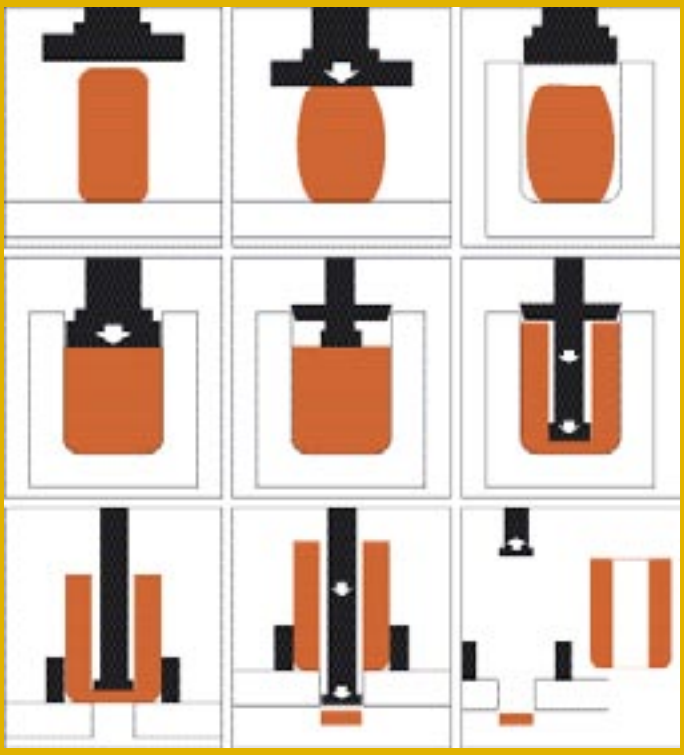
Nuclear Waste - Barriers, Biosphere and Society



Nuclear Waste

- Barriers, Biosphere and Society

KASAM's Review of the Swedish Nuclear Fuel and Waste Management Co's (SKB's) RD&D Programme 2004

KASAM
STATENS RÅD FÖR KÄRNAVFALLSFRÅGOR
National Council for Nuclear Waste

STATENS OFFENTLIGA UTREDNINGAR

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Cover picture: Step 1 of extrusion of copper canister
for spent nuclear fuel (Source: SKB)

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To the Minister for the Environment at the Ministry of Sustainable Development

KASAM's Review Statement on the Swedish Nuclear Fuel and Waste Management Co's (SKB's) RD&D Programme 2004 – Programme for Research, Development and Demonstration of Methods for the Management and Disposal of Nuclear Waste, Including Social Science Research

One of the tasks of KASAM – the Swedish National Council for Nuclear Waste – is (see Dir. 1992:72) to present to the Government its independent review of the RD&D Programme (research, development and demonstration programme) that the Swedish nuclear power companies, through SKB, must submit once every three years. According to the Act (1984:3) on Nuclear Activities, the programme shall concern the comprehensive research and other measures necessary to manage and dispose of nuclear waste in a safe manner as well as to decommission and dismantle the nuclear power plants.

This report contains KASAM's review statement to the Government on RD&D Programme 2004. The Programme contains SKB's plans for the period of 2005-2010, including a more detailed account of the issues which will be dealt with up to 2008. At that time, SKB intends to submit to the Government, applications for permissibility/licensing in accordance with the Environmental Code (1998:808) and the Act on Nuclear Activities for a repository for spent nuclear fuel.

KASAM's review statement ends with a number of recommendations. Most of these are directed at SKB, but some are directed to the Government.

KASAM proposes that the Government decide that the reactor owners, through SKB's RD&D Programme 2004, have complied with the requirements of § 12 of the Act on Nuclear Activities.

All of KASAM's members, as well as the experts, Hannu Hänninen, Sören Norrby and Olof Söderberg and KASAM's secretary, Mats Lindman, stand behind KASAM's review statement.

Stockholm, June 2005

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1 Introduction

1.1 Background

1.1.1 Background to the Legislation

The production of electricity by nuclear power plants in Sweden started when the first major nuclear power reactor, Oskarshamn 1, was taken into commercial operation in 1972. The planning of the first nuclear power reactors was conducted as early as in the 1960's. The legislation which, above all, regulated nuclear power issues at that time was the Atomic Energy Act. In connection with the start-up of Oskarshamn nuclear power plant, a discussion on waste from nuclear power plants started, although it was not until the next few years that the discussion seriously accelerated.

As early as the mid-1970's, the AKA government commission of inquiry proposed a system of facilities which is similar to the system, which now partially exists in Sweden and, which Svensk Kärnbränslehantering AB (the Swedish Nuclear Fuel and Waste Management Co, SKB) plans to develop. The complete system comprises the existing waste management facilities, the Central Interim Storage Facility for Spent Nuclear Fuel (CLAB) and the Repository for Radioactive Operational Waste (SFR), as well as the planned repositories for high-level and other waste. The AKA inquiry never led to a proposal for new legislation, although it had significant importance for the planning of the

Swedish nuclear waste system. In the Stipulation Act, which entered into force in 1977, requirements were made on "completely safe" disposal of spent nuclear fuel.

After extensive technical and political discussions and investigations, the Act (1984:3) on Nuclear Activities, which is currently in force, was passed. The Act stipulates the "safe" handling and disposal of spent nuclear fuel and nuclear waste and places the responsibility for research and development with the nuclear power industry. In accordance with the Act, nuclear power companies must present a research and development programme once every three years. The nuclear power companies founded SKB in order to prepare and develop this programme (known as the RD&D programme) and to manage the radioactive waste and spent nuclear fuel from the reactors. SKB is jointly owned by the nuclear power companies.

Funds are necessary in order to conduct research and development work in this area and to operate the waste facilities. According to the Financing Act (1992:1537), which was originally from 1981, the nuclear power plants must bear the costs of a safe handling and disposal of nuclear waste. This is achieved by paying a fee for each kWh generated into a special waste fund (the Nuclear Waste Fund) administered by the Government. This financing system has been effective. So far, the Swedish nuclear waste programme has cost just over SEK 15 billion. Current estimates indicate that a further some SEK 55 billion will be needed. Of this amount, about SEK 35 billion is currently in the Nuclear Waste Fund. The difference of about SEK 20 billion is expected to be covered by the yield on the funds that have already accumulated and by further fee payments as long as the reactors are in operation.

1.1.2 Comprehensive Programme Required

The Act on Nuclear Activities stipulates that a comprehensive research and development programme should be conducted. This requirement is particularly clear at the initial stage when the basis for deciding on the direction and concept should be very broad. However, it is also important, at later stages, that alternative solutions should be investigated as far as reasonable so that the programme provides a basis for making strategic choices without limitations to a single path which may turn out to be a dead-end. However, it is not reasonable or possible to investigate and develop all alternatives all of the time to the same extent. This could prevent the possibility of reaching a decision, especially since new variations and concepts for processes and facilities for the disposal of spent nuclear fuel and nuclear waste could be proposed as development work continues. It is possible and necessary to gradually focus the investigations on the alternatives which seem to be of particular interest. Naturally, this does not exclude the fact that one must be constantly prepared to re-evaluate decisions that have already been made if new facts emerge through ongoing research.

1.1.3 The Nuclear Industry's Reporting of the Programme

According to 12 § of the Act on Nuclear Activities, the nuclear reactor owners must prepare or have prepared a programme for the comprehensive research and development activities as well as the other measures necessary to safely handle and dispose of nuclear waste generated by the activity and to safely decommission and dismantle facilities that are no longer needed. The programme must be prepared every third year, must cover a period of six years and must be submitted to the Swedish Nuclear Power Inspectorate (SKI).

The reactor owners have given SKB the task of preparing this programme. *RD&D Programme 2004 – Programme for Research,*

Development and Demonstration of Methods for the Management and Disposal of Nuclear Waste, including Social Science Research – was submitted by SKB in September 2004.

1.1.4 Review Process

The RD&D programme is reviewed by SKI which, through a formal review process, invites comments from a large number of organizations. These comments are compiled by SKI. SKI submits its review statement together with the comments to the Government. In parallel with SKB's review process, the programme is reviewed by KASAM, which also submits its own review statement to the Government. With SKI's and KASAM's statements as a basis, the Government then decides on the programme and decides whether the programme fulfils the requirements of the Act on Nuclear Activities (with respect to comprehensiveness and other aspects). The Government also decides on the necessary stipulations for the rest of the research and development activities. Through these recurrent reviews of SKB's research and development programme, once every three years, and through the Government's decision, the programme is supported and approved by society as a whole.

1.1.5 Method and Site Selection

SKB has presented several alternatives with respect to the choice of disposal method. However, at an early stage, it was clear that disposal in stable geological formations at a great depth is preferable. There is also a broad international consensus among technical experts that geological disposal is the most suitable method for long-term storage of the most hazardous forms of radioactive waste. Such a focus is also preferred by most countries which have a research and development programme for high-level waste or spent nuclear fuel.

The KBS-3 method (which entails placing spent nuclear fuel in copper canisters with a cast-iron insert, a surrounding barrier of bentonite clay and depositing the waste in a tunnel system at a depth of several hundred metres in the bedrock) has been gradually developed over many years and has been recurrently reported and subjected to regulatory review. The KBS-3 method has been accepted by the Government as the main line for further development work. In a government decision from November 2001, concerning SKB's RD&D Programme 98 Supplement, the Government approved of this method as a "prerequisite for planning" the site investigations that SKB is now conducting at Forsmark (Östhammar municipality) and Simpevarp/Laxemar (Oskarshamn municipality). However, in the same decision the Government emphasized that "the final approval of a certain method for disposal can only be given in connection with a future decision on applications for permission under the Environmental Code and the Act on Nuclear Activities to construct a repository for spent nuclear fuel".

The geological investigations that SKB has conducted and is now conducting to obtain information for selecting a site for a repository for spent nuclear fuel were initially conducted with the aim of identifying the geological conditions in large parts of Sweden. To some extent, it is justified to say that SKB initially aimed at locating the "best" site for the repository. After opposition in the form of local referendums, the strategy has been changed so that SKB's main goal is to find an "adequate" site, namely a site that meets certain basic safety requirements.

For KASAM, it is obvious that the repository design, including the disposal method and the geological and hydrological nature of the site are dependent on each other. The geological barrier is part of the barrier system which is to prevent or, at least, retard the leakage of radioactive substances to the biosphere.

The Government's decision to accept the KBS-3 method as a prerequisite for planning made it possible for SKB to start the site investigations that are now underway at Forsmark and

Simpevarp/Laxemar. These site investigations provide knowledge of geological, hydrological and other conditions in the areas to be investigated and also provide more general information for the construction of a repository and for assessing the safety of a repository.

1.2 KASAM's Review of RD&D Programme 2004

KASAM – the National Council for Nuclear Waste – is an independent scientific committee attached to the Ministry of Sustainable Development charged with the task of studying issues relating to nuclear waste and the decommissioning of nuclear facilities and to advise the Government and certain regulatory authorities on these issues. KASAM's terms of reference include submitting to the Government its independent opinion of the nuclear companies' research and development programme. This report is KASAM's review statement to the Government on SKB's RD&D Programme 2004.

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

The basis of KASAM's review includes KASAM's review of RD&D Programme 2001 (September 2001) and previous RD&D programmes as well as the Government's decision on these SKB reports.

1.3 Findings of KASAM's Review

In Chapter 2 of this review statement to the Government, KASAM's *overall evaluation* of RD&D Programme 2004 is first presented. Subsequently, in Chapters 3 to 17, comments are presented on the sections of RD&D Programme 2004 that KASAM has reviewed in detail. The conclusions that KASAM reached from this review are summarized in bullet points at the end of each chapter.

2 Overall Evaluation

2.1 Background

RD&D Programme 2004 covers SKB's research and development plans for the period of 2005-2010. The emphasis is on the period up to 2008, when SKB intends to submit applications for permissibility/licensing under the Environmental Code (1998:808) and the Act on Nuclear Activities (1984:3) for a repository for spent nuclear fuel. According to RD&D Programme 2004, applications for permissibility/licensing for an encapsulation plant will be submitted in 2006.

The main focus of the programme is technical/scientific, with a certain emphasis on research and technology development, specifically focusing on canister and encapsulation issues for spent nuclear fuel. In this way, RD&D Programme 2004 will provide a basis for the application for permission in accordance with the Act on Nuclear Activities to construct an encapsulation plant for spent nuclear fuel that SKB intends to submit in 2006. Since SKB's previous report on its research and development programme, namely RD&D Programme 2001, a new chapter on "social science research" has been added.

In RD&D Programme 2004, SKB presented a plan of action for applications for permissibility/licensing under both the Act on Nuclear Activities and the Environmental Code for an encapsulation plant and a repository for spent nuclear fuel.

According to this plan, applications for an encapsulation plant in accordance with the Act on Nuclear Activities and the Environmental Code would be submitted in 2006 and applications for a repository in accordance with the Act on Nuclear Activities and the Environmental Code, would be submitted in 2008. Since it has since then become increasingly clear that applications for both of these activities are strongly linked to each other and that it is most reasonable for the Government to make a decision on both of these activities at the same time, SKB has, during the review of RD&D Programme 2004, changed its planning for the decision-making process. According to SKB's current proposal for a plan of action (March 2005), an application in accordance with the Act on Nuclear Activities for an encapsulation plant is to be submitted in 2006. In 2008, an application is to be submitted for a repository in accordance with the Act on Nuclear Activities and applications are to be submitted for both an encapsulation plant and a repository in accordance with the Environmental Code.

In the past, in its review statements on the RD&D programme, KASAM has presented many views on individual issues. KASAM has also made the general evaluation that the programmes meet the requirements of the Act on Nuclear Activities, including the requirement on comprehensiveness. Above all, KASAM has focused on three main issues, namely:

- Encapsulation.
- Disposal including site selection.
- The decision-making process, including applications for permission as well as issues relating to consultation and Environmental Impact Statements (EIS).

In addition to these issues, KASAM has commented on other matters dealt with in the RD&D programmes, such as safety assessment methodology, transportation of nuclear waste and spent nuclear fuel and the decommissioning of nuclear facilities.

In recent years, KASAM has also pointed to the need for social science research on issues relating to nuclear waste. Last but not least, KASAM has called the Government's attention to the need for independent expertise on issues relating to safety and radiation protection and has also emphasized this need with respect to social science research. Expertise is needed, that is independent of SKB and the nuclear power industry, to ensure that the review of SKB's programmes and applications for permission are conducted in a reliable manner in order to provide the credibility that is necessary in order for society to accept the disposal solution as well as to obtain an adequate basis for the Government's decisions.

2.2 KASAM's Evaluation

2.2.1 Overall Evaluation

KASAM's overall evaluation is that SKB's RD&D Programme 2004 meets the requirements of the Act on Nuclear Activities regarding a comprehensive research and development programme. At the same time, KASAM considers that there is a need for continued research and investigations with the aim of achieving a favourable development of the RD&D programme and of creating the best conditions for the ultimate choice of technology and site for the planned activities. Research and investigations are also needed to provide a basis for the preparation of adequate documentation for applications, including Environmental Impact Statements (EIS) and safety assessments for permissibility/licensing to be conducted by the Government and other authorities.

2.2.2 Evaluation on Certain Issues

2.2.2.1 SKB's Report in relation to the Requirements of the Act on Nuclear Activities

In KASAM's opinion, the reactor owners have, through RD&D Programme 2004, met the requirements of § 12 of the Act on Nuclear Activities.

2.2.2.2 Structure of the Report

In KASAM's view, SKB's presentation of its research and development programme is worthy of merit. This applies to what SKB has achieved as well as to what it intends to achieve. The report is well-structured and clear. In many parts, it contains a systematic account of earlier viewpoints expressed by the authorities, the Government and, in certain cases, KASAM and an account how it has acted on or it intends to act on these viewpoints.

2.2.2.3 Further Need for Technical Development

RD&D Programme 2004 shows that there is still a large need for development work in a number of important technical areas. This includes, for example, canister fabrication and sealing and control methods for these activities. SKB's research and development work at the Canister Laboratory in Oskarshamn is of great importance in this context.

2.2.2.4 Materials Technology Issues

The choice of method, based on the KBS-3 concept, rests on the assumption that it can be shown that the engineered barriers, including the copper canister, can fulfil its function, also in a

very long-term perspective. SKB has developed different methods for sealing copper canisters. In May 2005, SKB stated in a press release that a "safe method for spent nuclear fuel encapsulation is ready". Even if KASAM supports the choice of welding method, KASAM considers that SKB should have waited to make the choice until it had had access to the results of SKI's and KASAM's reviews of RD&D Programme 2004. It remains for SKB to show that the welding method functions on an industrial scale and can yield results that comply with the established requirements.

2.2.2.5 Other Scientific Issues

In other areas, such as geology, rock mechanics, hydrology, biology and chemistry, there is also a great need for further research and development work and for practical demonstrations of technical applications. Experience from the ongoing site investigations at Forsmark and Simpevarp/Laxemar as well as at SKB's Hard Rock Laboratory at Äspö have a considerable scientific value for the further development work for the disposal of spent nuclear fuel and other nuclear waste.

