractures or fracture zones are formed. Faults usually occur in connection with the deformation of the bedrock.

Conclusions

KASAM considers that the main direction of the further investigations of the geosphere, as reported in RD&D Programme 2001, is suitable.

9.3 Bedrock geology

SKB has earlier stated that its objective is to obtain a geological variety for the site selection through the study of different types of bedrock.

In its review of RD&D Programme 98, KASAM expressed the criticism that basic, magmatic rock types were dismissed in a cursory manner in the RD&D Programme. In a comparative perspective, KASAM considered that the basic rock types should not be written off at this stage.

In its review of RD&D Programme 98 Supplement – *Integrated account of method, site selection and programme prior to the site investigation phase* – KASAM, in June 2001, stated that SKB, in parallel with the start of investigations at proposed sites should consider whether conditions existed to identify an area which would represent other geological conditions than the three proposed areas in the municipalities of Oskarshamn, Östhammar and Tierp after the gneissic area of Fjällveden was eliminated when the municipality said no to site investigations. KASAM stated that the reasons for investigating such an area were so strong that investigations should not be limited to those municipalities where feasibility studies were carried out. KASAM referred to geological data from the earlier studied site of Gideå (Ceberg) which was dominated by gneissic rock types of sedimentary origin, sedimentary gneiss, with low hydraulic conductivity at repository depth and groundwater with low salinities, which were considered to be favourable conditions for a repository.

In RD&D Programme 2001, SKB uses the three earlier proposed sites for investigation: the municipalities of Oskarshamn, Östhammar and Tierp, as the basis of its work. The areas are designated *Simpevarp* (Simpevarp includes the Simpevarp peninsula and the large area to the west), *Forsmark* and *northern Tierp*.

However, after decisions by the municipalities concerned, only two of these siting alternatives remain as areas for site investigations, namely *Forsmark* and *Simpevarp*. The *northern Tierp* alternative (with the *northern Tierp/Skutskär* siting alternative) in the municipality of Tierp has been eliminated after a decision by the municipal council in April 2002.

This means that SKB will enhance geological knowledge with respect to two granite alternatives: Granite in *Simpevarp* and gneissic granite (in the form of a tectonic lens) in *Forsmark*.

However, this should not exclude the possibility of making a comparison, as a matter of principle, between the properties of the bedrock in both of these sites and the properties of other rock types (for example, basic magmatic rock types, sedimentary gneisses and grey wackes) which, to a certain extent, have been studied during study site investigations conducted at an earlier stage. Such a comparison should be included in the basis for decision-making for future site selection, in accordance with the stipulations of Chapter 2 § 4 of the Environmental Code.

Requirements of the Environmental Code

According to Chapter 2 § 3 of the Environmental Code (1998:808), the best possible technology must be used in connection with professional activities. In § 4 of the same Chapter, it is stipulated that a suitable site shall be selected so that the purpose of minimal intrusion and inconvenience to human health and the environment shall be achieved.

Conclusions

In KASAM's opinion, the properties of the rock, according to the results from the site investigations, should be described in the light of the properties of other rock types. The development of the "descriptive rock mechanical models for potential repository sites" stated by SKB should be supplemented by the possibility of conducting comparative assessments of rock types with different properties (both geochemical and hydrogeological properties).

9.4 Overview of processes

SKB states that

> The mechanical evolution is determined by how the geosphere responds to the different mechanical loads to which it is subjected. The loads may consist of the thermal expansion to which the heating of the repository leads, the pressure from swelling buffer and backfill, effects of faults and the large-scale tectonic evolution. Changes in the geosphere may include fracturing, reactivation (sudden movements in existing fractures) or rock creep (slow redistributions in the rock). Movements in intact rock, i.e. compression/expansion of otherwise intact rock blocks, also occur, along with erosion, i.e. weathering of the surface rock, particularly in conjunction with glaciations.

Rock creep

Rock creep occurs when part of the rock is subjected to a sufficiently high load that does not exceed the mechanical strength of the rock. If this load occurs over a long period of time, non-elastic deformations will arise which, in certain cases, can lead to fracturing.

In KASAM's opinion, the description of the mechanical loads, provided in RD&D Programme 2001, is good. If the description of the mechanical loads is to be complete, added information should be provided: that a stress redistribution occurs as a result of the removal of rock in connection with repository construction. This means that the stresses in certain parts of the rock increase while the stresses in other parts decrease. An increase means that there is an increased risk that the stress level will be critical, namely, higher than the stress that the rock can bear. A reduction could mean that tensile stresses will occur which means that natural fractures that intersect the opening, could open up. SKB does not mention changes caused by new glaciations. A 2-3 km ice cover entails an increase in the natural stress levels, at the same time that the groundwater level changes.

Whether or not the movements occurring in the intact rock blocks are assumed to be elastic is not evident from the description. An elastic deformation of a rock volume means that the form will change without any fracture formation. On the other hand, the change in form will result in the movement in the fractures surrounding the rock block. With this approach, maximum movements in the existing fractures are obtained although the rock block is protected. However, if the stress level is high, the possibility that non-elastic deformations can occur in the rock block, namely the formation of new fractures, cannot be excluded.

Conclusions

KASAM has no objection to make to the overall description of processes in the geosphere that is presented but recommends that SKB should develop the programme description bearing in mind the effects that can occur as a result of rock stress redistributions in connection with the construction of a deep repository.

9.5 Movements in intact rock

In SR 97, “movements in intact rock” are primarily defined as elastic movements without visible fracturing under moderate loads. No further research questions for this process were identified in SR 97, RD&D Programme 98 or the review of RD&D Programme 98.

A series of tests on rock type specimens from the Äspö Hard Rock Laboratory were mentioned as newly acquired knowledge since RD&D Programme 98 and SR 97 were published.

In the planned research programme, methods for the development of descriptive rock-mechanical models for potential repository sites will be developed prior to the site investigations. The need for work to describe and understand movements in intact rock will be analysed within the programme for method development.

Conclusions

With respect to remaining uncertainties concerning the elasticity of the rock, KASAM considers that SKB's programme proposal is well justified.

9.6 Thermal movement

In SR 97, "thermal movement" refers to the basic thermomechanical process of volume expansion that occurs with temperature increases. In SR 97, RD&D Programme 98 or the review of these reports, no questions were identified for further research. However, SKB states that thermal processes generate stresses that can result in reactivation and fracturing. In SR 97, the effects of thermal movements are treated under the headings of "Reactivation – movement along existing fractures" and "Fracture formation".

Conclusions

As far as remaining uncertainties concerning the understanding of thermal movements are concerned, KASAM considers that SKB's programme proposal is well justified.

9.7 Time-dependent deformations

In SR 97, time-dependent deformations refer to both the deformations that are due to changes in load conditions due to, for example, tectonic movements and those that are due to inherent time-dependent deformation properties of the rock.

In SR 97, the first type of time-dependent deformations is calculated by using tectonically-determined mean strain rates in the Baltic Shield and by converting these rates to stress growth. Furthermore, it is said that the conceptual understanding of creep movements in rock is poor, which means that the effects cannot be quantified or described in detail.

In KASAM's opinion, it is a deficiency that only the tectonic forces are commented upon as an example of load changes. An ice cover of up to 3 km on the ground surface will have a significant impact on the load.

In the proposed research programme, limits for the effects of creep-determined convergence of deposition tunnels will be set with the help of calculations to establish how the properties of the backfill material affect the convergence. Furthermore, a research programme may be started to investigate creep in fractures. The creep movements occurring in the intact rock are considered to be negligible.

Conclusions

In KASAM's opinion, SKB's assumptions and projects are reasonable for the improvement of knowledge on the issue of *time-dependent deformations*, where knowledge gaps still exist.

9.8 Fracture formation

In SR 97, SKB states that the understanding of how fracture formation processes should be handled in the calculations is deficient. Theoretical models for fracture formation and fracture propagation have been developed, but there is little knowledge of how these can be effectively converted into useful calculation models. On the other hand, experience-based mechanical strength criteria are available.

The conclusion of SR 97 is that changes in the geometry of the canister hole and the risk of damage to the canister due to fracture formation has very little importance in comparison to the effects of the reactivation process. The areas around the canister holes that are close to rupture are small, according to the fracture criteria that have been applied. Furthermore, it is stated that the authorities consider that the scope of the testing of rock specimens that was conducted to determine the mechanical strength and deformation properties is too limited.

Newly acquired knowledge since RD&D Programme 98 and SR 97 consists of further data for two rupture criteria.

In the planned research programme, methods for the development of descriptive rock-mechanical models for potential repository sites are to be developed prior to the site investigations. The need for possible work to describe and understand the fracture formation process will be analysed within the method development programme.

Furthermore, work is in progress to formulate fracture extension criteria for the simulation of brittle fracturing processes. Another project is investigating the role of the backfill/buffer in limiting the occurrence and propagation of progressive brittle ruptures in tunnel walls etc.

Conclusions

In KASAM's view, RD&D Programme 2001 should contribute to the necessary increased understanding of fracture formation processes.

9.9 Reactivation – movement along existing fractures

The bedrock must provide mechanical stability as well as prevent radioactive material from the repository from reaching the biosphere. Hazardous substances can be transported along the fracture system of the rock type/rock types. However, fracture-free bedrock, which would be preferable for this reason, does not exist. The fractures are also a mechanical weakness in the rock and new stresses are normally absorbed by the existing fractures.

Natural rock stresses and fracture systems at the repository site and changes that occur in connection with construction must be further investigated. An important issue is how the repository should be constructed in relation to existing fracture systems.

SKB states that

> this assumes that no deposition holes are intersected by fractures several hundred metres long and that the canister damage criterion (10 cm shear) that has applied to date also remains valid in the future.

This may give the impression that a shear of 10 cm requires several hundred metre-long fractures. The connection between the length of a fracture and the possible shear movement exists. However, the relationship between fracture length and shear movement that SKB describes must be verified by observations after earthquakes and fault slips in underground mines.

In planned research programmes, methods to develop descriptive rock-mechanical models for potential repository sites are being prepared prior to the site investigations. The need for work to describe and understand reactivation will be analysed in the method development programme.

Conclusions

In KASAM's opinion, the description of the need for a respect distance between a repository and fractures of various lengths should be clarified and the reasons for these distances should be well supported by published research results and empirical evidence.

9.10 Earthquakes and climate evolution

Issues relating to the modelling of earthquakes and climate evolution have been clarified and will be clarified further by SKB. The decisive factor for repository safety is not *when* an earthquake or glaciation will occur but rather *how* the repository will be affected by a strong earthquake and *how* it will react when continental ice sheet advances and presses down the bedrock. Seen from a historical geological perspective, earthquakes and continental ice sheets have affected the bedrock on several occasions. Issues relating to the impact of the load on a future repository and issues relating to how the groundwater has been oxygenated in connection with previous continental ice sheets should be intensified.

The tectonic scenario in SR 97 assumed that the fractures in the repository host rock are friction-free. According to the risk analysis of the scenario, this assumption has led to a considerable overestimate of the risk of canister failure, since there is no opposing force in connection with shearing. On the other hand, experience from earthquakes shows that it is the friction that means that considerable strain energy can be stored in the rock, and that this energy is abruptly released in the form of a shear movement when the shear strength is exceeded. This abrupt release of energy is the cause of the damage that occurs in the surroundings.

The issue is whether stored energy in a fracture, due to its friction, can lead to canister damage, which is as great or greater than the damage that arises when there is no friction.

The assumption of friction-free fractures and the effects caused by these fractures should be based on published research results.

SR 97 and the review of SR 97 show that the need for further research which deals with the purely mechanical aspects of the reactivation process (both primary movements in the seismically active zone and secondary movements in the repository fracture system) primarily concern the tectonic scenario.

In RD&D Programme 2001, SKB identified three prioritised research areas: 1) The prediction of future earthquake frequencies. 2) Mechanisms behind earthquakes. 3) Effects of earthquakes.

With in the area of *effects of earthquakes*, a pilot study has been launched to calculate deformations in host rock fractures using dynamic numerical models. The objective is to acquire relationships between distance from the earthquake, the magnitude of the earthquake and the maximum shear deformation of a given fracture. A programme to compile information on the documented effect of earthquakes on underground facilities will be conducted in co-operation with SKB's international sister organisations.

Conclusions

In KASAM's opinion, SKB's plans for further research on earthquakes and climate evolution are justified and important since there are still uncertainties associated with these issues.

9.11 Injection

A fracture-rich bedrock is normally injected with grout in traditional rock engineering. This method has been, and is, successful. The fractures are sealed with a calcium-based grout. New findings from grouting with silicon particles of colloidal size (particles less than one-thousandth of a millimetre) indicate that silicon can be used as a sealing agent. Silica, which is found in most rock types, could offer some advantages compared with calcium since it does not affect groundwater chemistry to the same extent as calcium. Its properties may mean that some advantages may be gained from the standpoint of long-term corrosion.

Conclusions

In KASAM's view, SKB should study different methods for injection in fractures in the aim of achieving a permanent limitation of the hydraulic conductivity in the host rock without having a negative impact on the chemical environment in the repository.

9.12 Groundwater flow

It has been found that the greatest uncertainty as regards the understanding and modelling of the groundwater flow is associated with the natural heterogeneity of the rock. In spite of this, there is no programme for the development of methodology for the classification of the heterogeneity of the rock in connection with the forthcoming site investigations. Consequently, it is not possible to conduct an objective comparison between the three sites. Furthermore, there is no possibility of verifying the statistical approach which “must be used for the modelling”.

The transient effects of land uplift have been analysed in the hydrogeological modelling within the SAFE Project (safety assessment of SFR 2001). On the other hand, the relationship between the intensity of the land uplift in different areas and the openness and hydraulic conductivity of the fractures has not been investigated by SKB and no work has been planned in this area in RD&D Programme 2001. Such a programme must also take into account other parameters besides fractures and land uplift intensity – for example, groundwater recharge, types and thicknesses of overburden as well as topography – since the effect of such parameters may hide the effects of land uplift.

Projects on recharge and discharge areas as well as the connection between surface-near and deep groundwater have been planned. KASAM is satisfied with the planning in these areas since these issues have been insufficiently investigated by SKB so far. However, the methodology for the investigation of the groundwater in the overburden is not specified. It is of particular importance to be able to determine the groundwater recharge from the sediment layers to the rock as well as the amount of the groundwater recharge that is formed within different parts of the site investigation areas and at different depths within these.

In its review of RD&D Programme 98, KASAM observed that when SKB had performed new calculations, SKB had obtained much longer transport times from a depth of 500 m compared with earlier numerical modelling results. SKB’s explanation that local rather than regional conditions determine the flow at these depths seems likely. Furthermore, it was noted that the models had overestimated the fracture openings by a factor of two compared with subsequently measured values. KASAM particularly emphasised the need to study the hydraulic contact between the sediment layer and the bedrock.

Questions relating to the importance of the transport time in comparison with other hydrogeological and hydrochemical conditions and in comparison with the properties of the recipients are of particular importance.

In the last paragraph of their report to SKI *(Recharge-area nuclear waste repository in southeastern Sweden: Demonstration of hydrologic siting concepts and techniques)*, under the heading of “Conclusions”, Voss and Provost, U.S. Geological Survey, state the following:

> Near-coastal sites may be among the less desirable choices possible in the region (southeastern Sweden) in terms of these hydrogeologic safety factors, because the coast is a discharge area for a ground-water flow system of some scale, either regional or local. This result is true irrespective of the properties of the bedrock.

In KASAM’s opinion, the more standardised conclusions of the Voss-Provost report, which is based on US conditions, must be viewed in the light of the actual conditions (for example the orientation of the water-bearing fracture zones and diabase sills/dikes) which can be registered on a regional-scale at the specific sites to be investigated.

SR 97 and the supplementary text in Chapter 2 of RD&D Programme 2001 also provides support for assessing the need for further research and to obtain better data. For example, the calculations of the maximum total annual dose, according to Figures 2-4 of RD&D Programme 2001, have resulted in values with a large spread. Furthermore, for Aberg, the average values of the dose-distributions are close to SSI’s risk limit.

Conclusions

KASAM recommends that SKB should present a programme to develop methodology for the classification of the heterogeneity of the rock in connection with the forthcoming site investigations. In KASAM’s view, the relationship between the land uplift intensity in different areas and the openness of the fractures and, thereby, the hydraulic conductivity, should be investigated. Furthermore, in KASAM's opinion, the amount of groundwater formed at different depths should be investigated and the groundwater flow on a regional scale should be modelled, taking into account the actual conditions. SKB should also describe the importance of the groundwater transport time in comparison with other hydrogeological and hydrochemical conditions and in comparison with the recipient's properties.

9.13 Decision-support models for the handling of complex problems, for example, geological deep disposal of nuclear waste

KASAM has dealt with issues relating to decision-support models for the handling of groundwater problems in Section 4.10.6 of KASAM's report, *Nuclear waste state-of-the-art reports 2001* (SOU 2001:35, June 2001). The report below is partly taken from this publication.

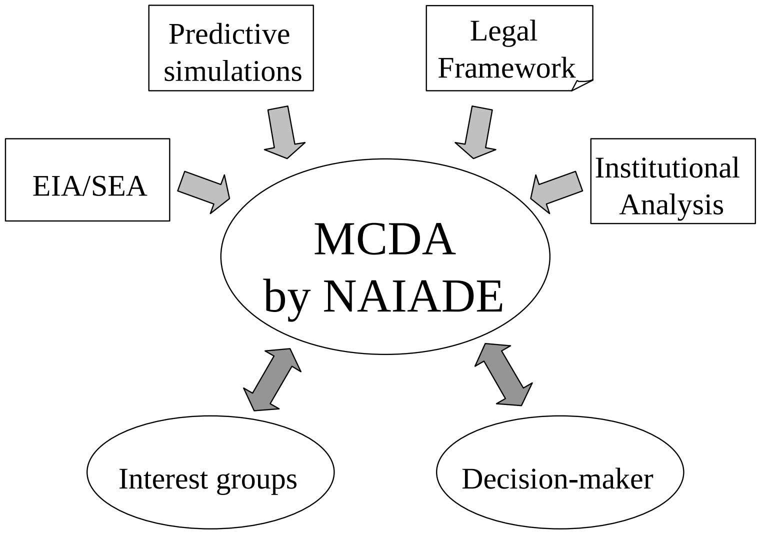
Results of, for example, groundwater modelling on different scales, are only one of many documents which must be prepared, evaluated and weighed together with the results of other scientific investigations, such as rock-mechanical, geochemical and technical investigations. These results must also be considered together with other factors or results from the models in connection with decision-making. The values may be economic values, different types of environmental and cultural values or sheer subjective judgements. Not many factors are required before a problem becomes very complex, rendering it difficult to maintain an overall perspective. A large number of different systems have been developed for various applications in hydrology.