2.2.2.6 Barriers in the KBS-3 Concept

In-depth knowledge of the barriers (canister-buffer-backfill-geosphere) is a basic premise for the siting and design of a safe repository. The selection of a site for spent nuclear fuel should therefore, in KASAM's opinion, be based on geological investigation data, which also represents other geological conditions than those now being investigated at Forsmark and at Simpevarp/Laxemar. In KASAM's view, a convincing line of argument is missing from RD&D Programme 2004 for the reasons behind SKB's statement that "the deep repository will be built in crystalline rock of granitic composition".

2.2.2.7 Biosphere Issues

A deeper understanding of biosphere composition and biological processes is also a basic premise for the siting of the nuclear waste facilities.

2.2.2.8 EIS Issues

At the same time that in-depth knowledge is necessary in order to identify and describe the direct and indirect environmental consequences (also with respect to the remote future) of the activities that will be specified in the applications, a broad basis for decision-making will be needed in order to, in a convincing manner, demonstrate what corresponds to the Environmental Code's requirements on the "best available technology" as well as requirements on a "suitable" site where "the purpose can be reached with minimum intrusion and inconvenience to human health and the environment". In this context, a detailed description of alternative sites and alternative technologies is considered to be a necessity for the EIS to fulfil its intended purpose. Such a "broad" account of alternatives should also facilitate an understanding of the final choice of repository design and site. Together with the requirements of the Environmental Code regarding a "non-technical summary", this account should fulfil the purpose of making the basis for decision-making more accessible to the public.

2.2.2.9 Previous Choices and Priorities

With the aim of shedding light on the strategic choices that SKB has made during the process, and thereby, putting RD&D Programme 2004 in a context that is easier to understand, the RD&D programme should, in the future, be expanded to include a background account which describes the premises, contents,

priorities and justifications for the considerations and decisions made in previous RD&D programmes. In KASAM's opinion, such a description should be presented no later than in connection with the submission of RD&D Programme 2007.

2.2.2.10 The Comprehensibility of the Safety Assessment

SKB should, in a clearer manner than at present, quantify and report the uncertainties in the different parts of the safety assessment. The premises and methodology of the safety assessment must be described and justified in a clear manner and a structured method for scenario selection is needed. Safety in connection with a possible retrieval of the deposited material must also be described.

Furthermore, it is important to focus on making the basis for decision-making comprehensible to a larger readership than the experts in the nuclear waste area, when structuring the safety assessments. By developing these assessments, understanding of the risks of a deep repository, compared to other risks in society, could be improved. Bearing in mind the need of the public and municipalities for insight and understanding in connection with the licensing process for spent nuclear fuel disposal, KASAM considers that both SKB and the authorities must publish pedagogical descriptions of the complex safety assessments.

2.2.2.11 Serious Events and Protective Measures

The possibility of being able to anticipate accidents, sabotage and terrorist action in connection with the transportation and other handling of spent nuclear fuel requires special attention. Such information is necessary for taking effective protective measures. The need to also take into account highly unlikely events is determined by the estimated consequences of an event. KASAM assumes that these risks and the need for protective

measures will be thoroughly described in connection with the safety assessments and EIS that will be included in the applications for permission to construct an encapsulation plant and a repository for spent nuclear fuel.

2.2.2.12 SKB's Plan of Action

In its review statement on RD&D Programme 2001, KASAM considered that SKB's timetable was too optimistic to guarantee the good quality of all of the work that must be done. KASAM continues to uphold this view and would like to stress that it is the requirement on the high quality of the basis for decision-making that should steer the research and development work and not a certain specified timetable for the decision-making process.

2.2.2.13 Co-ordinated Licensing of the Encapsulation Plant and Repository

KASAM is positive to SKB's changed timetable (March 2005) for consultation and applications etc. and emphasizes that an encapsulation plant and a repository for spent nuclear fuel should be evaluated for permissibility/licensing (under the Act on Nuclear Activities and the Environmental Code) in a single context since these facilities are two parts of one and the same waste system. Furthermore, in KASAM's opinion, a single, co-ordinated EIS should be prepared for these evaluations.

2.2.2.14 Decommissioning of Nuclear Facilities

KASAM is critical to the fact that SKB did not accord greater attention in RD&D Programme 2004 to decommissioning issues, especially with respect to issues concerning the estimate

of the cost of the decommissioning of nuclear power plants. These issues have become even more relevant through the Government's decision in December 2004 that the right to operate the nuclear power reactor, Barsebäck 2, to generate nuclear energy should be revoked at the end of May 2005. There are also more general aspects of decommissioning issues for which in-depth studies must be carried out in the next few years. With respect to the need for an EIS, in KASAM's view, the Government should take the initiative to ensure that relevant environmental policy, energy policy and legal issues in connection with the phase-out of nuclear power in Sweden are investigated in greater depth.

2.2.2.15 Need for Independent Research

In its review of RD&D Programme 2001, KASAM considered that humanities and social science issues of importance for the disposal of nuclear waste should be given greater attention. KASAM is satisfied to note that SKB has initiated a social science research programme as a part of RD&D Programme 2004. However, for the credibility of the research, it is of great importance that, in the humanities and social science area, research should be conducted that is financed by others besides the nuclear power industry. It is important for the Government to set aside funds so that independent researchers have the financial resources to initiate research which is important for the review of the industry's proposals as well as research on decision-making processes in connection with such reviews.

The need for research that is independent from the nuclear power industry, including SKB, also applies with science and technology.

2.2.2.16 Need for Expertise in Radiation Protection and Nuclear Safety

KASAM is concerned that the ongoing reduction in allocated resources in subjects such as radiation physics/radiophysics, reactor physics, nuclear chemistry, radioecology and radiation biology will lead to a lack of availability of necessary expertise in radiation protection and nuclear safety. As an example in the radiation protection area, KASAM notes that several universities have shut down departments active in this area. Furthermore, in practice, there is no research organization allocating funds for basic radiation protection research. With dwindling research, radiation protection in Sweden will suffer and expertise will decrease. As early as in 1994, the final report of a government-appointed commission of inquiry, "Long-term Radiation Protection Research" (SOU 1994:40) indicated that radiation protection research was in a serious situation. The commission's report was positively received by the reviewing bodies but did not result in additional funding being allocated for research in the area. The situation is even more serious today.

2.2.2.17 Scientific Breadth of Future RD&D Programmes

In conclusion, KASAM would like to emphasize that forthcoming reports on RD&D programmes should have a broad scientific breadth in order to be able to meet the requirements of the Act on Nuclear Activities with respect to comprehensiveness and to meet the requirements of the Environmental Code with respect to the basis for decision-making, including the EIS, in connection with licensing in accordance with Chapters 17 and 9 of the Environmental Code.

3 SKB´s Programme and Action Plan

3.1 Background

SKB's Research, Development and Demonstration Programme for the Management and Disposal of Spent Nuclear Fuel and Other Radioactive Waste in Sweden started more than 25 years ago. Changes in legislation, regulatory requirements and public perception of the importance of environmental and societal issues have changed the conditions of this programme over the years. SKB (and the regulators) started off with a clear focus on the technological solutions – the company would find a "completely safe disposal" solution. Over time, the environmental issues have gained greater importance; environmental legislation has become more stringent and Environmental Impact Statements (EIS) and licensing have become increasingly important instruments. In this way, many issues have come into focus, not only individual technological issues but also important issues of principle, such as accounts of alternatives with regard to choice of method and site. SKB changed its strategy (after difficulties in the programme) and went from a technical/geological site selection process (with the aim of locating what can almost be called the "best" site) to a participatory democratic process (with the aim of locating an accepted site with an "adequate" level of safety). Thus, the programme has emerged over a period of time with gradual changes in perceptions of the environment and society as well as

with changes in the technology and insight into the interaction between these issues. The legislation has also changed as a result of this evolution.

The Swedish nuclear waste programme is now reaching the point where SKB will submit applications for permission to construct and operate facilities for the management and disposal of spent nuclear fuel and other nuclear waste from nuclear power plants, in addition to the fact that the company is reporting, on a recurrent basis, on the RD&D programmes that the Act on Nuclear Activities stipulates. It can be assumed that the applications will be based on the KBS-3 concept.

SKB's RD&D Programme 2004 focuses on issues relating to the encapsulation of spent nuclear fuel. The programme also functions as a basis for an application for permission to construct an encapsulation plant which SKB plans to submit in 2006. According to SKB, RD&D Programme 2007 will focus on geology and the selection of a site for a repository for spent nuclear fuel. The programme will therefore be used as a basis for applications for permission to construct a repository that SKB plans to submit in 2008. New RD&D programmes will also continue to be prepared once every three years.

An encapsulation plant and a repository for spent nuclear fuel based on the KBS-3 concept must be licensed under the Act on Nuclear Activities and the Environmental Code. It is up to the Government to make decisions for licensing under the Act on Nuclear Activities and on permissibility under Chapter 17 of the Environmental Code for facilities at specified sites. Decisions on licensing under the Act on Nuclear Activities are prepared by SKI, while decisions on permissibility in accordance with Chapter 17 of the Environmental Code are prepared by the Environmental Court.

The Environmental Code and the EIS regulations in Chapter 6 are an important basis for the structuring of the consultative and decision-making process. The stipulations of the Environmental Code regarding the content of EIS are relatively

broad and, in order to fulfil these requirements, it can be assumed that investigations and some research will be needed.

In addition to the highly extensive scientific and technological report, in general terms, RD&D Programme 2004 deals with the needs of the EIA process and the need for social science studies.

3.2 KASAM's Considerations and Evaluation

An important question is how well the RD&D Programme 2004 meets the legislative stipulations. This is dealt with in different ways in the Programme.

KASAM's comments mainly refer to Chapters 1 to 3, including Appendix A, of RD&D Programme 2004

3.2.1 The Nuclear Waste System (Chapter 1 of RD&D Programme 2004)

Chapter 1 of RD&D Programme 2004 contains an overview of the Swedish nuclear waste system with its technical and scientific parts and function. No background is provided on the way in which the nuclear waste system, in addition to being a technologically advanced project, is also a health protection and environmental issue as well as a societal issue. However, this is described to some extent in Appendix A, where different considerations, safety principles etc. for the spent nuclear fuel repository are reported.

In order to contribute to knowledge transfer, continuity and clarity in the long-term planning and licensing process of which the RD&D Programme is a part, in KASAM's opinion, in the future, the programme must be supplemented by a special report which describes the premises, content and priorities of the previous RD&D programmes as well as, thereby, the background to the pertinent issues and considerations. Such a retrospective with justifications for the considerations and

decisions that were made at earlier stages would make it easier to determine the basis of the RD&D Programme's focus in relation to a repository for spent nuclear fuel as a societal and environmental issue in Sweden and whether the programme meets the legislative requirements. In KASAM's opinion, such a background description should be provided, for example, in a special report, no later than in connection with the submission of RD&D Programme 2007. An updated overall summary of such a background description should also be included in each future RD&D Programme.

3.2.2 Plan of Action (Chapter 2 and Appendix A of RD&D Programme 2004)

Chapter 2 of RD&D Programme 2004, together with Appendix A, shows the planning for the system for the management of spent fuel including high-level waste and for the system for management of low and intermediate-level radioactive waste. According to SKB, the plan of action was developed to provide a basis for the regulatory authorities to assess which regulatory reviews they need to carry out and so that they can assess how SKB should attain its goal of a safe disposal of nuclear waste. In this chapter, SKB presents various assumptions concerning technology, economic considerations, licence applications and licensing procedures.

It should be noted that SKB, after RD&D Programme 2004 was submitted, has presented proposals for a "modified plan of action" in discussions. These proposals entail changes in the assumptions regarding the deadlines for submitting licence applications and for the review of these applications. KASAM has applied these new assumptions in its review of the RD&D programme.

3.2.2.1 Decision-making Process Issues

Taking into account the discussions that SKB has initiated with KASAM and the participants in the ongoing consultative process in accordance with the Environmental Code, KASAM presents the following evaluation.

In KASAM's view, considering the stipulations of the Environmental Code regarding the use of best available technology, the licensing of the encapsulation plant and the repository for spent nuclear fuel in *a single* context is justified by fact, since these facilities are two parts of one and the same waste system, which is based on an interaction between engineered and natural barriers. The need for co-ordination between the processes for licensing of the encapsulation plant and the repository also follows from Chapter 16 7 § of the Environmental Code which stipulates the following: "In connection with the consideration of cases and matters pursuant to this Code, attention shall be paid to other activities or special structures that are likely to be necessary for efficient operations." Therefore, KASAM is positive to the changed proposals put forward by SKB in 2005 for a timetable for the licensing process.

It is also justifiable that licensing, in accordance with different types of legislation, primarily the Environmental Code and the Act on Nuclear Activities, is conducted in a co-ordinated manner and in a single context. In bill 1997/98:90, concerning follow-on legislation to the Environmental Code etc., the following is stated (see pp. 270-271) with respect to the co-ordination between licensing under the Environmental Code and the Act on Nuclear Activities: "If the action is of the type that the Government is to evaluate permissibility in accordance with Chapter 17 of the Environmental Code, the Environmental Court, after preparing the case, must hand it over to the Government for decision-making. It can be assumed that the handling of the matter by the Environmental Court will be conducted in parallel with a preparation of the matter by SKI of

the licensing action in accordance with the Act on Nuclear Activities. The evaluation of permissibility under the Environmental Code and the licensing process should thereby be co-ordinated so that the Environmental Court has access to the review reports of the expert authorities with respect to the Act on Nuclear Activities when the Court evaluate permissibility under the Environmental Code. The Government's final preparation and decision in accordance with both Act and Code should be co-ordinated. After the evaluation of permissibility under the Environmental Code has been completed by the Government, the matter should be referred once again to the Environmental Court if a licence under the Environmental Code is required and then all emissions and environmental impacts from the facility should be evaluated."

As already mentioned, after submitting RD&D Programme 2004, SKB initiated a discussion with KASAM and others about a changed time-table for submitting applications for the planned facilities and reported a changed time-plan for the decision-making process. SKB's "modified plan of action" for the decision-making process primarily entails the following.

Applications for licences, under the Environmental Code, for the encapsulation plant and the repository for spent nuclear fuel will be submitted in 2008. Applications for licences under the Act on Nuclear Activities are to be submitted, for the encapsulation plant, in 2006 (and supplemented in 2008) and, for the repository, in 2008.

In connection with the discussion on the modified plan of action, SKB has also stated that "SKB agrees with the consultation partners that the licensing of the different facility components in the KBS-3 system should be based on material which is as complete, compiled and accessible as possible."

3.2.2.2 Issues Relating to EIS

The Act on Nuclear Activities and the Environmental Code both require that applications should contain an Environmental Impact Statement (EIS). The EIS is to be prepared by the proponent after consultations have been conducted in accordance with Chapter 6 of the Environmental Code, namely with the government authorities, municipalities, general public and organizations concerned. In the continued discussions on a modified plan of action for the licensing process, SKB has stated that the company intends to submit a single EIS which will be applicable to both facilities (an encapsulation plant and a repository for spent nuclear fuel) and which will be applicable for licensing in accordance with both forms of legislation.

In KASAM's opinion, it is essential that a single, co-ordinated EIS should be prepared prior to the Government's permissibility assessment/licensing, which is expected to be conducted in a co-ordinated manner. This is justified by the need to obtain an overview of all of the consequences of an encapsulation plant and a repository for spent nuclear fuel, together with other activities in connection with the construction and operation of these activities. This is also justified by the need for co-ordination between the licensing in accordance with the two forms of legislation and between the licensing of the encapsulation plant and the repository. This would also satisfy the need for public insight into and transparency of the whole complex disposal issue, at a stage when the application documents, including the EIS, are supplemented by SKB and can be announced by the competent authority prior to the continued preparations and licensing actions.

3.2.2.3 SKB's Application for the Encapsulation Plant

In the light of this, KASAM takes a positive view of SKB's amended proposed time-table for the licensing process. The proposal means that SKB, at an early stage (2006), will submit an application (including EIS) for permission to construct an encapsulation plant only and for licensing only under the Act on Nuclear Activities. Furthermore, this "preliminary" application (like the accompanying EIS), will be supplemented from 2006 to 2008. This development of the application and the EIS will be achieved as SKB continues the extended consultation in accordance with Chapter 6 § 5 of the Environmental Code and as SKI, in addition to participating in the extended consultation, also reviews the "preliminary" application submitted by SKB as a basis for a final application at a later stage. The regulatory review of the "preliminary" application submitted by SKB may therefore resemble an in-depth part of the consultative process which will be of benefit for the content of SKB's final application with its accompanying EIS as well as for SKI's subsequent review of the complete application documents.