The principle of a *decision-support system* is to provide a decision-maker, facing a complex and unstructured problem, with a basis for decision-making, for example, to compare different sites in the siting of a deep repository, or, in greater detail, different positions for deposition holes. The idea is to quickly compile and examine, with the aid of a computer, very large quantities of data. This allows a better basis for decision-making to be obtained at a, hopefully, lower cost. It is important to emphasise that a decision-support system is intended to provide support to the decision-maker and not make the decision. *Expert systems* are used for simpler, less complex issues. It should be pointed out that, when using a decision-support system, *the responsibility remains with the decision-maker*.

Decision-support systems can be designed in many different ways. The two central parts of a decision-making system are some type of database, containing the information, and a model that extracts and processes the data from the database. The data are then treated and formed into a decision aid, that facilitates the evaluation and comparison of advantages and disadvantages of different alternatives. Scientific models are used to calculate or predict consequences of scenarios or input data. Systems that are especially interesting for SKB in connection with the choice of a site for a repository are probably systems that can handle results from models as well as sheer subjective judgements. Traditional cost-benefit-analysis has been used by environmental economists, but this is now regarded as an insufficient tool for the formation of a basis for decision-making. Instead, a number of different variants of Multiple Criteria Decision Aid models (MCDA) have been developed. The figure below illustrates how MCDA is used in the decision-making process for the handling of groundwater-related problems.

Figure. Example of the application of the NAIADE Mulitple Criteria Decision Aid to water resource problems (from

KASAM’s *Nuclear waste state-of-the-art reports 2001*, SOU 2001:35)



Conclusions

In KASAM’s view, it is important for SKB to exploit existing national and international knowledge within the decision aid area, as well as to develop and evaluate decision-support models prior to site selection.

10 Biosphere

10.1 Background

The biosphere can be defined as all living organisms in the environment, including man, as well as the part of the environment with which man and the other organisms interact.

10.2 Overall goals and international co-operation

Chapter 9 of RD&D Programme 2001 is a transparent and systematic report of the biosphere issues, based on earlier reviews. SKB comments to a large extent on viewpoints that were previously expressed by KASAM and others. The background reports are up-to-date and comprehensive.

In the RD&D Programme, SKB describes the programme that it has prepared for site investigations of the biosphere. The background reports specify how the inventory work will be conducted. Data from the site investigations are intended to provide the basis for an in-depth understanding of the biosphere processes as well as to develop models for safety assessments based on site-specific data.

According to RD&D Programme 2001, SKB, in its continued in-depth work, plans to increase its publications in academic journals with an international circulation. SKB expects that the collection and analysis of data will stimulate the interest of Swedish and international research groups working with radioecological and environmental problems.

In KASAM's opinion, the overall goals of the RD&D Programme indicate a high level of ambition. In KASAM's view, it is important that the data presented should be easily available for the necessary international peer review.

There are only a few countries which, like Sweden, directly stipulate that the environment should be protected against the harmful effects of the radioactive releases. The general view is still that the environment is given a satisfactory level of protection if man is protected.

In RD&D Programme 2001, SKB provides an insight into the international work that is in progress in the biosphere area.

SKB is participating in the FASSET Project (Framework for ASSessment of Environmental impacT) within the EU's Fifth Framework Programme. SSI is the co-ordinator of this project, which is expected to continue until 2003. The purpose of the project is to develop a methodology for safety assessments that can be understood not only by decision-makers, but which can also be used by the producers who are responsible for an operation and thereby for the safety analysis of the operation. The project may be of considerable importance for gaining an insight into and knowledge of the impact on the environment of radioactive releases.

It is clearly specified in the FASSET Project's presentation of its goals that the intention is to equip the nuclear energy industry with tools to, in the best way possible, facilitate the exploitation of the full potential of nuclear energy. FASSET would thereby be a useful tool for nuclear power industry safety analysts to satisfy the increasingly stringent requirements on environmental protection (FASSET – Contract No, 2002-11,22, Annex 1, Chap. 1.4.).

There is a strength in the ambition to, through this type of joint work, bridge the gap between licensees and regulatory authorities by adapting methodology and regulations so that they can also be understood, in the best way, by laymen, but still provide an adequate basis for expert risk assessments. The weakness may lie in the creation of a dialogue state where both parties have an interest in achieving a state of equilibrium which is primarily not dependent on the environmental goals but rather on the nuclear energy industry's interest in cost-efficiency.

The FASSET Project uses several of SKB's ecosystem types (boggy ground, sediment, brackish water and marine environment) as reference ecosystems. Therefore, it can be expected that SKB will use the results from the FASSET Project in its future safety assessments.

Conclusions

KASAM supports the overall goal of the biosphere programme with the aim of, with a modern knowledge base, describing the most important processes in the biosphere from the radiological standpoint, as well as to provide an adequate scientific support to assess environmental consequences of the construction and operation of a repository. KASAM particularly notices the ambition stated in the RD&D programme to confirm and deepen the knowledge obtained in ongoing projects by promoting increased publication in international journals. KASAM shares SKB's view that it is important to disseminate SKB's knowledge abroad in order to obtain viewpoints and the necessary scientific peer review.

10.3 Radionuclide transport in the groundwater

Radionuclide migration to the biosphere and to man is assumed to occur primarily via the flow of groundwater through the repository. In order for migration to occur, there must be a breach in the repository barrier system, for example, as a result of manufacturing defects in the copper canisters containing the spent fuel or as a result of canister corrosion over a long time or through some other type of canister damage. Groundwater comes into contact with different water systems such as wells, peat-bogs and wetlands, inland lakes, watercourses as well as coastal and sea water. The groundwater can also contaminate arable land with radionuclides via groundwater transport to the cultivation zone and via irrigation. In the case of a consequence analysis of leakage from a deep repository for spent nuclear fuel, it is the dilution volumes in the various water systems of the biosphere that largely determine the consequences of a release, in the form of radiation doses to mankind, animals and plants. Another way for radionuclides from a deep repository to reach man might be via sedimentation on sea and lake bottoms which, after a future elevation of the land, may dry out and subsequently be used for food production.

With respect to possible migration to the biosphere, it can be mentioned that KASAM, in its review of RD&D Programme 98, noted that the conditions in the transition zone between the bedrock and sediment layer are a neglected research area that must be activated due to its importance for the transport of radionuclides with the groundwater. In general, it can be stated that a delay on the order of 100 to 1,000 years of radionuclide transport can be expected in the actual interface before a balance occurs between the inflow of radionuclides from deeper groundwater and the outflow of these substances via the groundwater to the biosphere.

RD&D Programme 2001 sometimes refers to the SAFE Project (safety assessment of SFR in 2001), where interactions in the interface between the groundwater in the rock and the near-surface groundwater were studied. SKB states that, through field studies, it will study the capability of the groundwater to follow water-bearing layers in quartenary strata (with the possibility of discharge close to the shoreline).

In connection with the review of RD&D Programme 98, KASAM also considered that the risk of colloid formation in connection with the operation of the deep repository should be taken into account. KASAM noted that colloidal particles, which are normally rare in deep groundwater, can be formed through the penetration of oxygenated air and the subsequent oxidation of, for example, divalent iron as well as the possibility that the bentonite would be able to release colloids in the form of clay particles.

SKB has noted that a large fraction of the radionuclides in the environment will be bound to particles, humus complexes and organisms.

The development of system-ecological models for the description of the flow of particles (as organic material) in a coastal area is stated in RD&D Programme 2001. The model studies will be supplemented by field data from the site investigations.

In the earlier review, KASAM also considered that it is necessary to investigate and describe the composition and the properties of the surrounding biosphere to assess a repository's protective capability and possibility of complying with the requirements that SSI had established (in the SSI FS 1998:1 regulations with background and comments in SSI report 99:03). In KASAM's view, the importance of present-day local biosphere conditions and discharge areas for site selection must be clarified.

Conclusions

In KASAM's view, a deeper understanding of the hydrological relationships between a deep repository for spent nuclear fuel and different ecosystems is highly desirable. This knowledge is necessary in order to be able to make a reliable evaluation of transport paths and transport rates to the biosphere in the calculation models. Such a report should include an evaluation of the issue of the areas to which the surface water or groundwater from the repository can be transported. The report should also contain an analysis of the radionuclide transport from rock to sediment (from geosphere to biosphere).

10.4 Radionuclides and other substances

Radioactive releases can affect the entire biosphere. The safety assessment takes into account other parts of the biosphere besides man, and nowadays, more realistic process-oriented descriptions than before are conducted.

KASAM assumes that the overall environmental impact assessment, which must be conducted in accordance with Chapter 6 § 5 of the Environmental Code, will also contain an evaluation of the risk of *chemico-toxical effects* of released substances.

In RD&D Programme 98, SKB stated that it had not succeeded in providing a realistic description of the risks that a deep repository for spent nuclear fuel would entail for man and the environment.

In KASAM's opinion, RD&D Programme 98 lacks an analysis of the causes and proposals for what SKB intends to do to correct this problem. KASAM also noted that SKB's work within the area of biosphere studies so far had been limited and emphasised the importance of a clear description of the biosphere, especially due to the interest of the public in what is happening to the biosphere.

KASAM notes that RD&D Programme 2001 is more transparent with respect to continued investigations of the biosphere. However, the need for clarity warrants attention in the continuation of risk communication work with the public.

Conclusions

KASAM notes that the biosphere models should be applied to the turnover of the radionuclides and other substances which, due to their chemical toxicity, can have an environmental impact. KASAM also notes that the reporting of results from the biosphere studies should be designed bearing in mind the public's interest in understanding the risks of a deep repository and in being able to compare these with other risks in society.

10.5 Ecosystem

In the very long time-scale involved in the case of a repository for spent nuclear fuel, major changes will occur at the repository site. This is the case for the sediment layers, the hydrological conditions and the biosphere. In KASAM's opinion, the ecosystems proposed for studies (forest, bogs and sediment) are well justified with respect to these changes as well as possible accumulation effects and increased exposures. However, the need for enhancing the knowledge of other ecosystems should be highlighted in the continued discussion.

The agricultural ecosystem is supposed to have a considerable importance for the transfer of radionuclides to mankind via foodstuffs. The uptake in forest products such as (mycorrhizal) fungi and game, can also result in a radiation dose contribution via foodstuffs. Boggy grounds and sediments belong to the systems where there is reason to expect an increased concentration of radionuclides.

In previous reviews, KASAM has also pointed out the importance of studying changes in the biosphere conditions over time as well as improving the description of what occurs during the first few years after repository closure.

In RD&D Programme 2001, SKB states that the SAFE Project has developed time-dependent biosphere models and made an initial attempt to describe the first 1,000 years.

Conclusions

In KASAM's opinion, the ecosystems proposed for studies in RD&D Programme 2001 are important from the standpoint of radiation protection. In KASAM's view, knowledge of the agricultural lands (including land for the production of energy crops) as ecosystems should be developed in greater depth with special consideration being given to future cultivation of former accumulation bottoms in watercourses, lakes and seas as well as the use of boggy grounds that can contain increased concentrations of radionuclides. In further reporting, it is important that relevant main types of ecosystems are included in order to create the largest possible basis for the selection of ecosystems for further evaluation.

10.6 Modelling, monitoring, requirements and criteria

In its review statement of RD&D Programme 98, KASAM referred to SSI which, in its review of the programme, noted that the monitoring of a closed repository was still an open question. SKB had mentioned very little about the control of repository performance. In KASAM's opinion, this is an important issue, with respect to providing well-founded information to the public and it is important that the authorities promulgate requirements in this area.

In regulations, (SSI FS 1998:1), SSI has stated requirements regarding how the impact of radiation on the environment is to be taken into account. How SSI's regulations are to be applied has been and still is not completely clear. Discussions concerning the application of the regulations have been held between SSI and SKB. SKB has reinforced the development of process descriptions etc. with biosphere-related factors and can, thereby, facilitate the application of the regulations.

The analysis of the radiation protection aspects of alternative solutions requires different types of optimisations. A discussion is currently in progress regarding the need for certain adjustments of the international rules for radiation protection. A central issue is whether the radiation protection of the population as a whole is to be optimised (through the calculation of the “collective dose”) or with the help of the dose to individuals (“individual dose”). The means of optimisation may be important to the siting of a repository for spent nuclear fuel.

The question of (present-day) biosphere conditions as site selection criteria for a repository for long-lived waste has been the subject of discussion in the light of the change in the biosphere in connection with variations in climate, elevation of land etc. For very long periods of time, the geosphere offers more stable conditions than the biosphere. However, bearing in mind the facilities above the ground surface as well as transportation and other activities which are connected to the repository, it is important to take into account the present biosphere conditions at the site. In the case of the repository itself, there is also an initial period when the present biosphere conditions are important for the assessment of safety and the risk for environmental impact in general. SKB maintains that it is taking the biosphere into consideration in the site selection. Among other things, SKB has identified a number of biosphere-related factors that are being mapped at the sites in question.

With respect to the protection of other organisms besides mankind, in RD&D Programme 98, KASAM indicated a major difficulty for SKB, namely that generally accepted radiation protection criteria were lacking. In KASAM’s view, it is not enough to estimate the radiation dose or radiation risk. It is also important to know what is to be protected and how it is to be protected.

KASAM considered that SKB had to analyse how it can comply with the stated requirements regarding the protection of mankind and other organisms in practice and how it must change its programme in order to obtain the necessary information. KASAM noted that this particularly refers to the protection of other organisms. The necessity of protecting mankind and the environment as well as of developing a methodology to handle risk estimates for biota and the requirement that the impact of the deep repository on biodiversity must be negligible was only mentioned in general terms. KASAM considered that, above all, the environmental protection part of the RD&D report would have to be further developed. In KASAM's opinion, to show that the requirements that SSI has made are fulfilled, it is important to point out that the environment will not automatically be protected as a byproduct to the protection of mankind.

In RD&D Programme 2001, SKB has stated its intention of developing the system-ecological models with respect to the need for reporting the environmental consequences. The intention is also to specify a framework for how the environmental consequences should be handled in the joint work with SSI in the EU FASSET Project.

In its review of RD&D Programme 98, KASAM also pointed out that the models used for radionuclide transport (BIOMOVS I and II, BIOMASS) must be supplemented by specific data from the environment of the repository in question. This observation is still valid. With respect to the protection of other organisms besides mankind, KASAM has previously pointed out – and does so again – that many fundamental problems (not primarily problems with models) must be resolved before it can be shown that "biodiversity and the sustainable use of biological resources" have been protected against the harmful impact of ionising radiation.

KASAM also considered that the programme for further work would need to be revised and given a greater level of detail and clarity to understand how preparations are made in order to show with the safety assessment that a) the risk to mankind and b) the risk to other organisms/populations from radionuclide contamination in the biosphere will be acceptable.

In RD&D Programme 2001, SKB states that it intends to improve the data for the next safety assessment of the deep repository and future site investigations. SKB also states that the collection of data from the surface-near ecosystems are important for the understanding of the safety assessments and biosphere models.

In KASAM's opinion, an environmental monitoring programme for the repository should be established. The programme should be designed so that the impact from the repository can be distinguished form natural variations in the environment.

Conclusions

KASAM assumes that an environmental monitoring programme for the repository will be established and that this monitoring will be initiated before the start of construction to obtain comparable data on baseline environmental conditions. In KASAM's opinion, it is important that the continued research and development work should clarify the conditions for the selection of measurable parameters and organisms/species that can act as suitable indicators of an impact on the biosphere in connection with model calculations and monitoring. The report should clearly state how any recommended limits for the different parameters were arrived at. In this context, KASAM notes that there are certain uncertainties as to how the Swedish Radiation Protection Institute's *Regulations on the Protection of Human Health and the Environment in connection with the Final Management of Spent Nuclear Fuel and Nuclear Waste* (SSI FS 1998:1) are to be applied. However, the ongoing FASSET Project and the general recommendations that SSI intends to promulgate in 2003 should hopefully provide some guidance on this subject.

11 Alternative methods

11.1 Background

In its review of RD&D Programme 98, KASAM requested a summary of the state of partitioning and transmutation work. KASAM also approved a system analysis and a safety and performance assessment of disposal in deep boreholes (SOU 1999:67, pp. 2-3 and p. 37).

Chapter 16 of RD&D Programme 2001 contains an overview of the state of work and knowledge in partitioning and transmutation as well as a summary of the investigation into deep boreholes that SKB conducted and on which KASAM submitted its review in June 2001 to the Government (Review on SKB's RD&D Programme 98 Supplement).

11.2 Background to the reporting of alternative methods

The starting point for KASAM's review of Chapter 16 of RD&D Programme 2001 is the Government's evaluation of the method selection issue, presented in the government decision of November 1, 2001, in response to SKB's RD&D Programme 98 Supplement. In the Government's evaluation – and without anticipating decisions regarding future licence applications – SKB should use the KBS-3 method as a prerequisite for planning the two site investigations that SKB now intends to conduct. The Government also stated that, within the framework of the

RD&D programmes, SKB should also continue to monitor the development of technology with respect to alternatives for nuclear waste management. Furthermore, the Government reiterated an earlier statement that some form of final disposal in the bedrock is the most suitable strategy for the final disposal of spent nuclear fuel from Swedish nuclear power plants.