3.2.2.4 Issues Relating to Consultation

One of the aims of the RD&D Programme is to provide a basis for future applications in accordance with the Environmental Code and the Act on Nuclear Activities. An important issue is the extent to which the account provided in RD&D Programme 2004 corresponds to the requirements regarding the content of the applications in accordance with these two types of legislation. For example, the outcome of the most recent consultations in accordance with Chapter 6 of the Environmental Code and the possible impact of these on the content of the RD&D Programme could have been discussed.

SKB has conducted consultations (with parties concerned as stipulated in Chapter 6 § 5 of the Environmental Code) as a

basis of the preliminary scoping reports (for the EIS for an encapsulation plant and a repository for spent nuclear fuel in Forsmark or in Simpevarp/Laxemar). However, SKB does not state whether this preliminary scoping has had an impact on the RD&D Programme or how the results have been taken into account in relation to the needs of the RD&D Programme.

It is reasonable to assume that the work on preparing the EIS can result in the need for shorter research projects in addition to the major technical RD&D projects conducted by SKB. The company also states, in connection with its social science work, that these research results will contribute to the content of the EIS, although SKB still has to show how this can be done, for example, by preparing an initial outline of the content of the forthcoming EIS.

3.2.2.5 KASAM's Tasks

KASAM does not have a formal role as an actor in the consultation process in accordance with the Environmental Code or in the review of licence applications under the Environmental Code and the Act on Nuclear Activities. As can be seen in KASAM's terms of reference for 1992, KASAM's main tasks are to review SKB's RD&D programmes, to publish state-of-the-art reports on the issues that KASAM finds to be important in the ongoing process and to encourage an in-depth discussion on these issues, for example in the form of seminars. In KASAM's opinion, it is therefore necessary for KASAM to take into account the information that is presented in connection with the applications in order to comply with its terms of reference. This means that KASAM must partly conduct new work. This must be seen as a natural consequence of the new, more intensive phase that precedes the important decisions that must be made, in particular, by the Government (decisions on licence applications as well as decisions on the RD&D programmes).

3.2.2.6 Safety Issues etc.

Many purposes are specified in the various chapters of RD&D Programme 2004 and it is difficult to have an overview and to evaluate these different purposes. Appendix A contains a separate section on safety, which is naturally a central issue in this context. SKB states that "the ultimate purpose" is to achieve the safe disposal of spent nuclear fuel. SKB presents a number of "safety principles" to guide the work on achieving long-term safety. Such a classification is commendable. However, there are issues which need to be clarified. Questions regarding the safety principles include:

- What does SKB mean when it mentions rapid, radical and unpredictable societal changes which should be taken into consideration in connection with final disposal safety? Is any one of the social science projects focusing on this? Is this an important issue for the RD&D programme and the EIS?
- SKB only mentions the deep repository itself in the points raised. What is the situation with respect to safety around the encapsulation plant and with respect to transport and what are the risks for accidents, sabotage and terrorism? Is it reasonable to also take these issues into consideration? Two safety reports are to be prepared, namely, SR-Can (SKB's safety report which will provide a basis for the application for permission to construct an encapsulation facility; In 2004, SKB submitted a preliminary safety report which presents the methodology that SKB intends to use in forthcoming safety reports) and SR-site (SKB's safety report which will provide a basis for the application for permission to construct a deep repository). However, SKB does not specify what it intends to include in, for example, SR-site.
- SKB states that the overall system analysis must take into account mishaps and disturbances. However, what kinds of mishaps and disturbances can occur and is it possible to assess whether all have been taken into account? These issues

are not addressed in the appendix and the introductory chapters do not specify whether it is important to take them into account in the RD&D programme.

– SKB states that the EIS must show that the deep disposal project can be implemented with acceptable consequences to humans and the environment. Elsewhere, SKB states that compliance with environmental requirements will be achieved. What is meant by acceptable? Who will decide and how will it be demonstrated? It would have been reasonable to include a discussion on these considerations and their importance for the design of the RD&D programme. The same applies to the environmental requirements that SKB refers to.

SKB will report facts regarding the benefits that the project can bring to society, but will hand over the evaluation of this aspect to others, according to the information SKB presents in Appendix A. This is well thought out, but the selection of facts to present is also one way of choosing which view to present. For the sake of an open Environmental Impact Assessment (EIA), it would have been good if the overall need for knowledge prior to the preparation of applications and the design of the facilities had been presented as the background to the choice of the focus of RD&D Programme 2004.

To conclude, KASAM considers that the content of the EIS should be an important basis for justifying different parts of the RD&D programme. The need for knowledge for the EIS should therefore be reported in detail. It is also important for SKB to argue that the RD&D programme should continue to focus on this need for knowledge and on the objective of conducting an open EIA and, thereby, a good basis for achieving understanding and acceptance for the RD&D programme.

3.2.2.7 Other Issues in Appendix A

What degree of freedom for making choices will there be at different stages of the consultation and licensing process? SKB maintains that adequate time must be set aside for obtaining a solid basis for decision-making. However, there are no arguments concerning whether this has been achieved in SKB's planning of the RD&D programme or whether there are issues that are particularly critical with respect to the time horizon. Forthcoming decision-making processes are well-defined, according to SKB. However, SKB does not explain what it means by this or whether this is of any importance for the focus of the RD&D programme. The presentation is very general in nature which makes it difficult to distinguish the considerations that have gone into the RD&D Programme. For example, in Appendix A, Section 2.3.2, SKB states that it intends to make choices regarding the system at a detailed level, but that definitive choices will be made as late as possible, in order to benefit from the latest technological developments. From the standpoint of the general public, one can wonder whether one knows, at present, exactly which decisive considerations will remain to be made when the application is submitted and whether this degree of freedom is acceptable for society and its decision-making bodies? The RD&D programme does not provide a basis for evaluating this aspect.

3.2.3 RD&D Programme (Chapter 3 of RD&D Programme 2004)

Chapter 3 of RD&D Programme 2004 provides a short summary of the focus of RD&D Programme 2004. In this chapter, it is difficult to see the connection between the social science research and the whole disposal project and how results from the social science research will be taken into account. Furthermore, RD&D Programme 2004 does not provide any closer guidance

with respect to the connection between the needs for a knowledge base for the preparation of EIS, other planning, design, construction and operation and the social science programme.

3.3 KASAM's Conclusions

- In KASAM's opinion, the forthcoming RD&D programme should be expanded to include a special background account which describes the premises, contents and priorities of previous RD&D programmes. Such a retrospective with justifications for the considerations and decisions made at earlier stages would provide a better basis for deciding the premises on which the focus of the RD&D programme is based and whether the programme meets the requirements of the legislation. The background account should be presented no later than in connection with the submission of RD&D Programme 2007. An updated, overall summary of such a background account should also be included in each future RD&D programme.
- RD&D Programme 2004 contains general descriptions of the connection to requirements in accordance with the Environmental Code, but does not contain tangible arguments concerning the RD&D programme's focus in relation to the requirements on the content of the forthcoming EIS. (See also KASAM's comments in Chapter 14, with respect to social science research).
- RD&D Programme 2004 lacks an overall argument for the total need for knowledge prior to the preparation of applications for permission to construct a repository for spent nuclear fuel including an EIS and for the focus of the RD&D programme.
- KASAM recommends that the encapsulation plant and the repository for spent nuclear fuel should be licensed (under the Act on Nuclear Activities and the Environmental Code)

in a *single* context, since these facilities are two parts of one and the same waste management system, which is based on an interaction between engineered and natural barriers. In KASAM's view, it is therefore vital that a single, co-ordinated EIS should be prepared.

- KASAM is positive to SKB's changed proposed time-table for the licensing process but considers that it should be clearly stated that the preliminary applications that SKB intends to submit to SKI in 2006 should be considered as a basis for a deeper development of the ongoing consultation in accordance with Chapter 6 of the Environmental Code prior to licensing under the Act on Nuclear Activities.

4 Canister – Fabrication

4.1 Background

The function of the canister is to isolate the spent nuclear fuel from the environment. The canister plays a very central role as a barrier. As long as the canister is intact, no radioactive substances will leach out. The canister must be able to withstand the chemical environment of the deep repository and tolerate the mechanical stresses that can arise. The premise is that the canister must be able to withstand corrosion attack for at least 100,000 years. The canister must be thick enough so that radiation on the outside of the canister does not cause radiolysis since this would lead to rapid corrosion. SKB's reference canister consists of an outer corrosion barrier (shell) of copper and a pressure-bearing insert of nodular (spheroidal graphite) iron.

4.2 KASAM's Considerations and Evaluation

KASAM's comments mainly refer to Chapter 5 of RD&D Programme 2004.

4.2.1 Choice of Fabrication Method for the Copper Canister

SKB has mainly tested four methods for the fabrication of copper tubes for the canisters: roll forming, extrusion, pierce-and-draw processing and forging. With roll forming, metal plates are fed between three rolls so that their cross-section forms a semi circle. Extrusion involves a complete sequence of machining steps, see Figure 4.1.

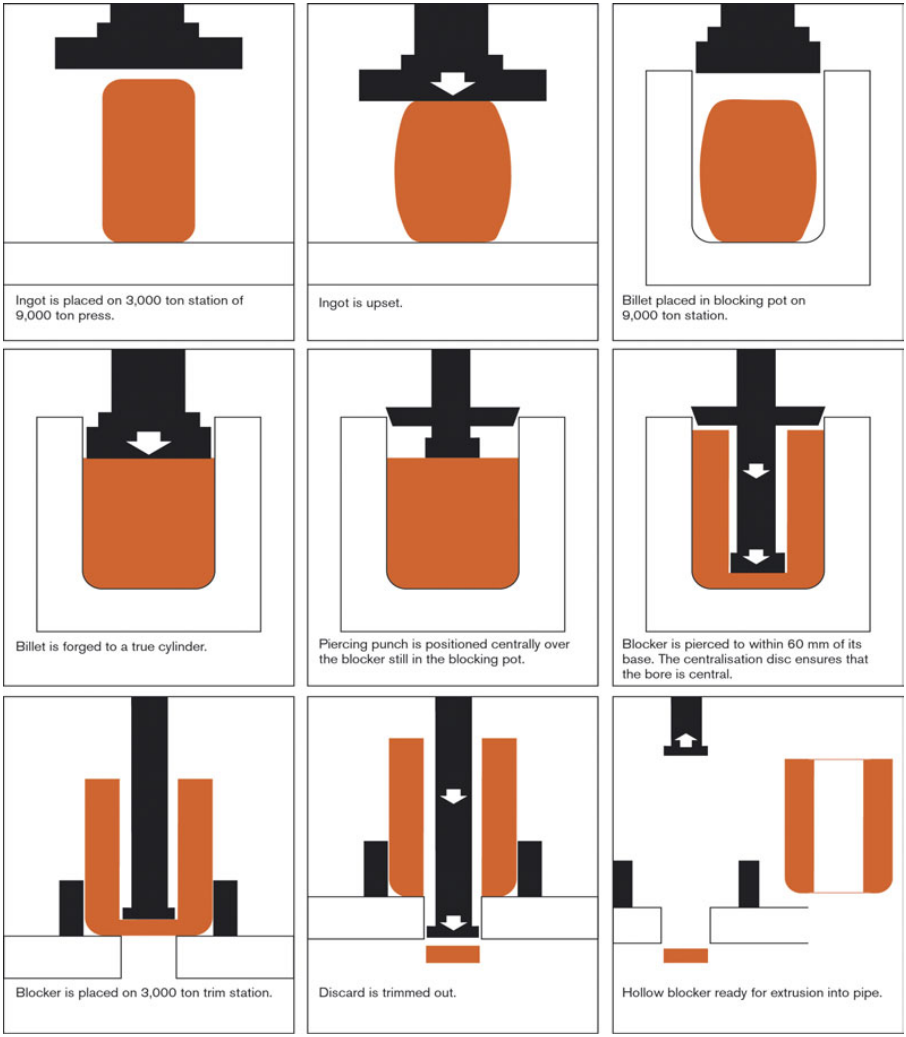


Figure 4.1 *Step 1 of the extrusion process (from "Development of Fabrication Method for Copper Canisters with Cast Iron Inserts. Status Report, August 2001" by Claes-Göran Andersson; SKB Report R-01-39).*

First of all, the ingot is pressed to achieve a larger diameter. It is then pierced and then placed in an extrusion press and extruded to its final size. With pierce-and-draw processing, the cylinder is extruded from two directions in a press to obtain a tube with an integral bottom.

SKB has started to study a new method to fabricate seamless tubes by forging, see Figure 4.2. A hot ingot is placed in a press and pierced on the one side then turned around and pierced from the other side. The pierced ingot is then placed in a mandrel and pressed to become longer and thinner. By successively selecting mandrel diameters and forging tools the desired dimensions can be achieved.

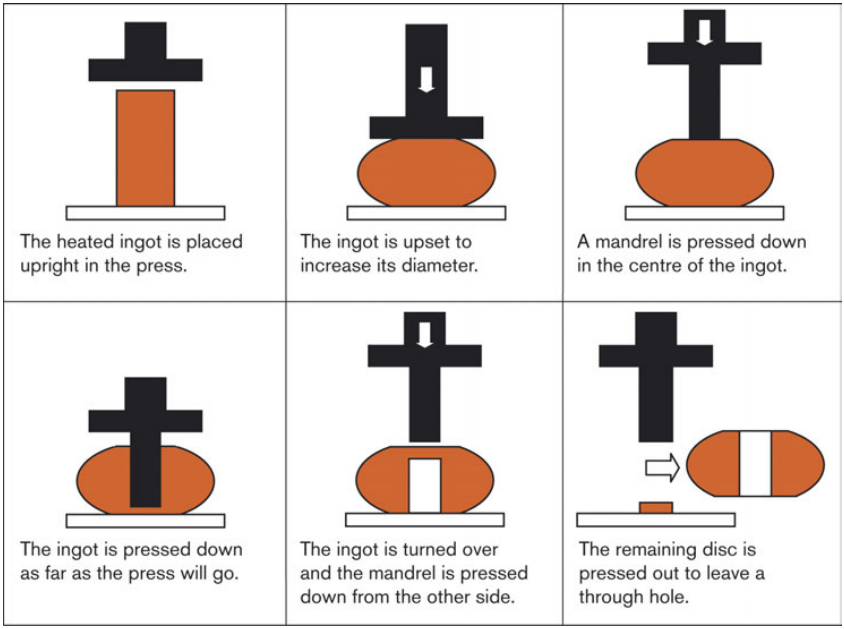


Figure 4.2 *Fabrication of an ingot for ring forging (from "Status Report on Canister Fabrication" by Claes-Göran Andersson, Göran Emilsson, Peter Eriksson and Marika Westman, June 2004; SKB Report R-04-14).*

The results obtained show that all four methods can be used but that extrusion has resulted in the best microstructure (an even microstructure and fine grain size). For a long time, it has been well-known that this is necessary for the canister to have acceptable mechanical long-term properties (creep ductility) and to be approved in connection with non-destructive testing. Unfortunately, since there seems to be only one company which has a press that is large enough to carry out the extrusion, it is necessary to have at least one other method that works.

KASAM recommends that SKB should focus on an additional fabrication method, besides extrusion, bearing in mind the extensive work that remains to be done with respect to the quality assurance of the canister fabrication, even if there is a good possibility of developing the other methods.

The natural fabrication method for the canister lid and bottom is forging. The homogeneity of the deformation and microstructure are important. Even if good results have been achieved, further modelling work should be carried out so that the spread of the microstructure can be predicted for different deformation sequences. This data is necessary for the specification of the fabrication requirements for the canister lid and bottom. It is unclear whether the grain size achieved in the lids that have so far been fabricated is small enough.

4.2.2 Corrosion Barrier

The most important function of the copper canister is as a barrier against corrosion.

Results so far obtained have not shown that any type of corrosion will limit the canister lifetime, even if this does not verify that critical mechanisms could not arise.

In KASAM's opinion, further studies are necessary within two areas: i) accelerated long-term experiments on stress corrosion and ii) corrosion induced by the interaction with bentonite. Furthermore, further in-situ experiments in the Äspö Hard

Rock Laboratory are necessary in order to show that the predictions are correct for the time span of about ten years which can be studied. Few corrosion studies have so far been conducted for welded material. In KASAM's view, it is important for such studies to be conducted.

4.2.3 Cast-iron Insert

In order to absorb hydrostatic pressure, SKB's intention is to equip the canister with a nodular iron (a form of cast-iron) insert. The form of the graphite in the cast iron determines the mechanical properties. In nodular iron, the graphite should be of a nodular shape in order to achieve adequate strength, ductility and brittleness. The shape of the graphite is controlled by the addition of small quantities of elements to the melt. SKB has fabricated a number of inserts. The inserts have varying microstructures and mechanical properties. It is difficult to obtain homogeneous nodular graphite in components of the size of the inserts. Furthermore, the mechanical properties do not completely comply with the requirements. Further identification of the relationship between the microstructure and mechanical properties is therefore vital. The composition and casting of the iron and the properties of the insert must be optimized so that specified requirements can be met.

An important issue is the risk for brittle fracture in the insert. If sufficiently large defects and defective microstructures exist there is a risk that the canister will collapse when it is exposed to the hydrostatic pressure of the deep repository. Such properties of the iron insert must therefore be absolutely avoided. Further investigations into how fracture toughness varies across fabricated inserts are therefore necessary. It is also necessary to apply these results in finite element calculations to verify that the facture risk is negligible. The results are a basis for the optimization of the fabrication process, the materials specification and the testing methods.

4.2.4 Non-destructive Testing

The quantity and size of defects must be limited in order for the performance of the canister to be assured. The ongoing work on formulating acceptance criteria for the canister must continue so that reliable fabrication requirements can be formulated. In order to determine the occurrence of defects, non-destructive testing (NDT) is used. The work on developing NDT methods has been underway for a long time but must nevertheless be intensified. Even if the methods that the manufacturers use to test the canister components have been identified, these methods have not been documented very well and it is not possible to determine the degree of precision of the results that can be expected.

In KASAM's view, this type of documentation must be prepared during the forthcoming three-year period. This particularly applies to the cast-iron insert where the occurrence of porosity and other defects can occur to a significant extent if a thorough control is not conducted. In SKB's view, the possibility of detecting defects in the inserts is good, but this must also be verified. For example, reference components with known relevant defects must be prepared so that an accurate calibration of the NDT can be made.

The experiments that have started on NDT methods to determine the grain size of the copper material and other microstructure parameters of the copper and the cast iron should be continued. If these experiments are successful, the precision of the microstructure of the fabricated canister can be increased.

4.2.5 Quality Assurance

The quality system for canister fabrication that SKB has already developed should be documented in detail so that independent reviewers can also see that it is satisfactory. As SKB points out,

the system will comprise SKB's own planned canister factory as well as sub-contractors.

4.3 KASAM's Conclusions

- KASAM recommends that SKB should focus its efforts on the fabrication of copper tubes on an additional method, besides extrusion, bearing in mind the extensive work that remains with respect to the quality assurance of canister fabrication.
- Further corrosion studies are required in two areas: i) accelerated long-term experiments on stress corrosion ii) corrosion induced by the interaction with bentonite.
- Further work on determining the relationship between microstructure and mechanical properties of the cast-iron insert is vital. Materials and process must be optimized so that specified requirements can be met.
- The work on developing methods for non-destructive testing (NDT) must continue at full intensity. It is especially important that the documentation is prepared so that it is possible to distinguish the expected precision of results.
- In terms of quality assurance systems, the documentation should be expanded so that independent reviewers can interpret the level of reliability.

5 Canister - Sealing

5.1 Background

Depending on the fabrication method, the canisters will have one or more welds. The development of welding methods for this purpose has been underway for a very long time and is now beginning to yield results. SKB is studying two methods: Friction Stir Welding (FSW) and Electron Beam Welding (EBW).

Friction stir welding (FSW) is a relatively new welding method that was invented in 1991. The method has revolutionized welding of aluminium alloys. In 1997, attempts were made to apply the method to copper. The method does not yet have a name in Swedish. Figure 5.1 is a diagram showing the principle behind the method. A rotating tool is inserted between two plates, effectively fusing the two. The temperature in the weld is close to but does not exceed melting point. This reduces the risk of distortion and for the formation of a vacuum in the weld.

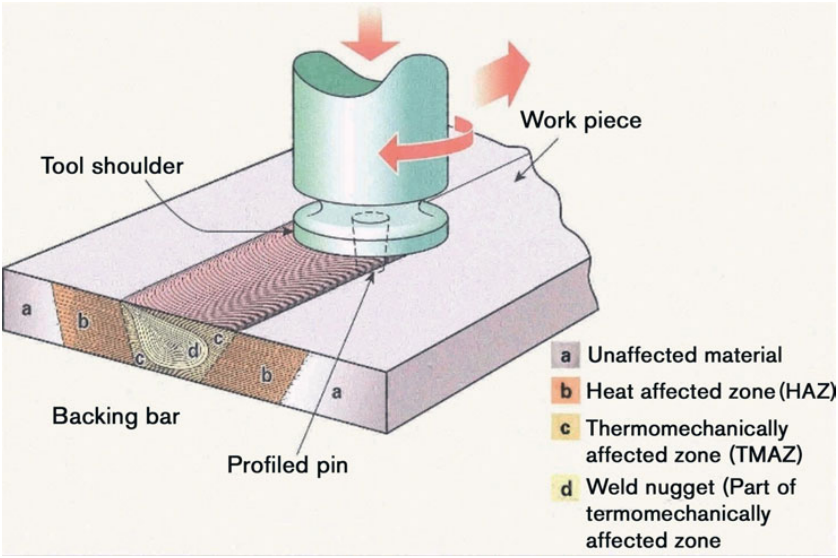


Figure 5.1 Diagram showing the principle behind Friction Stir Welding (from "Development of Fabrication Technology for Copper Canisters with Cast-iron Inserts. Status Report, August 2001" by Claes-Göran Andersson, SKB Report R-01-39).

5.2 KASAM's Considerations and Evaluation

KASAM's comments mainly refer to Chapter 6 of RD&D Programme 2004.

5.2.1 Choice of Sealing Method for the Copper Canister

Two welding methods for the sealing of the copper canisters are being studied in parallel at SKB's Canister Laboratory: Electron Beam Welding and Friction Stir Welding. In the past three-year period, significant progress has been made. Welds with a satisfactory structure have been fabricated using both methods.

KASAM considers that it is reasonable that SKB has chosen Friction Stir Welding as a reference method but finds that experience is still lacking concerning the possibility of showing that the welding processes can routinely yield results that meet established requirements.

5.2.2 Electron Beam Welding

The technology for Electron Beam Welding (EBW) has been developed for more than two decades and many problems are associated with this method. EBW of copper is a very complex process due to the high thermal conductivity of copper and the low viscosity of the melt.

Throughout the development work, the aim has been to design the welding process so that there is a low risk of defects in the weld. Several key efforts have been made from 2002 to 2004. A new type of cathode has been developed which results in a round profile in the bottom of the weld. This reduces the risk of defects in this part of the weld. Furthermore, equipment has been developed to oscillate the electron beam. For the welding of the copper, a special type of EBW with a limited vacuum is used. However, it has been necessary to improve the vacuum to avoid disturbances in the electron beam. Additional work is planned to further improve the equipment at the Canister Laboratory. In particular, the cathodes will be developed and the high-voltage system will be modified to minimize the risk of flashover.

Bearing in mind the development work that has been conducted, more systematic efforts could not be made until 2003 to determine important process parameters and, thereby, avoid undesirable defects in the weld. By utilizing higher welding speeds and improving electron beam oscillation, the weld quality has been considerably improved. SKB now maintains that it can achieve a homogeneous weld metal and a smooth weld surface.

KASAM would like to emphasize that it is now important to demonstrate that the method works on a broader range of specimens and that it can be used under production conditions. SKB is planning to conduct trials in this area.

5.2.3 Friction Stir Welding

One method that is becoming increasingly used in the industry in recent years is Friction Stir Welding (FSW). With this method, the material is fused using friction heat from a rotating tool without melting the material, see Figure 5.1. This prevents an inhomogeneous microstructure and distortion in the weld after hardening. In co-operating with TWI (Cambridge), SKB has developed the FSW method for the welding of copper canisters. Welds with a good microstructure have been successfully produced with the existing equipment at the Canister Laboratory.

In KASAM's view, further work should focus on determining the values of process parameters such as welding speed and tool forces so that defect-free welds with a good microstructure can be obtained. An important tool in this work is microstructure modelling using finite element methods. Extensive international activities are being conducted in this area nowadays and it is important to take advantage of this. The different welding phases can be described with the help of modelling, namely start and acceleration, steady state and termination. With modelling, the formation of flash during distortion can be studied.

When suitable process parameters are established, mechanical properties, including creep and ductility, are documented. Whether the welds have adequate corrosion-resistant properties should also be verified.

5.2.4 Residual Stresses

In KASAM's view, typical residual stresses in the sealing weld must be determined through experiments. In parallel, a new modelling of residual stresses should be conducted with new data for creep and plastic deformation. The residual stress should be low in order to minimize the risk of stress corrosion.

5.2.5 Non-destructive Testing (NDT)

Previously, flaws, primarily relating to porosity (where the volume of defects is high) were studied using X-ray methods. On the other hand, weld fracture and penetration flaws could only be investigated to a limited extent since suitable ultrasound technology was not available. The same applies to near-surface flaws which it is suitable to study using induction methods. This situation has now changed in that new technology has been developed.

KASAM recommends that SKB should continue to develop NTD methods for welds so that types of defects can be reliably detected. The methods should be calibrated with test bodies with known defects. Furthermore, systematic trials with blanks should be conducted, where the defect distribution that is not known in advance is characterized with NDT methods. When this characterization is completed, the blanks are then cut so that the NDT results can be verified. SKB plans to utilize theoretical results for ultrasound testing, which KASAM considers to be satisfactory. Moreover, work is underway internationally in this area with BAM in Berlin, which is of value.

It is important for SKB to publish the documentation of results obtained from NDT. SKB has so far only done so to a limited extent in spite of the regulatory authorities' recommendations.

5.2.6 Creep

Further studies of creep in copper material and, in particular, of weld joints, are necessary. The creep properties must be verified for weld joints produced under production conditions. Calculations of the creep deformation for whole canisters or parts of canisters should be performed.

5.3 KASAM's Conclusions

- It is important for SKB to demonstrate that Electron Beam Welding works on a broader range of specimens than has so far been studied and that the method can be used under production conditions.
- KASAM considers that it is reasonable that SKB has chosen Friction Stir Welding as a reference method but considers that SKB should have waited to make the choice until it had had access to the results of SKI's and KASAM's reviews of RD&D Programme 2004. It remains for SKB to show that the welding processes can yield results that comply with the established requirements.
- In KASAM's view, work on Friction Stir Welding should focus on determining the values for process parameters such as welding speed and tool forces so that defect-free welds with a good microstructure can be obtained. Further work should also be conducted on modelling the microstructure obtained.
- When suitable process parameters for the welding methods are established, mechanical properties including creep and ductility should be documented. Whether the welds have adequate corrosion properties should also be verified.
- The size of the residual stresses in the weld joints should be determined.
- KASAM recommends that SKB should continue to develop Non-destructive Testing methods for welds so that types of

defects can be reliably detected. It is important for SKB to publish the documentation of results obtained from Non-destructive Testing so that the accuracy of results can be evaluated.

6 Encapsulation Plant

6.1 Background

According to RD&D Programme 2004, SKB counted on submitting an application for permissibility/permission in accordance with both the Environmental Code and the Act on Nuclear Activities for an encapsulation plant for spent nuclear fuel in 2006. In a proposal for a "modified plan of action" submitted at a later stage, SKB expects that the application that it will submit in 2006 will be limited to licensing under the Act on Nuclear Activities. SKB's main alternative is to construct the encapsulation plant next to CLAB, where spent nuclear fuel is in interim storage pending encapsulation and disposal. SKB has also studied the possibility of siting the encapsulation facility at Forsmark if the repository should also be sited there. Consultation with the parties concerned in accordance with Chapter 6 of the Environmental Code is in progress with respect to both of these siting alternatives, with the aim of obtaining data for an application and accompanying Environmental Impact Statement.

6.2 KASAM's Considerations and Evaluation

KASAM's comments mainly refer to Chapter 8 of RD&D Programme 2004.

The choice of method to manage and dispose of nuclear waste is a decisive issue. SKB's proposal for the design of the encapsulation plant is based on the assumption that the KBS-3 method, in connection with forthcoming licensing will be found to comply with the safety requirements, in accordance with the Act on Nuclear Activities, and be approved as the best available technology, in accordance with the Environmental Code, for the final management of spent nuclear fuel. According to RD&D Programme 2004, the design of the encapsulation plant is dependent on the choice of welding method for the copper canister as well as on where the plant is sited. In KASAM's view, the decision on what can be considered to be the best available technology and adequately safe should be made taking into account both encapsulation plant and repository as a whole, since these facilities are two parts of the same waste management system, based on an interaction between engineered and natural barriers.

The design of the encapsulation plant must also take into account abnormal operating events and accidents that can occur in the activity. Special requirements on the design, for example, to handle damaged fuel and defect canisters containing spent nuclear fuel, should be described in greater detail. KASAM also assumes that SKB, within the framework of the Environmental Impact Statement and the safety assessments, will describe and evaluate in detail the consequences of any disturbances in operation to human health and the environment etc. as well as describe the protective measures that are planned in the event of different types of more or less severe events.

6.3 KASAM's Conclusions

- In KASAM's view, the decision on what can be considered to be the best available technology and adequately safe should be made taking into account both encapsulation plant and repository as a whole.

- In KASAM's opinion, special requirements on the design to handle damaged fuel and defect canisters containing spent nuclear fuel should be described in greater detail.
- KASAM assumes that SKB, within the framework of the Environmental Impact Statement and the safety assessments, will describe and evaluate in detail the consequences of any disturbances in operation to human health and the environment etc. as well as describe the protective measures that are planned in the event of different types of more or less severe events.

7 Transportation of Encapsulated Fuel

7.1 Background

7.1.1 Transportation System

SKB plans to transport spent nuclear fuel using tried and tested technology. According to RD&D Programme 2004, SKB has good experience within this area and there is an exchange of experience between countries, especially within the IAEA's programme, and SKB is participating in this work. SKB's account of transportation issues in RD&D Programme 2001 was very brief – far too brief in the opinion of some of the reviewing bodies. In order to provide a more detailed description of the transportation of spent nuclear fuel, SKB has presented transportation issues in a separate chapter in RD&D Programme 2004.

Transportation between the encapsulation plant and the repository will be carried out in special casks (70 to 75 metric tons, including the load). Besides the transport casks, the most important components of the transport system are the ship, m/s Sigyn (with a capacity of about 10 fuel transport casks) and terminal vehicles. About 200 shipments per year will be necessary. The same transport system (with different types of casks) has been used for several years for transporting different types of nuclear waste and spent nuclear fuel from the nuclear power plants to CLAB.

As mentioned above, the special transport casks which are expected to be used for the fuel canisters weigh 70 to 75 metric tons, including the load. The casks are 1.6 m in diameter and the thickness of the material is 25-30 cm including neutron-absorbing material. The transport casks meet the requirements established by the IAEA for radiation shielding and leak-tightness. Control is conducted through calculations and tests.

M/S Sigyn may have to be replaced by a new ship with primarily the same functions. The shipments of fuel canisters will be integrated into the transportation system that is needed in the future for different types of nuclear waste.

The protection issues that are relevant in connection with transportation are, above all, radiation shielding, safety and safeguards. Special permission for transportation must be obtained from the Swedish Nuclear Power Inspectorate (SKI) and the Swedish Radiation Protection Authority (SSI) which also regulate and supervise transportation activities.

7.1.2 SKB's Programme

SKB's programme for the forthcoming six years is a continuation of the current programme (shipments from the nuclear power plants and Studsvik to CLAB and SFR). There are plans for a new ship. The requirements on the new ship have not yet been decided. However, in principle, the ship's functions will be the same as Sigyn's. Other parts of the transportation system may also have to be replaced in time. As was previously mentioned, transport casks for the fuel canisters are being planned. In connection with the application for permission to construct a deep repository, a description of the transportation system will be presented and, prior to the application for permission to construct the encapsulation plant, a status report will be presented.

7.2 KASAM's Considerations and Evaluation

KASAM's comments mainly refer to Chapter 9 of RD&D Programme 2004.

KASAM does not see any difficulty in the development, maintenance and operation of the transportation system from a technical standpoint. Existing technology can be used and extensive experience of transportation exists as well as effective supervision through SKI and SSI. However, KASAM would like to reiterate that the transportation of spent nuclear fuel – even when the fuel is encapsulated – is a potential source of hazard to human health and the environment. Spent nuclear fuel contains high quantities of radioactive substances which require an effective containment of the material and radiation shielding.

The threats that spent nuclear fuel represents with regard to transportation are of the same type as when the fuel is stored in nuclear power plants or in CLAB and comprise radiation protection, safety and safeguard aspects. However, the risks could be greater in connection with transportation than storage and handling in the special facilities that exist and these risks must be highlighted and analyzed in detail. Such risks include the increased risk of mishap, sabotage and terrorist action which have come to the fore in other contexts. The description of these aspects should be improved.

Therefore, KASAM assumes that SKB is performing an assessment of safety issues (and related issues) in connection with the transportation of encapsulated spent fuel and that such an assessment will be presented in connection with the forthcoming application for permission to construct the encapsulation plant. The assessment could be presented in the status report on canister transportation that SKB intends to submit as a basis for this application.