In KASAM's opinion, it is justifiable to treat the description of alternatives in a future environmental impact statement, in accordance with Chapter 6 § 7. 4 of the Swedish Environmental Code. The Government assumes, as is evident from the government decision of November 1, 2001,

> that issues concerning which alternatives are to be reported in the EIS (environmental impact statement) will be subjected to in-depth consideration in connection with the stipulated consultation process.

KASAM reiterates its opinion on the issue of alternatives in its review of SKB's RD&D Programme 98 and its review of SKB's RD&D Programme 98 Supplement. KASAM's line of reasoning concluded with a statement that alternatives to the KBS-3 method which are to be reported in accordance with the Environmental Code should be identified from the category of repositories that can be mined within the uppermost kilometre of the bedrock.

In its review of SKB's RD&D Programme 98 Supplement, KASAM maintained – and continues to maintain – that *deep boreholes* cannot be considered to be a realistic alternative. There is considerable reason to doubt the performance of certain barriers in the aggressive environment at the repository depth (high temperature and high salinity). Furthermore, it cannot be simply assumed that the stagnant groundwater at great depths will remain stagnant when a considerable heat source (the deposited spent fuel) is in place. The possibility of retrieving the spent nuclear fuel, for example, if performance should be found to be inadequate, would be almost non-existent and it would also be considerably difficult to conduct a meaningful demonstration stage for such a repository.

KASAM notes that SKB, since RD&D Programme 92, has assumed that it will be possible to demonstrate the method and that this has been accepted in the decisions made by the Government on the RD&D programmes. It can also be noted that the objective of some form of repairability cannot be satisfied by disposal in deep boreholes.

To KASAM's understanding, the basic purpose of the provision of §7. 4 of the Environmental Code on reporting "alternative designs" is that such a report should concern alternatives that it is technically feasible to implement within a time-period that is not too far from the time-period for the implementation of the project proposed by the proponent.

At present, it is probable that SKB's future application for permission to start the construction of a repository will be based on a method that is within the boundaries of the KBS-3 concept. In KASAM's opinion, if this is the case – based on what has been stated in the previous paragraph and based on present-day knowledge – neither partitioning and transmutation nor disposal in deep boreholes are the type of "alternative designs" which should be primarily presented in the environmental impact statement. In KASAM's view, these alternatives do not meet the requirement of feasibility of implementation within a reasonable time frame, which is an implicit requirement of the Environmental Code. On the other hand, the environmental impact statement should clearly present the arguments for and against these alternatives as well as for and against the other alternatives that have been investigated and then eliminated from further discussion. The line of reasoning that has led to the identification of feasible alternatives to the KBS-3 method should also be presented.

As mentioned above, KASAM has recommended in previous reviews that alternatives to the KBS-3 method should be identified from within the category of repositories that can be mined within the uppermost kilometre of the bedrock. KASAM still holds this view and reiterates the reasons presented above.

In its review of RD&D Programme 98 (pp. 32-35), KASAM identified two alternatives from the category of repositories mined within the uppermost kilometre of the bedrock. These are Long tunnels and WP Cave. It is also possible that variations on the KBS-3 concept, such as those presented on pages 257-258 of RD&D Programme 2001 (horizontal deposition holes of varying lengths) can be considered to be alternatives in the sense intended by the Environmental Code. KASAM assumes that related issues, including possibilities for demonstration and retrieval, will be treated in depth during the forthcoming in-depth consultation between the proponent and parties concerned.

Conclusions

The Government has assumed that issues concerning which alternatives are to be described in a future environmental impact statement, in accordance with Chapter 6 § 7. 4 of the Environmental Code, will be the focus of in-depth consideration in connection with the stipulated consultation. In KASAM's view, a reiteration is warranted of KASAM's evaluation of the alternatives issue in its review of SKB's RD&D Programme 98 and its review of SKB's RD&D Programme 98 Supplement. KASAMconcludes that alternatives to the KBS-3 method, which are to be reported in accordance with the Environmental Code, should be identified from the category of repositories that can be mined within the uppermost kilometre of the bedrock. KASAM has not found any reason to change its opinion on this issue. In KASAM's opinion, a method such as disposal in deep boreholes is not a realistic alternative method, that is required to be described in the environmental impact assessment under the Environmental Code. Possibilities of retrieving the spent nuclear fuel are likely to be non-existent and there could, thereby, also be considerable difficulties in implementing a meaningful demonstration phase for such a repository.

11.3 Partitioning and transmutation

KASAM has no objections to make to SKB's description of newly acquired knowledge since RD&D Programme 98. KASAM has the following comments to make concerning the information presented by SKB under the heading of *Research programme*.

In KASAM's opinion, there are considerable reasons in favour of the present focus of the Swedish nuclear waste management programme, namely, further development work on direct disposal in accordance with the KBS-3 method. This development work must be conducted in a goal-oriented manner.

However, it cannot be excluded that new knowledge and new research might lead to the conclusion, some time in the future, that the choice of the method which appears to be most promising at present must be revised. This view has guided the approach to the nuclear waste management issue that KASAM has applied since the end of the 1980's and which has also been reflected in the government decisions since the beginning of the 1990's in connection with the review of SKB's RD&D programmes.

A focus on partitioning and transmutation would entail a different strategy for the management of spent nuclear fuel. This strategy differs, in essential respects, from direct disposal in accordance with the KBS-3 method.

From KASAM's perspective, the prime reason for research on partitioning and transmutation is the possibility that such research could result in a substantial reduction in the quantity of long-lived radionuclides which, in any case, will have to be deposited in the bedrock. However, extensive and highly cost-intensive research and development work is necessary before it is possible to use such a method on an industrial scale. The method would involve reprocessing connected to the recovery of nuclear energy in some form.

As stated by KASAM in its review of RD&D Programme 98 (pp. 25-26), the transmutation of long-lived radionuclides prior to disposal, can be an alternative only if it is a by-product of a possible use of accelerator-driven nuclear reactors as a new energy source. However, the development of new forms of nuclear power production would require a complete change of direction in Swedish energy policy.

Major research projects on partitioning and transmutation are underway within the larger nuclear power-producing countries as well as within the framework of the EU's research programme. Swedish researchers are following and/or participating in several of these projects. The cost of Swedish participation is primarily financed by SKB's contributions to a few university departments. SKB has informed KASAM that SKB's subsidies for research and information work within transmutation amounted to a total of SEK 23.4 million during the five-year period of 1997-2001. The annual cost during the period varied between SEK 4.2 million in 1997 and SEK 5.0 million in 1999. In 2002, the cost is estimated at SEK 4.9 million.

KASAM cannot judge whether or not this particular level is adequate. It is important to ensure that there are a number of active researchers in Sweden who are familiar with this research area. These researchers are necessary in order to contribute to the basis for strategic decision-making which SKB, the regulatory authorities, the Government and other actors must conduct in the coming years. KASAM proposes that the Government should request that SKB should present, in RD&D Programme 2004, a more detailed basis for the evaluations made of the size of SKB's financial support to research and acquiring of information on transmutation.

SKB reaches the conclusion (page 298) that it is not reasonable for the company to initiate major development projects within the transmutation area on its own. In summary, the goals that SKB has formulated for its research programme in this area entail evaluating the technological developments and assessing how and when such a technology can be applied to the spent nuclear fuel from the Swedish nuclear power plants. SKB also notes their own interest in participating in EU projects in this area.

KASAM shares SKB's opinion that it is not reasonable to undertake major independent initiatives within the near future. KASAM agrees with the research goals for the next three-year period that SKB has specified. Nevertheless, KASAM is still left with the impression that SKB's planned work in this area is characterised by considerable scepticism with respect to the possibility of success. In KASAM's view, SKB should be open to the possibility that increased work within the framework of the currently discussed EU-funded research on transmutation can lead to a need for increased work by Sweden.

According to SKB, overall evaluations must be made prior to important decisions in the nuclear waste management programme. Furthermore, an overall evaluation, "in connection with the evaluation after the first stage of deposition of encapsulated fuel in the deep repository" (page 298) is envisaged. KASAM underlines the need for such evaluations to be conducted. A status report should always be included in the future RD&D programme reports.

In this context, KASAM reiterates that the issue of alternatives to the KBS-3 method will be evaluated by different authorities, and ultimately by the Government, as early as in connection with SKB's application for permission to conduct a detailed characterisation prior to the construction of a repository. Furthermore, the issue of alternatives can be evaluated in connection with SKB's submission of an application to construct an encapsulation plant. SKB plans to submit these two applications within the coming five-year period. In addition, the alternatives issue will also be a pertinent topic on many occasions later on. Examples of such occasions include the submission of applications for permission to construct a repository, permission to operate the repository during an initial demonstration phase and permission to continue spent fuel deposition after such a phase.

In order to evaluate the alternatives issue, a sound basis for decision-making is required, including an evaluation of partitioning and transmutation as a possible comparable method. In turn, the evaluation requires access to an up-to-date status report on the subject.