7.3 KASAM's Conclusions

- KASAM does not see any particular difficulties in the development, maintenance and operation of the transportation system from a technical standpoint. Existing technology can be used and extensive experience of transportation exists. However, attention should be paid to the risks associated with transportation, in the light of the threat of sabotage and terrorist action etc.
- A better description of the consequences of sabotage and terrorist action should be provided.
- KASAM assumes that SKB is performing an assessment of safety issues in connection with the transportation of encapsulated fuel and that such an assessment will be presented in connection with the forthcoming application for permission to construct the encapsulation plant.

8 Safety Assessment

8.1 Background

Safety assessments for the disposal of spent nuclear fuel deep in Swedish crystalline bedrock have been conducted on several occasions by SKB as well as SKI and SSI. The results have been reported in the form of technical reports with detailed accounts of the knowledge basis, calculation methods and estimated results. These reports have been perceived by many as difficult to understand. Politicians and the general public in the municipalities where SKB plans to conduct or has conducted feasibility studies for a deep repository are likely to attach considerable importance to the question of whether disposal is safe or could entail serious risks for them or future generations.

The question of whether it is possible to dispose the spent nuclear fuel at all has also been raised in discussions regarding whether it is responsible to continue to operate the existing nuclear power plants for a limited or indefinite time. In view of these discussions, methods for developing safety assessment are an important part of the RD&D Programme. There is also a need for a summary of what has been done on the issue so far and why it has been done.

8.2 KASAM's Considerations and Evaluation

KASAM's comments mainly refer to Chapters 13 and 14 in RD&D Programme 2004.

8.2.1 Why Conduct Safety Assessments?

Spent nuclear fuel is hazardous. It contains radioactive substances that emit ionizing radiation. It is not possible for human beings to handle or be in the vicinity of a fuel element which has been removed from a reactor unless the fuel element is enclosed in a thick-walled container or has been placed deep below the surface of a water-filled pool. Radioactive substances can – if they leak into the environment – also accumulate in organs and tissues in the human body if we ingest or inhale them.

However, the fact that radioactive substances in spent nuclear fuel are hazardous does not necessarily mean that spent nuclear fuel is a danger to human beings and the environment. Provided that the fuel is surrounded by such thick radiation shields that its radiation cannot penetrate and that the radioactive substances are so well enclosed that they cannot leak out into the environment, the fuel does not pose a risk to human beings or to fauna and flora at any stage of the spent fuel management process.

The purpose of safety assessments is to show how effectively the radioactive substances in the fuel can be shielded and contained and how robust and lengthy this protection is expected to be. It must also show the risks that arise if the protective barriers are damaged or if we are forced to or wish to retrieve the waste. These risks must be compared with other risks of the same type, for example, the dose contribution from Chernobyl or from natural radioactive substances that are constantly released from crystalline bedrock through erosion and weathering.

Safety assessments are not only used to judge the safety for disposal at a certain stage but also as a tool to identify the need for research and development. Safety must subsequently be assessed on a continuous basis throughout the time that the spent nuclear fuel is hazardous.

Any assessment of the long-term safety of a deep repository for spent nuclear fuel must also include a number of ethical judgements.

8.2.2 How Are Safety Assessments Used?

SKB and the regulatory authorities all need to assess repository performance and safety. Analyses must be conducted on several occasions, from the initial design proposals throughout the research and development programme and until the operation and closure of the repository.

In the initial stages, knowledge is incomplete in many respects. Reasonable assumptions have to be made since reliable data on the properties of the barriers are not available. When the development work approaches the implementation stage, involving site investigations and prototype fabrication of individual barriers, assessments are needed in order to prepare specifications of requirements for the bedrock and the engineered barriers.

In the application for permission to construct facilities, an overall assessment of the safety of the entire disposal system (system analysis) must be included. This is due to the fact that the different stages of the spent fuel management system, such as encapsulation, possible interim storage, transportation and disposal, each has safety requirements that must be known before the formal application. This has been explicitly stated by the Government in its decision after SKB submitted its supplement to RD&D Programme 92. The Government found that an overall system analysis should be included as a basis in an

application for permission to construct the planned encapsulation plant.

It is important for SKI and SSI to also form their own view of the requirements that must be made on the repository as a whole and on individual barriers so that they can have their own basis for the regulatory review of the applications well before they are submitted by SKB at various stages in the process. Both SKI and SSI have been working for a long time on developing their own safety assessment competence. In KASAM's view, it is important for this type of activity to continue.

Safety assessments of the disposal system are important to stakeholders at several levels: the Government and its authorities, local government authorities, the local population affected by the siting of different facilities and those citizens concerned about nuclear issues. For this very reason, it should be possible for everyone concerned to understand the safety assessments. Both SKB and the authorities must make efforts to explain and, for example, publish pedagogical descriptions of the safety assessments that have been conducted. This is not a question of simplifying the analysis but of producing pedagogical descriptions of the complex analyses that are necessary. The regulatory authorities must be regarded as the experts to whom the municipalities can turn during the licensing process.

8.2.3 What Has Already Been Done?

The planning of a repository for high-level radioactive waste and spent nuclear fuel started in 1977. Within a few years, three safety assessments were presented. The first, KBS-1 (1977), showed that it was possible to comply with an extremely high degree of safety by depositing high-level vitrified radioactive waste (after reprocessing, which was being considered at that time) in a deep geological repository. The Government accepted

this judgement and two completed reactors were given permission to start operation based on this safety assessment.

A few years later, two new studies, KBS-2 and KBS-3, were carried out which investigated the disposal of non-reprocessed spent fuel in copper canisters. These safety assessments also showed that it was possible to do so with a very high level of safety. In KBS-3, the solution is fuel encapsulated in copper canisters and deposited in deep boreholes in excavated tunnels at a depth of about 500 metres below the surface. The containers are surrounded by compacted bentonite clay. This concept is the basis of the current programme and has also been utilized by many other countries as a starting point for their own development work in the area.

Currently, two sites are being investigated, one in Simpevarp/Laxemar (Oskarshamn Municipality) and one in Forsmark (Östhammar Municipality), as possible sites for the deep disposal of spent nuclear fuel from all of the Swedish reactors. It is expected that one of these sites will be used, provided that the properties of the bedrock and other conditions are acceptable.

The safety assessments that have so far been conducted are based on models of possible releases and transport of radioactive substances through the engineered barriers and through rock and soil – mainly via the groundwater – to the biosphere.

Substantial information on flows and transport properties in rock and rock material has been obtained from the laboratory in the Stripa Mine (1978-1992). The new Hard Rock Laboratory at Äspö, which started to operate in the early 1990's, has provided very important information on flows and transport properties, rock mechanics, clay properties etc. and this information is currently being used for the design and safety assessment of a future deep repository.

Various national and international models and databases have been used to gain knowledge about the biosphere.

8.2.4 International Work

The methodology for analyzing the long-term safety of a repository has been the focus of extensive international co-operation and this is still the case. Work has largely been chanelled through the OECD/NEA and the IAEA. Extensive work has also been conducted in the form of joint projects directly carried out between countries. In the international projects, methodology issues have been analyzed and developed and models for parameters such as groundwater and nuclide transport have been analyzed and compared. Databases for scenario analysis have been developed and are available. The reliability and limitation of the models have been evaluated (verified and validated) and an extensive knowledge base is available for disposal safety assessment. Issues relating to relevant time horizons for safety assessment and the quality of the knowledge base have been discussed.

This type of international work is continuing within the NEA, IAEA etc. and SKI, SSI and SKB are all participating in this work. In doing so the programmes are subjected to independent peer review.

8.2.5 Scenario Methodology

The assessment of the safety of a disposal system must deal with encapsulation, transportation, the deposition phase – when the spent nuclear fuel is deposited with the buffer in the prepared positions in the rock – and the further development of the repository after closure, including possible waste retrieval.

The analysis of safety, in the long term, is carried out with the help of assumptions regarding the evolution of the barriers and the external conditions, especially the climate. Such an assumption, known as a scenario, is described in as much detail as necessary in order to calculate the consequences with respect to safety for man and biota. Although no-one can claim to be

able to predict this evolution in its entirety, a thorough inventory of possible developments and events is still warranted. With the help of scenario analyses, a repository can be designed so robustly that it can withstand the future stresses that can be predicted, to an extent that is considered justified.

However, safety assessments cannot determine the size of the resources that the present generation must put into preventing harm, which could hypothetically fall upon future generations. The way in which the precautionary principle should be applied to the findings of safety assessments is ultimately a political decision.

The assumption of the future that is closest to hand is that the bedrock and climate will continue as they are today. This assumption is applied by SKB as well as SKI and SSI as a starting point for long-term safety assessment. The assumption will be valid for some time after repository closure, although no longer than a few thousand years at most. Although the bedrock is expected to change very slowly, the climate will probably change considerably within a few thousand years (see the comments to Chapter 21, Climate, in RD&D Programme 2004).

8.2.6 FEP Handling and FEP Databases

In recent years, a logical method has been developed to construct models for the biosphere, using so-called FEP lists (and FEP databases). FEP stands for Features, Events and Processes in geology, chemistry, ecology, physics etc. These FEPs can occur with a certain probability within a given system. Each individual FEP component (event, feature or process), for example, the assumption that a fault in the bedrock occurs after the retreat of a glacier over a land area, can, together with other FEP components, be used to build a scenario. For example, it can be assumed that this fault occurs directly in connection with the deep repository, combined with unfavourable flow

conditions in the bedrock which lead to rapid transport and dispersion of radionuclides from the repository to the biosphere.

There are many safety assessments, carried out in different countries, where the method of preparing lists of different FEP components has been used. Such FEPs can then be combined into different scenarios after evaluation and screening to eliminate scenarios of a low probability. The consequence, in the form of the effective dose to the critical group, is then calculated for the chosen scenarios. The identification of factors to take into account is an important part of the safety assessment. The initial state is described as well as processes, external conditions, safety functions, function indicators and criteria for these indicators. A preliminary set of scenarios are then selected for analysis. After selecting the input data, the evolution of the system for the scenarios selected is analyzed. These scenarios are evaluated and additional scenarios may be selected if necessary. Thermal, mechanical, gas-related and chemical processes are then modelled and analyzed and calculations for radionuclide transport are conducted.

8.2.7 Regulatory Requirements on Safety Assessment

An important aim of safety assessments is to demonstrate compliance with regulatory requirements. These requirements are summarized in regulations promulgated by SSI (SSI FS 1998:1) and SKI (SKI FS 2002:1).

The main criterion for accepting the repository is that it should be designed so that "the annual risk of damage (fatal cancer) after closure should not exceed 10^{-6} for a representative individual in the group exposed to the greatest risk". This corresponds to a dose constraint of about 0.01 mSv/year, which is about 1 % of the natural background radiation. As KASAM previously indicated, this is a very stringent requirement. SKI has promulgated regulations and general recommendations concerning the application of the regulations. SSI's proposal for

"general recommendations" for the application of one of its regulations is currently being reviewed by external bodies and KASAM has recently submitted its comments on the proposal. Most often, the "general recommendations" contain important information which supplements the regulations.

8.2.8 SKB's Safety Assessment Programme

The safety assessment mainly focuses on the description and calculation of the groundwater's ability to penetrate the barriers and to, subsequently, transport radioactive substances from the fuel to the biosphere. An overall and comprehensive description of these processes is best visualized if the repository and its surroundings are divided into three parts, each of which functions in a different manner.

The first is the engineered barriers. Their task is to contain the radionuclides and to prevent them from leaching into the rock. The second is the rock surrounding the repository. The rock cannot contain the radionuclides since it contains mobile groundwater which can transport the radionuclides. However, the rock can retain and dilute the radionuclides. The third part is the biosphere, where the radionuclides are distributed between the sediment in wetlands, surface water, with the sea as the ultimate sink, and the groundwater. Wet areas can dry out and become arable land, animals living in water can become part of the human food chain and groundwater can be tapped by wells for domestic purposes or irrigation of crops. In the safety assessment, work is conducted using mathematical models of each of the different processes, but the basis of the model is a detailed description of the processes.

In the chapter on safety assessment (Chapter 14 in RD&D Programme 2004), large parts of the RD&D programme are linked together. The chapter describes SKB's programme for developing its methodology for long-term assessment of repository safety. The design of the assessment depends on the

initial time selected for the description of the repository. The safety assessment still focuses on long-term safety. One new feature is the addition of social science research. At this time, the most important safety assessment projects are the analyses that must be attached to the applications for permission to construct an encapsulation plant or a deep repository for spent nuclear fuel.

SKB is working on detailed and complex system models which comprise several integrated submodels. Numerical calculations of radionuclide transport are performed using newly developed computer codes. The codes allow deterministic as well as probabilistic calculations to be conducted. The safety assessment work focuses on the KBS-3V repository alternative (vertical disposal in holes drilled from underground horizontal tunnels). The KBS-3H alternative (horizontal disposal) is being studied by the Finnish company Posiva Oy, in co-operation with SKB.

In addition to the main scenario, a situation is now being analyzed involving damaged canisters – a requirement that was earlier put forward by KASAM.

8.2.9 Summary of Comments

KASAM finds that SKB has continued to develop its methodology with respect to analyzing the long-term safety of the deep repository. An impressive effort is now underway on the long-term safety of the KBS-3 concept. The work is well structured and has been logically developed and has the potential to provide a good basis for future safety assessment work after further development. However, the reporting of the different parts of the safety assessment is still uneven – from detailed descriptions with calculation examples to very general information or a lack of information on certain aspects.

The selection of scenarios for the analyses of the long-term safety of the repository is a central part of each safety assessment. Selected scenarios must cover a broad enough

spectrum of uncertainties and unfavourable FEPs. Initially, SKB should adopt a broad approach to the preliminary selection scenarios and should not, from the start, exclude less probable but unfavourable FEPs and deviations from the initial state from the risk analysis. SKB needs a structured method for selecting scenarios. Different types of sabotage and terrorist actions should also be included in the scenarios. In spite of the degree of detail used in the models, they can still not provide anything more than very general descriptions of reality. In KASAM's view, it is important and obvious that the models should also continue to be thoroughly evaluated by independent reviewers.

SKB has applied the methodology described in RD&D programme 2004 for a detailed assessment of the safety of the entire disposal system (see "Interim Main Report of the Safety Assessment SR-Can," SKB TR 04-11). It is positive that the methodology is, already now, being demonstrated and can be evaluated before it is used when the application for permission to construct the encapsulation plant is submitted in 2006. The use of function indicators is a good initiative which would reinforce the safety assessment.

This is in line with previous requests by KASAM that separate and detailed safety assessments should be conducted, for example, for the encapsulation plant (for which the safety assessment has now begun), for transportation, for the repository operation phase and for possible retrieval. The site investigation phase also requires a safety assessment. SKB should, as soon as possible, specify when and where the remaining safety assessments are to be conducted.

In its review of SKB's RD&D Programme 2001, KASAM pointed out the necessity of assessing safety in connection with a possible retrieval of fuel canisters from the repository. Such an assessment has not yet been reported. It is important that this work should start as soon as possible.

Even if SKB's (and the authorities') safety assessments are well conducted and understandable to people with insight into this area, interested members of the general public may find

them difficult to understand. This, together with the fact that SKB is conducting almost all of its research on its own, could have a very negative impact on credibility and the formation of public opinion which will grow in view of SKB's forthcoming application. Therefore, KASAM proposes that SKB should carry out simple and popular accounts of its safety assessments.

8.3 KASAM's Conclusions

- KASAM finds that SKB has continued to develop, in a consistent and logical manner, its methodology for assessing the long-term safety of a deep repository in accordance with the KBS-3 concept.
- However, KASAM considers that greater clarity and a greater overview of safety reporting is needed.
- Separate and detailed safety assessments are needed for site investigations, the encapsulation plant, transportation as well as the repository, including the operation phase and possible retrieval; an assessment effort which has just started.
- SKB should, in a clearer manner than has been the case, quantify and report the uncertainties in the different parts of the safety assessment.
- The premises and methodology of the safety assessment must be described and justified in a clear manner. SKB needs to have a structured method for scenario selection.
- Safety in connection with a possible retrieval of the deposited material must be described.
- Both SKB and the authorities must explain and publish pedagogical descriptions of the safety assessments that have been carried out and the models upon which the assessments are based. This is not a question of simplifying the analysis but of producing pedagogical descriptions. The regulatory authorities must be regarded as the experts to whom the municipalities can turn during the licensing process.

9 The Buffer

9.1 Background

The bentonite buffer plays a key role in repository safety. Its function is to keep the copper canister in place in the middle of the borehole and to remove the residual heat in the fuel which is generated during radioactive decay. The buffer's function is also to prevent the water flow from coming into contact with the canister and to prevent or highly limit radioactive gas and water-soluble pollutants from leaching into the surrounding bedrock. The buffer must be able to retain the same properties at high temperatures, after exposure to high radiation doses and after a long time.