According to SKB, it would not be the time for the type of evaluation, referred to by SKB in the quotation above, until around the year 2020. In KASAM's opinion, it is obvious that such a strategic and financially important decision as continuing to deposit all of the remaining fuel should not be made until all parties concerned are strongly convinced that they should continue to pursue this line of action. In this context, "parties concerned" refers to both SKB and other actors within the nuclear waste management area, including political decision-makers in the municipalities concerned and, ultimately, the Government. A decision on the issue must be made in the light of the evaluations which can be made with respect to the possibility of creating such a large-scale industrial facility as that required for the complex processes of partitioning and separation. These evaluations will probably be made on the basis of technical/safety-related and financial as well as environmental and energy policy-related considerations. Furthermore, general considerations will probably be taken into account concerning whether such a facility can be located in Sweden and be designed solely for the Swedish nuclear power programme. One alternative could be for several countries to together support a process facility, but for each country to take care of its own share of the waste that must ultimately be disposed of.

As KASAM has indicated above, in order to obtain a sound basis for such evaluations, Sweden must have access, at that time, to a number of experts with adequate insight into the area. However, the access to such expertise, in the long term, cannot be viewed in isolation from the energy policy guidelines that the

Swedish parliament and the Government decide. Therefore, in KASAM's view, there is reason to call into question the prohibition against "preparing design drawings, making cost estimates, ordering equipment or adopting other such preparatory measures with the aim of constructing a nuclear power reactor in Sweden", which is stipulated in § 6 of the Act on Nuclear Activities. The provision was introduced into the Act in 1986 and is based on the energy policy guidelines decided by the Swedish parliament in 1980 whereby nuclear power would be phased out by the year 2010. At the same time, a provision was also introduced – which now exists in § 5a - according to which permission to construct a nuclear reactor may not be granted. The provision has the primary character of a prohibition on the Government to exercise its right to grant permission for new reactors – a right that the Government formally had according to the previous formulation of the Act.

In 1996, KASAM recommended – in a review statement to the Ministry of Industry on the Final Report of the Energy Commission (SOU 1995:139) on the reformation of the energy system – that the provision in § 6 should be amended, even if the prohibition in its current form does not directly target research in the nuclear waste management area. To justify this recommendation, KASAM stated the following:

> Such an amendment is important, especially in order to provide a better basis for research on new solutions, in terms of principle, within the nuclear energy area. From KASAM's perspective, research on more efficient use of nuclear fuel, the minimisation of waste quantities, partitioning of existing nuclear waste etc. is of particular interest. Qualified nuclear engineers and researchers in Sweden should not need to stand aside and passively observe this development, which can lead to results of considerable interest, also for Sweden. Stimulating work and funding are necessary in order to attract competent researchers to the nuclear area. In particular, these factors will be essential when it is time to phase out nuclear power and safely dispose of the waste.

In KASAM's view, there is even greater justification at present to amend this paragraph. In 1997, the parliament passed new energy policy guidelines which entail the phase-out of nuclear power, in the long term, although no deadline for the decommissioning of the last reactor was set. In a bill to the parliament in March 2002 (bill 2001/02:143), the Government presented its intention to attempt to reach an agreement with industry concerning a long-term, sustainable policy for the further phase-out of nuclear power and the reformation of the energy system. According to the bill, such an agreement would create favourable conditions for an economically defensible continued operation of nuclear power plants and successive phase-out of nuclear power, at the same time that other environmentally-acceptable electricity generation facilities are commissioned and the electricity supply is secured.

KASAM emphasizes that two conditions must be met in order for the 1997 guidelines as well as the proposed guidelines that are presented in the above-mentioned bill to be implemented. One of these conditions is that, during the time that nuclear power is used, competent operating personnel must be available. Another condition is that researchers with a high level of competence in the nuclear field must be available. In order for this area to be attractive for young researchers, KASAM believes that the research topics must be considered to be both sufficiently challenging and relevant to industry and society.

The existence of the prohibition against preparatory measures aiming at the construction of a nuclear power reactor in Sweden (§ 6) is probably viewed by several researchers as a clear signal from parliament and the Government that they should not focus on the nuclear field. In this way, society could lose researchers who, under other circumstances, could have made important contributions to alternative solutions of the nuclear waste issues.

However, the stipulation in § 5a which forbids the Government from granting permission for the construction of a new nuclear reactor is of more decisive importance.

Development work in the nuclear area has, in the nuclear power-producing countries, increasingly focused on a system for energy generation (reactors) and “waste incineration” through transmutation in an accelerator-driven process. The prohibition in § 5a against granting permission for the construction of a new nuclear reactor is probably applicable to the type of facility needed for partitioning and transmutation. Such a facility would indeed require the construction of a nuclear reactor, although the prime justification would be nuclear waste management. However, this issue is not explicitly dealt with in the preparatory work to the Act (compare bill 1986/87:24 and NU 1986/87:13). This is probably due to the fact that the construction of a facility for this purpose was not a topic of concern when the parliament decided on the formulation of the provision in question.

As was previously pointed out in this section, a number of researchers in Sweden are following or participating in development work on partitioning and transmutation. In KASAM’s view, it is clear that the prohibition in § 6 of the Act on Nuclear Activities against certain types of preparatory measures “with the aim of constructing a nuclear reactor in Sweden” allows the research activities in transmutation which are now being conducted in Sweden. Through a statement of justification by the parliament, in connection with the treatment of the bill (cf bill 1986/87:24, NU 1986/87:13) it was established that the prohibition would not restrict the possibility of research and development work in the nuclear area. However, KASAM notes that due to the wording of § 6, the meaning can easily be misunderstood unless the preparatory work to the Act is studied in detail.

KASAM strongly considers this lack of clarity to be unsatisfactory. § 6 of the Act on Nuclear Activities should be revoked for two reasons. Firstly, its meaning is difficult to interpret, depending on whether one reads the wording of the Act alone or whether one also consults the parliament’s statement of justification. Secondly, the reasons that may have existed when the provision was introduced are now no longer relevant.

Furthermore, the Government should investigate how the prohibition in § 5a against granting permission for a new nuclear reactor can be modified. In KASAM's view, the provision should be formulated in such a way that the Government is not formally prevented from granting permission, in Sweden, for a facility for the partitioning and transmutation *if* further work indicates that such a facility is desirable.

KASAM emphasizes that the rescinding of § 6 and a modification of § 5a do not leave the way open for new nuclear power plants to be constructed and operated, since such activities, in any case, require special permission by the Government. The institutions with a political responsibility already have the necessary tools for implementing the energy policy decided in a democratic process.

Conclusions

KASAM has no objection to make to SKB's presentation of newly acquired knowledge in the transmutation field. In KASAM's opinion, there are good reasons for the current direction of the Swedish nuclear waste programme, namely further development work focusing on direct disposal in accordance with the KBS-3 method.

It is important that SKB is actively tracking developments in the area of partitioning and transmutation. KASAM proposes that the Government should request that SKB in RD&D Programme 2004 should present a more detailed basis for assessing suitable levels of funding for this work.

KASAM shares SKB's opinion, that it is not reasonable for the company to initiate major development projects in the area of partitioning and transmutation at present. However, in KASAM's opinion, SKB should remain open to the possibility that such increased work within the framework of EU-funded research on transmutation, currently discussed, can lead to the need for increased Swedish contributions.

The Act on Nuclear Activities (1984:3) contains two provisions which, in KASAM’s opinion, many researchers perceive as a signal from the parliament and the Government that they should not focus on the nuclear field. In this way, society could lose researchers who, in other circumstances, could have made important contributions to resolving the nuclear waste management issue.

KASAM refers both to the prohibition in § 6 against preparatory measures with the aim of constructing a nuclear reactor in Sweden and to the more decisive stipulation in § 5a which prohibits the Government from granting permission for the construction of a new nuclear reactor.

The prohibition in § 5a is probably applicable to the type of facility that would be needed to conduct partitioning and transmutation. § 6 of the Act on Nuclear Activities allows research to be conducted in the nuclear field although, due to the wording, the exact meaning can hardly be understood without a detailed study of the government bill behind the Act.

KASAM proposes that § 6 should be revoked, partly because its meaning can easily be misunderstood and partly because the justifications that may have existed when the provision was introduced are no longer topical. Furthermore, the Government should investigate how the prohibition in § 5a against granting permission for a new nuclear reactor can be modified. In KASAM’s view, the legislation should be formulated in such a way that the Government is not formally prevented from granting permission, in Sweden, for a facility for the partitioning and transmutation *if* further work indicates that such a facility is desirable.

KASAM emphasizes that the revoking of § 6 and a modification of § 5a do not leave the way open for new nuclear power plants to be constructed and operated, since such activities, in any case, require special permission by the Government. The institutions with a political responsibility already have the necessary tools for implementing the energy policy decided in a democratic process.

11.4 Disposal in deep boreholes

Conclusions

In the light of what KASAM has stated concerning the reporting of alternative methods (Section 11.2), KASAM shares SKB's opinion that adequate reasons do not exist for implementing the previously described RD&D Programme for deep boreholes. Like SKB, KASAM considers that the company should continue to follow developments in the area.