9.1.1 What Is Bentonite?

The name "bentonite" comes from Fort Benton in Wyoming, USA. Bentonite mainly comprises a clay mineral, montmorillonite (see Figure 9.1), which belongs to the group of clay minerals called smectites. Other minerals in the group are hectorite, saponite, beidellite and nontronite, which are composed of two tetrahedral silicon layers (SiO_4 layers) surrounding an octahedral MO_5OH layer, where M is aluminum (Al), magnesium (Mg) or iron (Fe). The silicate layers have a negative charge which is compensated for by positive ions

(cations), preferably, calcium ions (Ca^{2+}), magnesium ions (Mg^{2+}) and sodium ions (Na^{+}). These ions are hydrated in a water-soluble solution, namely, they are surrounded by a sheath of water molecules, and the whole "package" can be adsorbed between two silicate layers (intercrystalline adsorption), causing the clay to swell.

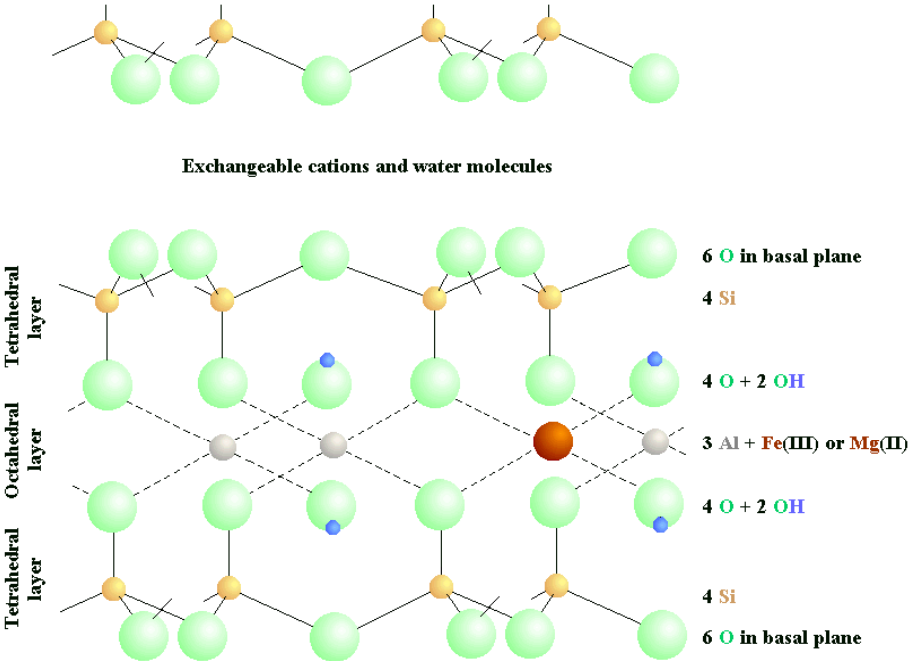


Figure 9.1 *The structure of montmorillonite, the major clay mineral present in bentonite. A portion of the lower tetrahedral layer of an adjacent mineral particle is shown in the upper part of the figure. Water molecules and cations reside between the particles, the cations being strongly sorbed on the surface due to the negative charge arising from partial substitution of divalent magnesium for trivalent aluminum in the octahedral layer [from KASAM's State-of-the-Art Report 2001, SOU 2001:35; adapted from Andrews et al. (1996) and Hemingway & Sposito (1989)].*

Depending on the conditions during formation and in the subsequent environment, the bentonite may contain a number of impurities, such as quartz, feldspar, calcite, gypsum or pyrite. The presence of these minerals affects the properties of the bentonite and, thereby, its value in different applications.

The reference material so far used by SKB is called MX-80 and is a mixture of natural clays from the USA. The material is of the sodium bentonite type and, according to SKB, has a montmorillonite content of about 85 %.

Over the years, MX-80 has been an important material in the KBS-3 concept. Its properties with respect to swelling in water, density, diffusion, microbial properties, gas transport, chemical stability, heat conductivity and several other properties have been described in a number of research reports published by SKB as well as in independent work published in different scientific journals.

A summary of the state-of-the-art with respect to the role of bentonite in the repository was previously provided by KASAM in "Nuclear Waste State-of-the-Art Report 2001" (SOU 2001:35).

9.1.2 SKB's Requirements on the Buffer

In RD&D Programme 2004, SKB summarized the requirements on the buffer as follows:

- Low hydraulic conductivity so that transport of radionuclides and corrodants is only achieved through diffusion.
- The buffer must retain its dimensions after swelling so that the entire space is filled and no large gaps occur over time.
- The buffer must have a self-healing capacity, so that no permanent cracks can form.
- The buffer must be physically and chemically stable in the long term.

Furthermore, in order to perform effectively, the buffer must meet a number of other demands, for example:

- To prevent microbial activity which can cause canister corrosion.
- To release large quantities of gas that can form during corrosion inside the canister.
- To allow heat from the canister to be removed without causing chemical or physical changes.
- To not contain impurities that can have an adverse effect on other barriers.
- To filter out colloidal particles.

9.2 KASAM's Considerations and Evaluation

KASAM's comments mainly refer to Chapter 17 of RD&D Programme 2004.

As was previously mentioned, the extent to which the bentonite buffer can meet the specified requirements has been the subject of extensive research, which has been summarized in a large number of reports and publications by SKB and in papers by international research groups.

For several years, KASAM has also been involved in the issue of the performance and long-term properties of the bentonite buffer, by summarizing international research results in "Nuclear Waste State-of-the-Art Report 2001", through its review report on RD&D Programme 2001 and through its participation in public hearings in Oskarshamn (2001) and other locations.

KASAM's criticism has largely been positive, even if the need for greater knowledge has been emphasized with respect to certain decisive parameters for buffer performance. In its review report of RD&D Programme 2001, KASAM made a number of such comments and KASAM will revisit some of these earlier viewpoints and proposals, here, in this review report.

9.2.1 Alternative Buffer Material

SKB states that it is currently conducting an extensive programme into studying alternative buffer materials. However, the basic reason behind this action is not completely clear.

Is SKB taking this action in order to secure approved suppliers in the long term or is it for financial reasons?

KASAM is positive to the fact that references have been provided for the extensive studies on sodium bentonite which have been presented in many research reports, but is concerned that one of SKB's conclusions, already at this early stage, appears to be that calcium bentonite "entails a lower swelling potential, but its sealing properties are equivalent to those of sodium bentonite" (RD&D Programme, p. 196). Can this claim be made at such an early stage? What references support this claim? Scientific reports that KASAM has referred to in previous KASAM reports ("Nuclear Waste State-of-the-Art Report 2001") show that the diffusion coefficients for many ions are of the order of magnitude of 10 times higher in calcium bentonite than in sodium bentonite.

In its review of SKB's RD&D Programme 2001, KASAM recommended that the properties of calcium bentonite should be studied in a better manner. The reason behind the proposal was primarily not to replace sodium bentonite as a buffer but in view of the fact that, through the action of the groundwater, sodium bentonite could sooner or later be converted into calcium bentonite.

The conversion rate will depend on the relative moisture content of the environment. Under all conditions and especially in situations with surplus water, such a conversion should result in the shrinking of the buffer and the release of water. SKB has itself described this process in RD&D Programme 2001, p. 115.

SKB also states that this does not affect buffer performance without specifying the references that can support this conclusion.

KASAM proposes that SKB should conduct a survey of properties with respect to the swelling and density of sodium bentonite that has been saturated with calcium-rich water.

9.2.2 Importance of Impurities

Normally, as mentioned above, bentonite contains a number of impurities which have a positive or negative impact on the properties of the bentonite. Since the quantity of impurities varies depending on where the bentonite was formed and recovered, it is important for SKB to know how the different impurities, individually and in combination with each other, affect buffer properties.

KASAM has pointed this out in previous review reports and this work is even more relevant now that SKB has stated that it is looking for alternative materials to sodium bentonite, MX-80.

9.2.3 Long-term Stability

The long-term chemical stability of sodium bentonite has been questioned over the years in a number of contexts. Critics have indicated the risk of a possible conversion of montmorillonite – which is the main component of sodium bentonite – into illite, (illitization) which is accelerated by increased temperature and potassium ions from the surrounding potassium-rich minerals, such as the backfill.

The clay mineral illite is similar to montmorillonite but more silicon substitution by aluminum occurs in the layer structure, which leads to an increased negative charge. The negative charge is compensated for by strongly adsorbing potassium ions which can easily become dehydrated, resulting in no or poor swelling properties in water. Such a conversion would cause the buffer to shrink and this could lead to cracking.

KASAM earlier proposed that SKB should investigate how limited conversion into illite or calcium bentonite would affect the buffer properties. However, completely replacing sodium bentonite as a buffer would require extensive studies with respect to the criteria established by SKB. KASAM interprets the research programme in RD&D Programme 2004 to mean that SKB has understood this.

One factor that has only been discussed in passing (sections 17.1.4, 17.2.2 and 17.2.20 in RD&D Programme 2004) is changes in the properties of the buffer as a result of the extreme irradiation of the bentonite close to the canister. The dose rate is initially estimated at 0.5 Gy/hour, which is about 4 kGy per year. The dose contribution is dominated by ^{137}Cs, which has a half life of 30 years. Consequently, the effect is of interest during the first few hundred years. It is reasonable to believe that the radiation doses achieved, up to a few hundred kGy, could result in microstructural changes in the bentonite which, in turn, could affect the adsorption capacity, gas transport etc. In KASAM's view, it is important that SKB should give an account of its own research and that of others in the area and, if necessary, conduct further research.

9.2.4 Processes in connection with Swelling

The adsorption of surrounding water by the unsaturated buffer is a critical process which, in many respects, will affect its future properties with respect to sealing against the canister and the surrounding bedrock, pore structure and, thereby diffusion routes for dissolved substances and gases, for example. Since water saturation in the initial stage will largely occur through advection (pressure-induced flow) due to underpressure in the buffer pores, ions from the surrounding water will be comparatively quickly transported relatively far into the buffer.

Furthermore, this occurs under the influence of a temperature gradient where the water closest to the canister has a

temperature of 80-90ºC, while the temperature of parts of the buffer that are closest to the surrounding bedrock will be of the same temperature as the bedrock.

This condition will probably exist for a long time, depending on the access to water from the surroundings and its composition. The properties of the bentonite, with respect to swelling rate and level, are affected by the temperature. This also applies to the solubility of different substances in the pore water. A temperature reduction can result in precipitation of, for example, calcite, gypsum and calcium silicates and, thereby, prevent or make further water transport and swelling difficult during this initial stage.

In KASAM's view, these heterogeneous conditions during water uptake, can lead to long-term defects occurring in the buffer performance and the consequences of this should therefore be specifically studied.

It will be particularly important for sealing against the canister to be as good as possible in order to prevent the transport of corrosive substances and bacteria.

9.2.5 Buffer Density

An important parameter in the buffer is the density which, as a result of heterogeneous conditions during swelling, can vary considerably in different places and in different directions. Since this, in turn, affects a large number of other properties (such as pore size, pore water composition, ion diffusion, microbial activity), this will have consequences for the properties of the buffer.

A high value for the density is critical for the properties of the bentonite buffer and this has been reported in a large number of reports published by SKB and scientific works published by others. The density of the bentonite buffer in a water-saturated condition is decisive for radionuclide diffusion, gas conductivity and microbial activity.

Compacted bentonite will swell on contact with groundwater in the repository. The ultimate density and swelling pressure will be dependent on water composition, temperature, the volume that is to fill the borehole and by the counterpressure from the environment. These parameters can all vary more or less.

Under these circumstances, how is it possible to be sure that the bentonite buffer in the repository has the properties, in terms of for example density, that are the premises upon which the research reports and studies that SKB refers to are based?

In its earlier review of RD&D Programme 2001, KASAM raised these issues and there is still a considerable need to obtain answers to these issues, particularly in connection with the fact that SKB now intends to test new buffer materials.

9.2.6 Gas Transport

SKB reports that it is currently conducting a relatively extensive research programme concerning studies of gas transport through bentonite. As is mentioned in RD&D Programme 2004, current knowledge is largely only based on experiments on a relatively small scale. Therefore, it is noteworthy that SKB, elsewhere in the programme text, now claims that it knows that the bentonite can open up and release large quantities of gas without leading to an actual deterioration of properties.

In KASAM's view, this conclusion that SKB has drawn, particularly in the light of the discussion in the previous section, should be considered to be more of a hope than a claim supported by evidence.

KASAM would like to underline the need for further research in the area.

9.2.7 Diffusion Model

In its review of RD&D Programme 2001, KASAM considers that a more sophisticated sorption model of radionuclides and other ions in the buffer can be achieved. In a very recently published report, "Migration Parameters for the Bentonite Buffer in the KBS-3 Concept", SKB TR-04-18, SKB has presented a selection of transport parameters for radionuclides in a buffer of MX-80 bentonite.

Facts

If a defect occurs in a copper canister and water comes into contact with the iron insert, hydrogen gas will be formed in the canister through water reduction, through the following reaction:

$3\ Fe(s) + 4\ H_2O(aq) \Rightarrow Fe_3O_4(s) + 4\ H_2(g)$.

The hydrogen gas must then, in one way or another, be transported through the bentonite buffer.

The pressure of the gas formed through anoxic corrosion, radioactive decay and radiolysis of water must probably be higher than about 12 MPa before any significant cracking in the bentonite can be initiated. (See KASAM's report "Nuclear Waste State-of-the-Art Report 2001" (SOU 2001:35, p. 203).

However, the transport of soluble gas through bentonite can occur in connection with a much lower gas pressure, even if it occurs very slowly. (SKB in RD&D Programme 2004).

It may be of interest to perform a rough estimate of how slowly this process occurs, providing that hydraulic conductivity is negligible.

The solubility of gas in water is determined by Henry's law, $X_B = P_B/K_H$, which assumes that the solubility X_B is dependent on the partial pressure of the gas P_B and Henry's constant K_H which is dependent on water temperature and ion strength as well as on the gas in question.

If Henry's law is followed exactly, the solubility will increase linearly with the pressure and this is the case for, H_2, He and N_2, for example, up to about 10^7 Pa, namely, in the pressure range that is relevant for the repository.

Henry's constant for H_2 is 1260 bar/(mol/L) at 20°C, which means that the equilibrium concentration for $H_2(aq)$ in the surrounding porewater is $1 \cdot 10^6 \cdot 10^{-5}/1260$ mol/L ≈ 20 cm^3/L = 2 vol % at a pressure of 1 MPa.

The diffusivity (D) for $H_2(aq)$ is $4.5 \cdot 10^{-5}$ cm^2/s (at 25°C) and with the help of the formula, $x^2 = 2Dt$, an understanding can be achieved of the average distance that a dissolved hydrogen gas molecule can travel in one year (about 0.5 m) which should be a considerably shorter distance in the buffer, bearing in mind its complex pore structure.

The above calculation has not taken into account the concentration gradient, although this does not have a significant impact on the result.

Decisive parameters in this context still consist of distribution coefficients (Kd) which are conditional, which means that they apply at a certain temperature, ion strength, density porewater composition, pH, redox conditions etc. Since all of the parameters can vary at different places, even inside the repository itself, while the distribution coefficients are determined at 25ºC, the measured values must be extrapolated, resulting in significant uncertainties.

The argument made above is that conditional constants should be used rather than thermodynamic models. This is consistently justified by the fact that the conditions in the repository are too special to be captured by thermodynamic parameters. Bearing in mind the length of time that SKB has conducted its own research in this area and, furthermore, initiated diffusion studies in bentonite at different universities, it is surprising, that it has not found it necessary to compare results from a thermodynamic sorption model with the migration models that it has consistently reported.

In KASAM's opinion, such a comparison could and should have been made by SKB for at least one important positive ion in this context (for example cesium ion, Cs^+) and an important anion (such as iodide ion, I^-) with the aim of determining if a more general model for radionuclide transport can be achieved through the buffer.

KASAM regrets that SKB has stated in RD&D Programme 2004 that sorption in bentonite will not be a prioritized area.

9.3 KASAM's Conclusions

- SKB should propose limits for the concentration of impurities in the bentonite buffer.
- Buffer performance as a result of combinations of impurities should be investigated.

- The consequences of a probable conversion from Na bentonite to Ca bentonite as well as limited illitization should be studied.
- SKB's own research and that of others on the impact of radiation on the buffer should be reported.
- SKB should describe how it can ensure that buffer density can be maintained to a sufficiently high level in the repository.
- In KASAM's view, SKB's research on gas transport on a large scale through the bentonite buffer is important.
- An overall thermodynamic model should be established for the transport of the most important radionuclides through the buffer.

10 Backfill

10.1 Background

The backfilling of all of the deposition tunnels and other cavities in the bedrock caused by the construction of the repository is a critical process for the continued performance of the repository.

In RD&D Programme 2004, SKB immediately establishes that the backfill in the tunnels is not an independent barrier in the KBS-3 concept but that the barrier is necessary for the buffer and bedrock to perform as intended.

Furthermore, SKB has identified and formulated the requirements made on the backfill in a number of points:

- The backfill must have a stiffness that minimizes the upward expansion of the buffer so that the density of the buffer can be maintained.
- The backfill must have a hydraulic conductivity that is comparable to that of the surrounding rock. Otherwise the deposition tunnels may act as conductive pathways that influence the water flux in the repository.
- The backfill must exert a certain swelling pressure against the roof to maintain a swelling capacity that can seal possible effects of piping and creep movements.
- The backfill may not have any adverse impact on the barriers in the repository, which makes demands on chemical composition.

10.2 KASAM's Considerations and Evaluation

KASAM's comments below mainly refer to Chapter 18 of RD&D Programme 2004.

Backfilling is a critical process which requires special attention. The quality of the backfill material is of decisive importance for the future performance of the repository. The technical solution that SKB chooses must also provide adequate sealing against the roof, walls and floor in order to block transport routes for water. KASAM would like to emphasize the need for realistic experiments with the aim of determining the optimum technology.

In all previous review reports on SKB's RD&D Programme (from 1995 onwards), KASAM has emphasized the important role of the backfill for long-term repository performance. In all of these reviews, attention has been called to problems with ensuring quality with respect to the criteria identified above.

KASAM has emphasized that the function of the backfill in maintaining the density of the bentonite buffer, by resisting swelling, should be prioritized. Furthermore, KASAM has recommended that SKB should conduct performance analyses with respect to different types of backfill, including only natural clays, mixtures of crushed rock and clay as well as only crushed rock with an optimum size distribution to provide maximum resistance against the pressure of the swelling bentonite.

KASAM has also recommended that SKB should set a limit for the quantity of potassium in the backfill, in order to minimize the risk of an adverse effect on the bentonite buffer through long-term illitization of the bentonite.

10.2.1 Requirements on the Backfill

SKB clearly emphasizes that the backfill is not an independent barrier. Since it is an important requirement for the hydraulic conductivity to be of the same order of magnitude as that of the

surrounding rock, which is a natural barrier, it is difficult to understand what SKB means by this statement.

In the original reference concept, the backfill comprised a mixture of mineral particles. Such a design entails a natural occurrence of water in different forms.

In addition to more or less unbound water and hydrated ions, pore water, surface adsorbed water and chemically bound water will exist in crystal structures in original and secondary precipitated minerals.

The addition of swelling clays will mean a certain redistribution of the available water and an average reduction in the pore size. However, the mixture of different mineral particles of varying sizes means that the backfill will hardly be homogeneous. Therefore, there will be more and clearer diffusion routes for radionuclides, ions, colloids and gases in the backfill than in the bentonite buffer and even in comparison with the surrounding rock, at any rate if the rock does not contain large fractures.

In this context, it is an advantage that the sorption surface is significantly greater in the backfill than in the surrounding rock.

Such a homogeneous particle size distribution as possible in the backfill is probably preferable. Therefore, KASAM supports SKB's plans to study concept B (only swelling clay) in greater depth together with further studies of the original concept A (a mixture of bentonite and ballast) (p. 232 of RD&D Programme 2004).

10.2.2 Processes in the Backfill

The backfill concept is based on low water transport, with the aim that it should be of the same order of magnitude as the surrounding bedrock. This can only be achieved if the density is high and the seal against the walls and, above all the roof, is adequate.

The occurrence of gaps in the backfill entails a considerable risk for water flow and, thereby, for a rapid erosion and transport of colloids. Therefore, KASAM supports SKB's justification to primarily use swelling clays. In accordance with concept B, swelling clay probably entails a smaller risk for the supply of chemical substances, such as potassium ions, which can damage the buffer. In KASAM's opinion, if SKB ultimately chooses to use concept A, limits should be established for substances that can damage the buffer. The relatively large exposed surface of particles in crushed rock primarily leads to increased solubility of component minerals. This can be compared with the restrictions that apply to crushed rock and gravel when using concrete.

KASAM agrees with the viewpoints that SKB presents on pp. 236-239 concerning advection, osmosis, ion exchange, montmorillonite conversion and microbial processes. However, KASAM would like to emphasize that these processes will be different, in principle, in the different concepts (A and B) that SKB intends to further investigate.

According to concept A, the backfill will comprise different types of mineral particles together with bentonite. These particles will subsequently have different properties, such as surface charge, type of surface-active groups, adsorption capacity etc. under the same external conditions. Altogether, this means that the determination of radionuclides and mechanisms for transport will be more complex.

SKB states, on p. 239 that radionuclide transport in the backfill through diffusion is of limited importance. Nevertheless, on the following page, SKB considers that the speciation of radionuclides is important for sorption and diffusion. What does SKB mean by this? Why is speciation important if the process is of limited importance?

In KASAM's view, SKB is dismissing the importance of radionuclide transport through the backfill. The density will probably be lower in the backfill than in the buffer and, thereby, the diffusion routes will be shorter and more significant.

The lower density in the backfill will lead to an increase in microbial activity. SKB seems to consider that this alone is positive since it contributes to oxygen reduction. However, an undesirable consequence of bacterial activity is probably an increase in leaching from mineral particles which are a part of the backfill, in accordance with concept A. This can have a negative effect on the bentonite buffer. KASAM recommends that SKB should more closely study the long-term effects that this could have.

10.3 KASAM's Conclusions

- The function of the backfill in maintaining buffer density should be prioritized.
- KASAM supports SKB's intentions to investigate the backfill only using swelling clays (concept B) to achieve maximum sealing against the walls and roof.
- SKB should investigate how microbial activity affects the solubility of minerals and leaching in the backfill, both in concept A and B.
- How the lower density in the backfill, compared with the bentonite buffer, will affect radionuclide transport and how speciation will affect transport still have to be explained.
- SKB should investigate and describe the importance of impurities to long-term backfill performance.

11 Geosphere

11.1 Background

The main function of the bedrock in a deep repository is to provide stable mechanical and chemical conditions which are favourable for the durability of the canister and clay barrier and to delay radionuclide leaching from the spent nuclear fuel for as long as possible. The siting of a deep repository in suitable bedrock which fulfils the corresponding mechanical and chemical properties is therefore of decisive importance. In order to evaluate the mechanical stability, knowledge of Swedish bedrock and its geological history is required. In a similar way knowledge is required of the substances in the groundwater that affect buffer and canister stability under natural conditions and which are of importance for radionuclide migration. Specific knowledge of several parameters is also required in order to evaluate the water-mineral equilibrium and the different factors that impact on the evolution of the water chemistry.

The occurrence of groundwater, its flow and chemical composition are therefore of central importance for the siting, design and construction of underground facilities in the rock, especially for the disposal of spent nuclear fuel. Bedrock with high hydraulic conductivity will make repository construction and waste disposal difficult. The groundwater conditions in different parts of the landscape around a repository site, the magnitude of groundwater recharge and groundwater flow

patterns at different depths must therefore be determined. However, the groundwater can also attack the engineered barriers (canister etc.), especially if salinity is high, and dissolve and transport harmful components which can, thereby, reach the biosphere or wells. Different groundwater types, the chemical composition, origin and evolution of the groundwater as well as dominant reactions and reactive processes in the bedrock must therefore be determined.

In the very long time horizon involved in the disposal of nuclear waste, the groundwater conditions must also be predicted for land uplift as well as various possible climate conditions: a varmer and more humid climate due to greenhouse effects as well as a colder climate in connection with a future glaciation. The magnitude of groundwater recharge is also directly affected by climate changes, groundwater flow patterns are affected by changes in land and sea levels, and these also affect groundwater chemistry.

The description provided above shows that identifying a deep repository site that meets safety requirements necessitates extensive geoscientific investigations, modelling and advanced geological, hydrogeological and geochemical knowledge.

11.2 KASAM's Considerations and Evaluation

KASAM's comments mainly refer to Chapter 19 of RD&D Programme 2004.

According to SKB's RD&D Programme 2004, the deep repository for spent nuclear fuel is to be located in crystalline rock of granitic composition (line 1, p. 243). KASAM considers that this statement eliminates a discussion about the composition, texture, structure and properties of the bedrock, with respect to other rock types besides granitic rock. SKB's previous attempt to achieve geological variety in connection with investigations has therefore been limited to the two sites that are currently being investigated, namely Forsmark and

Simpevarp/Laxemar, which have a similar bedrock. KASAM would like to see a convincing line of argument for the reasons behind this limitation.

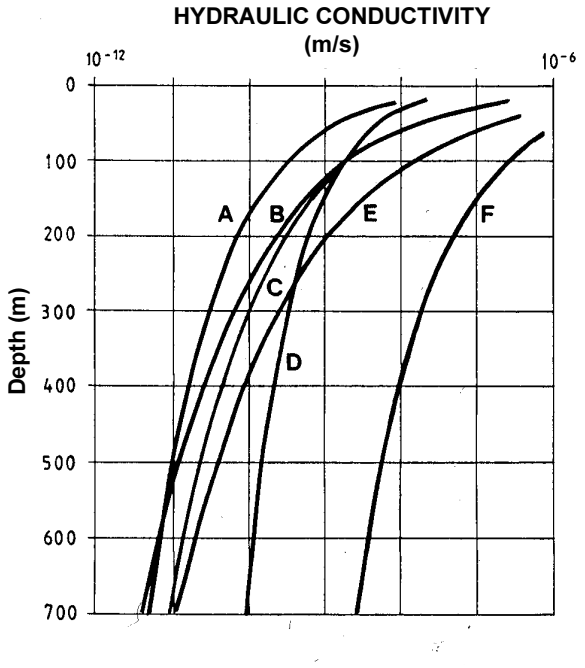
In RD&D Programme 1998 Supplement (submitted in December 2000), SKB stated that the site investigation programme should include more alternatives besides Forsmark and Simpevarp (which were considered to have clear advantages from the standpoint of "establishment and society", that is for other reasons besides geological reasons) in order to be robust. SKB stated that the site investigation phase should therefore "comprise studies of alternatives that have good conditions, but are different compared to Forsmark and Simpevarp. Additional sites should primarily represent other geological conditions and be located in other municipalities." SKB referred to the siting alternatives of Tierp-North/Skutskär and Skavsta/Fjällveden which were expected to "contribute to a greater variety of geological data for decision making"

In its review of RD&D Programme 1998 Supplement, KASAM stated that "it would be a strength if the choice of site for the future detailed characterization could be based on results from site investigations with the geological variety that SKB has sought to attain."

For various reasons, it was not possible for SKB to investigate the following alternatives: Tierp-North/Skutskär and Skavsta/ /Fjällveden in the manner proposed by SKB in 2000. However, this situation does not mean that the need no longer exists to develop and present a basis for decision-making that has a large geological variety for licensing (under the Environmental Code and the Act on Nuclear Activities) and the selection of a site for a repository for spent nuclear fuel. This was pointed out by KASAM in its review of RD&D Programme 2001 (p. 72 of KASAM's review report, SOU 2002:63).

The differences between the properties of different rock types, for example hydraulic conductivity, justifies a greater geological variety in the basis for deciding on a site. (Figure 11.1 shows the hydraulic conductivity of a number of rock types in a

few selected study sites in Sweden. Hydraulic conductivity is a measure of water permeability and is defined as the water flow per unit of time under certain given conditions). Although hydraulic conductivity decreases with depth, the diagram shows that the difference between different rock types remains, even at depth of 600-700 metres, according to SKB's own investigations.



A = Gabbro, Taavinunnanen (27 data)
B = Veined paragneiss, Fjällveden (175 data)
C = Dolerite dykes, Gideå (28 data)
D = Granite dykes, Taavinunnanen (11data)
E = Veined paragneiss, Gideå (74 data)
F = Anorogenic granite, Kråkemåla (20 data)

Figure 11.1 *Hydraulic conductivity for the rock mass (excluding fracture zones) in the Fjällveden, Gideå, Kråkemåla and Taavinunnanen study sites. The figure also shows the hydraulic conductivity for granite dykes in Taavinunnanen and dolerite dykes in Gideå (from "Water-bearing Properties of Different Rock Types Based on Investigations for Nuclear Waste Disposal" by Ahlbom, K., & Carlsson, L.; Documentation from the "Geohydrology in Practice" symposium by Viak AB and the Swedish Hydrological Council, May 4, 1988.)*

As a result of SKB's decision, that the deep repository is to be located in crystalline bedrock with a granitic composition, there is reason to raise the questions of how inhomogeneous the granitic bedrock may be (for example, with respect to the occurrence of dykes, fractures and fracture zones) and how SKB defines granitic composition. KASAM has previously recommended that SKB present a programme to develop methodology for the classification of bedrock heterogeneity.

In KASAM's opinion, there are geologically sound reasons to continue to work on the site investigations in Forsmark and Simpevarp/Laxemar. However, in KASAM's view, SKB should expand the investigation data with the aim of achieving an adequate geological variety. One way of doing so could be to analyze and, if necessary, supplement previous investigations in Gideå and Fjällveden. This may entail performing new calculations and measurements using new methodology. It is important for the investigations to be conducted in a similar way so that the sites can be compared in a scientifically correct manner and so that an objective analysis can be carried out.

Such analyses and supplementary work could expand the basis for selecting a suitable site as required by the Environmental Code (cf Chapter 2 § 4 of the Environmental Code) as well as the basis for the application (including an Environmental Impact Statement in accordance with Chapter 6 § 7 of the Environmental Code) for permission (in accordance with, primarily, the Act on Nuclear Activities and the Environmental Code) to construct a repository for spent nuclear fuel.

11.2.1 Processes in the Geosphere: Overview of Processes

The mechanical evolution is determined by the geosphere's response to the different mechanical loads to which it is subjected. Changes can occur in the form of fracture formation with sudden movements in existing fractures or in the form of

slow creep movements in the bedrock. By groundwater flow, the groundwater is distributed in the fracture system of the geosphere.

In KASAM's view, questions relating to natural rock stresses and fracture systems at the repository site as well as the changes that repository construction leads to as well as the occurrence of the groundwater, its flow and chemical composition, are important for making a final decision regarding a repository site.

11.2.2 Heat Transport

KASAM notes that the work on developing, calibrating and verifying methods of determining thermal properties is continuing and that the temperature measurements in the rock that are being conducted in the prototype repository and in the retrieval experiment at the Äspö Hard Rock Laboratory will be evaluated with the aim of determining heat transport properties. The results will be used to develop and describe the thermal site model.

11.2.3 Groundwater Flow and Groundwater Recharge

KASAM notes with satisfaction that SKB has conducted some of the important studies that KASAM requested in its previous review of the RD&D programme, namely, modelling of groundwater flow on a regional scale with a good topographical resolution as well as modelling of groundwater recharge at different depths. As expected, the local topography proved to have considerable importance for the superficial flow pattern, while groundwater flow from the repository depth is limited to well-defined low points in the terrain, such as wetlands and lakes.

It was also found – as was the case earlier in Finnsjön – that saline groundwater deep in the bedrock can act as a floor and

thereby further reinforce superficial flow. It was found that the longest flowpaths tend to be located below lakes with dense bottom sediment.

There is reason to question whether knowledge of the structure of the wetlands is adequate since embogged peatlands often have as dense bottoms as lakes and, as a rule, thicker sediments with both dense clay sediment and dense organic soil types, such as gyttja and dy. However, the layering beneath lakes, watercourses and wetlands does not need to be uniformly dense everywhere but can contain more permeable parts, especially below watercourses where erosion during the high water flows, for example after snow melting, can expose sand-gravel bottoms and shores. During periods with high surface water levels, this can lead to surface water leaking into the groundwater reservoir which at the same periods has low groundwater levels due to delayed groundwater recharge as a result of a perhaps long and cold winter. Detailed information about sedimentary layering and water levels is therefore necessary in order to demonstrate the complex water exchanges that can occur between surface water and groundwater. In especially sensitive areas, the most reliable way of investigating this exchange is by conducting tracer tests in different water situations.

An additional question is whether, in general, the detailed geological data is satisfactory, when, in addition to the thickness of the soil layer, it is the importance of the topography for the flow pattern that has mainly been mentioned. Structures in the bedrock, both the most permeable in the form of gently dipping fracture zones and more or less vertical fracture zones such as the most dense, for example, dolerite dykes, would probably be able to determine the flow pattern in another way than only topographic differences.

The programme describes further work within this problem area, especially further testing of calculation tools, attempts to obtain a coherent picture of the evolution of the groundwater chemistry in a 10,000 year perspective, an improved

understanding of the near-surface hydrogeology and the effects of groundwater lowering in an open repository as well as the development of a linked hydrological model for surface water, superficial and deep groundwater. The biosphere could perhaps be incorporated into this model. In all cases, land uplift as a possible climate change must be taken into account relatively soon as must a future glaciation.