12 Decommissioning

12.1 Background

SKB states that it is the reactor licensees that are responsible for the decommissioning of the nuclear power plants. This responsibility covers consultation and the preparation of licence applications as well as the planning and implementation of own facilities. SKB has been commissioned by the reactor owners to conduct certain general studies to ensure that the necessary technology and expertise are available and that the decommissioning costs should be investigated and estimated.

12.2 Planning and need for resources

In KASAM's opinion, the decommissioning area is not controversial from the technical/scientific standpoint. In KASAM's view, the investigation work that SKB conducts is reasonable.

However, KASAM would like to draw attention to a few issues in this area. Even if decommissioning technology, cost estimates etc. are not controversial issues in themselves, there are issues of considerable importance for planning, implementation, maintenance of expertise and cost estimates that must highlighted.

These issues include logistics and time-tables in the planning of the decommissioning work. How long should one wait before conducting decommissioning? Which facilities are necessary for further interim storage, handling and disposal of the decommissioning waste? When should these facilities be available? How should the co-ordination with the programme for the disposal of long-lived waste be conducted and how should the siting process be co-ordinated for a planned repository for long-lived waste (which will be partially used for certain types of decommissioning waste) with the siting process for the spent nuclear fuel? How can the availability of expertise be secured for a programme that covers such a long period of time?

These issues can each affect expenses and the need for funding. The issues are partially investigated in SKB's programme.

Conclusions

KASAM emphasizes the importance of ensuring that the decommissioning issues are accorded attention and is positive to the review of the Financing Act announced by the Government where these issues will be dealt with to some extent.

13 Other long-lived waste

13.1 Background

According to SKB's timetable, it will not be time to decide on the siting of a repository for long-lived, low and intermediate-level waste (SFL 3-5) until about 2035. Therefore, SKB does not consider that it is under any time pressure to improve knowledge on other long-lived waste (besides spent nuclear fuel) and its disposal.

Long-lived waste is generated by research, health care and industry as well as in the form of core components, reactor components etc. from nuclear power plants. SKB specifies the total volume of such waste that is expected, but does not state anything about the different waste types. Since waste from different fields can have very different properties, it is important for the composition of the waste to be taken into account. KASAM would like to emphasize the importance of SKB conducting a detailed characterization and documentation of this waste and the importance of SKB recognising these issues in its research.

13.2 Repository design and safety assessment

Concrete plays an important role in the proposed repository for other long-lived waste. Consequently, the properties of the concrete in a longer time-frame are extremely important for the safety assessment, which SKB has recognised. However, KASAM notes that the long-term tests to which SKB refers do not extend over a longer time-period than 90 years. SKB also refers to certain cement analogues, which can provide support for the assumption that the concrete can retain parts of its barrier function for long time-periods. However, KASAM considers that there is reason to maintain the need for more knowledge about the long-term properties of the concrete in different environments. The foundations of the Öland bridge and other constructions show that concrete is not always a durable material.

KASAM would also like to emphasize the need to develop the safety assessment for the repository for long-lived waste. Even if SKB can use experience from both the safety assessment for SFR (which mainly contains relatively short-lived operational waste from nuclear power plants) and the safety assessment for the repository for spent nuclear fuel, the long-lived waste, which is intended here, and its disposal system, have certain special properties which require the development of a special safety assessment methodology. In RD&D Programme 2001, SKB states that, after the implementation of the site investigations for the repository for spent nuclear waste, which is now being planned, the time should be ripe for a new safety assessment for the disposal of long-lived waste (see overall timetable in Figure 17.1 in RD&D Programme 2001).

Conclusion

In KASAM's view, it is important that other long-lived waste (besides spent nuclear fuel) should be characterised and documented. It is also important to investigate the long-term properties of the concrete that is to be used as a construction material in the repository for such waste. Furthermore, the safety assessment methodology must be developed for the special type of waste as the existing, long-lived waste.

14 The need for a research programme focusing on aspects of the social sciences and the humanities related to the nuclear waste issue

14.1 Background

KASAM notes that, in recent years, SKB, partially on the initiative of the feasibility study municipalities, has prepared a number of reports on subjects relating to social science issues within nuclear waste. Additional analyses of employment, industry and tourism have been conducted in several feasibility study municipalities. After the local referenda in Storuman in 1995 and Malå in 1997, SKB published scientific studies on feelings and attitudes in each of these municipalities. During 2001, the following studies were completed: *Risk perception and attitudes to a deep repository for spent nuclear fuel in four municipalities* (SKB-rapport R-01-54, in Swedish) and *Psychosocial aspects of a deep repository for spent nuclear fuel. Literature review and interviews with inhabitants of Uppsala* (SKB-rapport R-02-13, in Swedish).

14.2 Justification for the programme

KASAM has noted that the feasibility study municipalities, in their review statements to SKI on RD&D Programme 2001, have consistently requested that SKB should pay considerably more attention than it has so far to the societal and democratic aspects of the nuclear waste issues. Similar viewpoints have been expressed by Uppsala University and the Swedish Environmental Protection Agency. After RD&D Programme 2001 was completed, representatives from SKB have, on different occasions, mentioned that the company is preparing a research programme within the social sciences and plans to work with Linköping University in this respect.

KASAM would like to emphasize that, even if the technical-scientific research programme is central to SKB's activities, the implementation of such a programme cannot be isolated from other societal developments. KASAM notes that SKB's local work may be important for local and regional societal conditions. Therefore, it is important that this work should be conducted in close contact with developments on the socio-economic, legal and democratic arenas.

There are several subject areas that should be the focus of attention in the future work on site investigations and during a subsequent detailed characterisation and construction phase. Examples of such issues are the effect of the site investigation phase on requirements for information and democracy, including work and decision processes in the political area. Other examples are possible effects in the legislative area, changes in regional conditions with respect to the labour market and the municipal economy as well as the development of opinions on a local and national level with respect to the further work on a repository. In particular, it may be of interest to investigate issues relating to the role of the mass media in forming public opinion.

Knowledge of possible changes in the municipalities and regions in areas concerning democracy and decision processes as well as economy are not only essential for local work but also essential to understand and document work relating to a national issue.

Issues that have been raised by the municipalities during the ongoing site investigation process include the following: What happens when SKB considers that it has concluded its work and when the company is closed down? Who is responsible if unexpected complications arise after that time – the municipality, the state, the Nuclear Waste Fund? What is the full implication of the provision in § 8a of the Financing Act which stipulates that funds from the Nuclear Waste Fund, under certain conditions, can be repaid to the reactor owners? A detailed study of applicable legislation and the preparatory work to this legislation provides answers to questions of this nature. However, this knowledge is not easily accessible and the answers are not always as precise as many would like. There may be reasons for researchers with suitable expertise to investigate the meaning of the regulations and to possibly demonstrate the need for greater clarity.

There are also reasons to continue and develop the discussion on ethical issues on disposal that KASAM has conducted since it started in the mid-eighties and which was recently the focus of an in-depth discussion at the "Anne-Marie Thunberg Seminar" held on May 3-5, 2001 (see the report, *Nuclear waste – present-day responsibilities and the freedom of future generations*, SOU 2001:108, in Swedish).

It should also be stated that the competence-building activities in the municipalities and regions concerned should continue, even if some of this work takes other directions or forms. Information on and the analysis of the status of public opinion and changes in status are important in order to be adequately equipped to deal with issues that should be taken into account in the work.

The issues mentioned above originate from the work on identifying a suitable site for the repository for spent nuclear fuel. KASAM emphasises that issues of this nature are relevant to the work on the entire *disposal system*. In addition to the construction of the repository for spent nuclear fuel, this work includes the construction of an encapsulation plant and a repository for long-lived low and intermediate level nuclear waste as well as the extension of a transport system.

According to the current time-table, the deposition of spent nuclear fuel and nuclear waste will continue until at least the

2050's. It is highly likely that the Swedish society will change in several respects during this time. However, no-one can predict with certainty what these changes will be and how the changes will affect attitudes to the technical solutions for the nuclear waste issues that are developed in our time. In KASAM's view, this fact is a further reason to start a social-scientific research programme which focuses specifically on the nuclear waste issues.

14.3 Organisational responsibility for implementation of the programme

Certain practical reasons may indicate that the responsibility and funding for a research programme focusing on societal and humanistic aspects of nuclear waste issues should lie with SKB, namely, the organisation that is well versed in the scientific and technical aspects of the issues. One reason could be that this activity needs to be started up quickly. Another reason could be that the financing should be arranged in a similar way as for the rest of SKB's research, namely, through the Nuclear Waste Fund. One prerequisite for such a research programme that is under the management of SKB to be perceived as credible by the scientific community and the public is probably that the researchers involved should be attached to established research institutions, in other words, that they should be independent of SKB. Another prerequisite is probably that, at the same time, a system should be in place for the peer review of the research results. A parallel can be drawn with the structure of SKB's current scientific and technical research and development work. This research is largely being conducted by researchers at universities and by researchers at consultancy companies. The quality and focus of the work is regularly reviewed primarily by the regulatory authorities, SKI and SSI, and by KASAM.

However, there are strong reasons why SKB should not have the main responsibility in Sweden for ordering social science and humanities research on nuclear waste issues. While KASAM considers that it is important for SKB to focus adequate attention on other aspects of nuclear waste issues besides the purely technical and scientific aspects, issues in the social sciences and humanities described in Section 14.2 do not, in the same way as the technical and scientific issues, have immediate relevance for SKB's ability to carry out its primary task. On the other hand, there is a strong national interest in ensuring that this research can be conducted, because it can provide insights that can be useful in connection with the necessary decision-making by public institutions on other complex issues. The main responsibility for such research should therefore rest with institutions that are completely independent of SKB.

One possibility is to engage the two regulatory authorities, SKI and SSI, in social science and humanities research in the nuclear waste field. Both authorities have experience of research administration, even if this research has traditionally focused on safety-related issues and radiation protection.

Another possibility would be to, at least initially, use KASAM for this task.

KASAM is a body with strong links with the scientific community. KASAM's members have always included representatives from both science/engineering and humanities/social sciences. This interdisciplinary composition has had a positive impact on KASAM's work, both with respect to the review of SKB's RD&D programmes and with respect to the choice of subjects for various seminars throughout the years. This has resulted in a general improvement in the insight that issues relating to the disposal of nuclear waste must be viewed from a holistic perspective and that it is not solely a question of technology and science.

Furthermore, KASAM has the impression that the actors in the nuclear waste area perceive KASAM to be a body with a high level of integrity. In particular, representatives from the feasibility study municipalities have, in different contexts, expressed their general confidence both in KASAM's activities so far in the scientific/technical field and in KASAM's interdisciplinary work on incorporating ethical and other "soft" aspects into the debate on the nuclear waste issues.

A possible model for involving KASAM in the implementation of a research programme, focusing on the societal and humanistic aspects on the disposal of nuclear waste, is outlined below. KASAM's members currently include highly qualified scientists in the fields of sociology/psychology and ethics. In order to carry out the tasks outlined below, KASAM may need to have access to expertise in areas such as business administration, law, cultural history and political science.

The model is based on two stages.

During an initial stage, the Government gives KASAM the task of defining important research questions in the humanities and social sciences, which are relevant to the disposal of nuclear waste. This work must naturally be conducted independently of SKB. The task requires considerable commitment, both by the KASAM members primarily concerned and by KASAM's scientific and technical experts in order to investigate the relevance of the research questions. The members may also have to consult different institutions in the research community. In order to assist in these issues, KASAM's secretariat may have to be reinforced by an individual with a research background. KASAM estimates that this initial stage will take 6-12 months to complete. One prerequisite for starting the work must be that it should be established that research funds will be made available and the approximate size of the funding should be specified. KASAM is prepared to submit a report to the Government on the result of this initial stage, within one year after the Government has decided to allocate the task to KASAM.

During the second stage, KASAM will identify, after consulting suitable institutions in the research community, qualified researchers who will be asked about their interest in becoming involved in the research tasks that have been identified during the initial stage. Subsequently, KASAM will give researchers the task of conducting projects that KASAM considers to be particularly important, KASAM will administer financing and will agree with researchers on how the results are to be reported. It must be possible to provide some compensation to the KASAM members who are involved in planning and review work. Naturally, during this stage, KASAM will not be limited solely to the research tasks defined during the initial stages; it can be assumed that new research needs will emerge during the course of work. In order to co-ordinate the research activities, KASAM will need a resource at the secretariat with a similar background as during the initial phase.

14.4 Costs and financing

What financial resources would be required for social science research on nuclear waste disposal? In KASAM's opinion, a reasonable level, after a successive development period of 2-3 years, would be of the order of magnitude of SEK 10 million per year. This level should be maintained during the site investigation phase, namely until the time that SKB obtains permission in accordance with the Environmental Code and the Act on Nuclear Activities to start work on a repository. At this time, it is justified to consider whether the programme should continue along the same lines, whether the direction of work should be changed or whether the programme should be terminated.

Financing should be secured by the Government making resources available to KASAM from the Nuclear Waste Fund.

The size of the amount should be viewed in relation to what both SKB and the regulatory authorities SKI and SSI currently spend on research with a largely technical and scientific focus. SKB's costs for safety assessment and research on long-term processes are estimated at SEK 70 million per year during the site investigation phase (this amount does not include the cost of method development in the Äspö Hard Rock Laboratory and in the Canister Laboratory). During the present budget year, SKI has a research grant for about SEK 71 million, of which just over SEK 13 million is used in the Nuclear Waste Safety area. SSI's nuclear waste-related research is at an essentially lower level, about SEK 3 million. Almost all nuclear waste-related research conducted by both authorities concerns technical and scientifically-oriented projects.

Most of the work on projects outside the technical-scientific area concern the area of Risk Communication, where SKI has allocated just over SEK 0.6 million and SSI, about SEK 0.4 million for 2002.

Altogether, SKB and the regulatory authorities in the nuclear field allocate about SEK 85 million to nuclear waste-related research with a technical and scientific focus and about SEK 1 million per year to research relating to humanities and social science issues.

SEK 10 million per year on a research programme, focusing on the social sciences and the humanities, over the next few years, should also be seen in relation to the amounts that have been disbursed from the Nuclear Waste Fund in the form of compensation to the feasibility study municipalities for their information work and knowledge improvement. Over the past five-year period (1997-2001), these disbursements amounted to about SEK 52 million. In practice, this compensation was a prerequisite for the involvement of the inhabitants of the municipality and their active participation in the site selection process so far undertaken. In KASAM's view, the amount should be considered to be a part of society's costs for a democratic process, based on knowledge and commitment.

14.5 Conclusions

KASAM concludes that there is a need to now start a research programme focusing on the societal and humanistic aspects of the nuclear waste issues. One possibility is for the Government to initially give KASAM the task of defining research needs and for being responsible for the implementation of such a research programme. Work should be conducted in two stages.

During an initial stage, the Government could give KASAM the task of defining urgent research tasks within the humanities and social sciences that are relevant for the disposal of nuclear waste. This work must naturally be conducted independently of SKB. This task requires considerable work, both by the KASAM members primarily concerned and by KASAM's scientific and technical experts in order to investigate the relevance of the research questions. The members will probably also have to consult different institutions in the research community. In order to assist in these issues, KASAM's secretariat may have to be reinforced by an individual with a research background. KASAM estimates that this initial stage will take 6-12 months to complete. One prerequisite for starting the work must be that it should be established that research funds will be made available and the approximate size of the funding should be specified. KASAM is prepared to submit a report to the Government on the result of this initial stage, within one year after the Government has decided to allocate the task to KASAM.

During the second stage, KASAM will identify, after consulting suitable institutions in the research community, qualified researchers who will be asked about their interest in becoming involved in the research tasks that have been identified during the initial stage. Subsequently, KASAM will give researchers the task of conducting projects that KASAM considers to be particularly important, KASAM will administer financing and will agree with researchers on how the results are to be reported.

It must be possible to provide some compensation to the KASAM members who are involved in planning and review work. Naturally, during this stage, KASAM will not only be limited to the research tasks defined during the initial stages; it can be assumed that new research needs will emerge during the course of the work. In order to co-ordinate the research activities, KASAM will need a resource at the secretariat with a similar background as during the initial phase.

In KASAM's opinion, a reasonable level of funding for the social science research programme on nuclear waste would be in the order of SEK 10 million per year. This level should be reached after a development period of 2-3 years and would be maintained during the site investigation phase, in other words until the time that SKB obtains permission in accordance with the Environmental Code and the Act on Nuclear Activities to start work on a repository. At this time, it is justified to consider whether the programme should continue along the same lines, whether the direction of work should be changed or whether the programme should be terminated.

Financing should be secured by the Government making resources available to KASAM from the Nuclear Waste Fund.

Baksidestext:

KASAM – the Swedish National Council for Nuclear Waste – established in 1985 – is an independent committee attached to the Ministry of the Environment. KASAM's task is to investigate issues relating to nuclear waste and the decommissioning of nuclear installations and to provide the Government and certain regulatory authorities with advice on these issues.

KASAM's members – who largely comprise professors from Swedish and Nordic universities and institutes of technology – represent independent expertise within different areas of importance for the disposal of radioactive waste, not only in natural science and technology, but also in areas such as ethics, psychology and social sciences.

KASAM is responsible for presenting a special independent evaluation of the state of knowledge within the nuclear area once every three years.

An important part of KASAM's activities is to provide a forum for alternative views and for experts in Sweden and abroad to discuss nuclear waste issues. Consequently, a number of seminars have been held over the years.

KASAM is also responsible for evaluating the programme for research and development – concerning the disposal of spent nuclear fuel – which the Swedish nuclear power utilities, through the Swedish Nuclear Fuel and Waste Management Company (SKB), present every three years. This publication is KASAM's review statement to the Government on SKB's RD&D Programme 2001 – programme for research, development and demonstration of methods for the management and disposal of nuclear waste.

KASAM, Ministry of the Environment, SE-103 33 Stockholm, Sweden

*ISBN 91-38-21714-7 * ISSN 0375-250X*