Coupled models are an interesting and productive development in hydrological modelling which has been applied to other areas as was discussed in KASAM's State-of-the-Art Report 2001. Since that time, a new coupled model, ECOFLOW, has been developed with promising results through a PhD thesis at the Royal Institute of Technology, Stockholm (KTH), namely, a coupling between a Russian hydrological model, ECOMAG, and the US groundwater model, MODFLOW. With the new model, the exchange between surface water and groundwater and the transport of certain chemical pollutants can be calculated. The model can be adapted to the conditions that apply in a catchment area, some aspects of which can be studied at a fairly general level, but which, in other respects, need to be studied in detail, for example, for a possible site.

In KASAM's view, it is very important that the planned programme for groundwater flow should be conducted. Much understanding and realism would be gained if more concrete geological information were added to the regional flow simulations. What is the importance of the gently-dipping open fractures found in the Forsmark area and the steeply-dipping, deep fracture zones found in Eastern Småland? Much credibility would also be gained if the information from the modelling of the magnitude of natural groundwater at great depths could be verified through the testing of several and completely independent methods of determining groundwater recharge on the same area, in the way that has been done in Yucca Mountain, USA – see KASAM's State-of-the-Art Report 2004.

After this is done, an analysis should be conducted of the impact that measures such as groundwater extraction in connection with tunnel construction could have in terms of changes in groundwater recharge. The lowering of the groundwater levels around a tunnel or a rock vault often leads to changes and magnification of the recharge area, resulting in increased groundwater recharge, faster water turnover and changes in water chemistry. For example, during the construction of the railway tunnel through Hallandsås (a horst of crystalline rock) the groundwater recharge at the tunnel level increased by 25 % with a maximum lowering of about 100 m of the groundwater level.

KASAM has previously pointed out that it is particularly important to develop methods for measuring the groundwater flow between soil layers and the bedrock. Knowledge of this phenomenon is too deficient. It is important for assessing and calculating (modelling) both the magnitude of the groundwater recharge in different sedimentary layers and the upward flow and transport of groundwater and any pollutants to surface systems and the biosphere.

11.2.4 Movements in Intact Rock

KASAM finds it surprising that the GPS measurements in Oskarshamn – aiming at studying movements in the bedrock – have not been included in RD&D Programme 2004. Furthermore, these measurements should be extended to a measurement area in Forsmark and should be carried out for as long as possible.

11.2.5 Thermal Movement

According to RD&D Programme, the risk of canister damage due to thermo-mechanical loads is zero, providing that no canister holes are intersected by fractures extending more than 700 in the dip direction. This remains to be demonstrated.

11.2.6 Reactivation (Movements along Existing Fractures) and Fracturing

In KASAM's view, valuable new knowledge has been gained over the past three-year period, with respect to documented seismically induced damage on underground constructions and with respect to dynamic calculations performed using different models of fracture movements in connection with earthquakes of a magnitude of 6.0. On the other hand however, SKB has not presented a report of the results of the GPS measurements in the local seismic network in Oskarshamn, which started in 2000, see Figure 11.2.

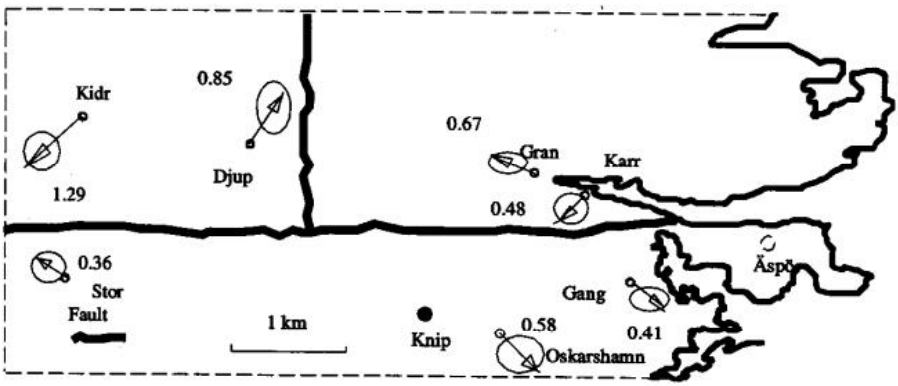


Figure 11.2 *The detailed GPS network in the Oskarshamn region for determination of block movements. The observation points have been given shortened place names. Fault zones are marked with a thick line. Arrows mark the displacement velocity in mm per year that have occurred during the observation period (from KASAM's State-of-the-Art Report 2004, SOU 2004:67, from Sjöberg et al. 2002).*

In KASAM's State-of-the-Art Report 2004, KASAM pointed out that such measurements in a local network, which complement the overall, nationwide network, were exemplary. Measurements of this type are vital for the monitoring of seismic events in the area and in order to obtain knowledge of the deformation processes that may occur. KASAM stated that it was important for similar measurements to also be started as soon as possible in the Forsmark area. However, SKB has stated that the measurements in Oskarshamn have been terminated since they were apparently considered too costly to be continued. However, in order to reduce the cost, it would have been wiser to cut down on the number of stations and measurement occasions and to continue the measurements over

a longer period of time than to terminate all measurements. Furthermore, it is important, for the sake of comparison, to establish a local network in Forsmark. Since the processing method and instrumentation are being developed, more reliable and accurate results will be obtained. Even if no significant movements should be demonstrated after a long period of measurement, such results and underlying measurement data would be a very important basis in connection with an application for siting permission and for the continued work on the repository. Models cannot replace field data. KASAM would therefore like to strongly emphasize that the GPS measurements should be resumed in Oskarshamn and that a local network should be established in Forsmark. It should be pointed out that, in Finland, GPS measurements have been underway since 1995. They are considered to be of great value and it is proposed that they should continue for at least one full solar activity cycle, namely 11 years (ref: "Review of the GPS Deformation Monitoring Studies Commissioned by Posiva Oy on the Olkiluoto, Kivetty and Romuvaara Sites, 1994-2000" by Vermeer, M., 2002; Report STUK-YTO-TR 186, Radiation and Nuclear Safety Authority, Helsingfors.

KASAM emphasizes the importance of SKB's programme for demonstrating the validity of the general relationships between fracture extension and the movement that can occur along the fracture at a given load and in a given fracture system. It is also of interest to study the movement of two or more minor fractures interacting via a bridge of partially intact rock and how this movement can be underestimated if the interaction between the fractures is not taken into account.

SKB does not deal with the issue of the "respect distance" in RD&D Programme 2004. It seems as though SKB has intentionally avoided direct reference to the safety assessment's need for data from the site investigations. Furthermore, in turn, the site investigations are not dealt with in the programme apart from as points in timetables. In KASAM's opinion, the description of the need for a "respect distance" between a

repository and fractures of different lengths and types should be clarified. In addition, the arguments for the distance should be well supported by published research results and empirical experience. Therefore, KASAM would like to see the overall goal of reaching a well-defined and systematic basis for determining the "respect distance", namely, the distance from a fault plane/fault zone that a repository can be located. Such research should be part of the already initiated research on fracture minerals and mineral transformation in the ancillary rock.

Furthermore, it is of interest to follow the discussion on whether the repository itself, in interaction with fractures and fracture zones, can function as a plane of weakness in the bedrock.

11.2.7 Time-dependent Deformations

The programme refers to a literature survey which aims at setting limits to the stress changes that the repository rock can be exposed to over time, as a result of slow tectonic movements. This is of great importance, as is the modelling methodology for setting limits to the convergence of tunnels and deposition holes that can occur over thousands of years as a result of the inherent time-dependent properties of the bedrock.

11.2.8 Advection/Mixture – Groundwater Chemistry, Radionuclide Transport

The development of the M3 computer code for performing mixing calculations for groundwater chemistry has been very productive and has resulted in an essentially increased understanding of groundwater origin and age, especially at great depths in hard rock. Therefore, it is very important to conduct the planned update and verification of M3 and the proposed calculations of salinity evolution in extensive climate change

scenarios. It is therefore necessary to work with different scenarios for both the greenhouse effect and a future glaciation and to couple hydrochemistry and hydrogeology.

Radionuclide transport should primarily be studied by using a coupled flow and transport model, not by a simplified model which exaggerates retention.

11.2.9 Diffusion – Groundwater Chemistry, Radionuclide Transport

Previous investigations and mixing calculations indicate that the transport process is very long and diffusive, which can explain the occurrence of saline groundwater at great depths. Therefore, it is a very interesting proposal to use data from depths below the continental ice sheet in Greenland to verify this assumption. KASAM strongly supports this proposal. Since the water could be very old, ^{36}Cl analyses should be conducted on the water.

The development of electrical methods to measure radionuclide diffusion seems to be a successful methodology. It is important to conduct the planned long-term field experiments to measure diffusion in the intact matrix.

11.2.10 Reactions with the Rock – Dissolution/Precipitation of Fracture-filling Minerals

To understand the evolution of the groundwater chemistry with respect to redox conditions, it is very important to study the dissolution and precipitation of fracture-filling minerals which is a constant, ongoing process. KASAM notes that this research has been given significant scope in the RD&D report.

The programme also shows that SKB has allowed the dating of fracture-filling minerals and studies of fracture orientation to start.

11.2.11 Microbial Processes

Much new and valuable knowledge has been gained in this research area in recent years: microbes in combination with iron oxides form very effective filters for tracer metals and microbes from great depths emit complexing agents which can mobilize radionuclides from solid phases. The planned experiments are therefore of very great interest and should be conducted with as adequate resources as possible in the field at the Äspo Hard Rock Laboratory and at the investigation sites.

11.2.12 Colloid Turnover – Colloids in the Groundwater, Radionuclide Transport with Colloids

New knowledge has also been gained in this area, partly from other environments besides hard crystalline bedrock. The planned tracer experiments should be conducted, bearing in mind the role of the bentonite.

11.3 KASAM's Conclusions

- In KASAM's view, the starting point for site selection should be site investigation data with a large geological variety, with reliable information about conditions at repository depth. Therefore, there is a need for SKB to analyze and, when necessary, supplement previous geological investigations which would represent other geological conditions than those that are now being investigated in Forsmark and Simpevarp/Laxemar.
- In KASAM's opinion, it is very important for SKB to conduct the planned programme for groundwater flow. In connection with this programme, it is important for concrete information on geological structures and boundaries as well

as detailed information on sediment sequences and water levels to be added to the regional flow calculations.

- The natural groundwater recharge at repository depth should not only be calculated by modelling but also determined by different methods that are independent of each other. The disturbed groundwater recharge by the construction of a repository and tunnels should then be calculated. Predictions of natural and disturbed groundwater recharge in connection with possible future climate changes should also be made.
- Measurements to monitor seismic events and deformation processes in the bedrock are very important and should be carried out over a long period of time. GPS measurements on a local scale should therefore be resumed in Oskarshamn and established in Forsmark.
- Investigations into groundwater chemistry and geochemistry should be carried out in accordance with proposed programmes. The age determination of groundwater at great depth, under continental ice sheet conditions, for example, should be conducted using different dating methods, including ^{36}Cl analyses.

12 Biosphere

12.1 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.

In recent years, SKB has successively increased its efforts within the biosphere area. Chapter 20 of RD&D Programme 2004 provides a clear and systematic account of the current programme. The review comments that have been submitted concerning RD&D Programme 2001 are reported and commented upon. Many of the viewpoints have been taken into account in the preparation of the new programme and, in the case of other viewpoints, a plan exists for later action. New knowledge is reported separately, which is convenient for the reader. In KASAM's view, the material in the background reports is extensive. The overall goals for the biosphere programme indicate a high level of ambition.

Data from the intensified and, subsequently, increasingly scientifically conducted site investigations are intended to provide a basis for a deeper understanding of the biosphere processes as well as for the development of safety assessment models, in accordance with the requirements of the Environmental Code, the Act on Nuclear Activities and the Radiation Protection Act, including accompanying regulations.

The system-ecological approach and the development of process-based models are important new features of the work.

SKB has increased its publications in journals with an international readership. In KASAM's view, it is – as was previously pointed out – important that reported data should continue to be made easily accessible for national and international peer review. With respect to the possibility of independent national peer review, one problem is that Swedish research organisations have more or less completely abandoned the areas of radiation protection and nuclear safety research in favour of more "trendy" research. In a situation where the authorities are also being forced to cut back their research work, SKB itself is playing a dominant role in research within the area and is also funding grants to several university-based research groups. It is positive that SKB is raising its ambitions. However, the fact that society is gaining fewer and fewer opportunities for independent review of results is a threat to credibility.

As in previous research programmes, in RD&D Programme 2004, SKB provides an insight into international work that is underway within the biosphere area. SKB participated in the FASSET project (Framework for ASSessment of Environmental impacT) within the EU's Fifth Framework programme, which started in 2003. SKB is now continuing its work in ERICA (Environmental Risk from Ionizing Contaminants: Assessment and management), the followup project to FASSET. SKB is also participating in a joint international project between different companies and organizations which are active in the nuclear waste area.

12.2 KASAM's Considerations and Evaluation

KASAM's comments mainly refer to Chapter 20 of RD&D Programme 2004.

KASAM supports the overall goals of the biosphere programme to describe, from a radiological standpoint, the most

important processes in the biosphere using a modern knowledge base as well as to provide adequate scientific support to evaluate the environmental consequences of the construction and operation of a repository.

KASAM particularly notes the explicit ambition of the RD&D Programme to consolidate and deepen knowledge in ongoing projects through increased publication in international journals. KASAM shares SKB's view that it is important to convey the company's knowledge to both Swedish and international research groups in order to obtain viewpoints and the necessary independent peer review.

However, the Government should, as soon as possible, focus its attention on the ongoing funding of Swedish research in the area and the consequences that this will have for independent research opportunities and independent review.

12.2.1 Site Investigation Programme and Model Development

SKB has, in recent years, conducted important work in this area. A new site investigation programme for the biosphere has started. Important work has been done to increase the understanding of processes and properties of the site-specific ecosystems. This will provide important basic material for safety assessment. In spite of the new efforts, substantial basic data for safety assessment will be missing, both with respect to source terms and radionuclide behaviour in the biosphere.

There has been a high level of activity on developing new models for radionuclide dispersion in the biosphere. Previous models such as BIOPATH and PRISM have been developed and alternative process-based models – based on system ecological principles – have started to be developed and tested.

The question of whether today's biosphere conditions can be used as site selection criteria in connection with the siting of a repository for very long-lived waste has been the subject of

discussion, in the light of biospheric changes in connection with variations in climate, land uplift etc. For very long timescales, the geosphere offers a very stable barrier function. However, for shorter timescales (which apply in the case of land-based facilities and activities such as transportation which is connected to the repository), it is important to take into consideration biospheric conditions at the site. In the case of the repository itself, there is also naturally an initial period where (current) biospheric conditions are of importance to safety. SKB maintains that it is taking the biosphere into consideration in site selection. SKB has, for example, identified a number of biosphere-related factors which are being mapped at the sites in question.

12.2.2 Environmental Monitoring

KASAM assumes that an environmental monitoring programme will be established for the control of the repository environment and that this control is being initiated already at the site investigation stage in order to obtain comparable data on the original state of the environment. The programme must be designed so that any impact from the repository can be distinguished from natural variations in the environment. In KASAM's view, it is important that further research and development should investigate the premises for choosing measurable parameters and organisms/species that can comprise suitable indicators for impact on the biosphere in connection with modelling and monitoring.

The way in which reference values have been derived for the different parameters should be explicitly described in the report. In this context, KASAM has observed that uncertainties still remain regarding how "SSI'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.

12.2.3 Transport Processes

Radionuclide transport to the biosphere, including to humans, primarily occurs through the groundwater flow, which passes through the repository. For such transport to occur, the repository barrier system must be defect, for example, due to fabrication defects in the copper canisters containing the spent fuel, or as a result of canister corrosion over a long period of time or through other damage to the canister. The groundwater is in contact with different water systems such as wells, swamps and wetlands, inland lakes, watercourses as well as coastal water and seawater. The groundwater can also contaminate arable land with radionuclides via groundwater transport to the cultivation zone and via irrigation.

In an impact assessment of leakage from a deep repository for spent nuclear fuel, it is the dilution volumes in the different water systems of the biosphere that largely determine the consequences of a release, in the form of radiation dose, to humans and to animals. Another way for radionuclides from a repository to reach humans is via sedimentation on sea and lake bottoms which, after future land uplift, could dry out and then be cultivated for food production.

In terms of possible transport to the biosphere, it should be maintained that KASAM, in previous reviews, has stated that conditions in the interface between the bedrock and soil layer is a neglected research area, which needs to be activated due to its importance to radionuclide transport in the groundwater. In general, it can be said that a delay on the order of hundreds of yeas of radionuclide transport can be expected in the actual interface before a balance is achieved between the inflow of radionuclides from deep groundwater and the outflow of these substances via the groundwater to the biosphere.

RD&D Programme 2001 refers to the SAFE Project (safety assessment of SFR in 2001) where interactions in the boundary layer between the groundwater in the bedrock and superficial groundwater have been studied. SKB states that it will conduct

field studies into groundwater capacity to follow conductive layers in quarternary deposits (with possible discharge near the shoreline).

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

KASAM's view, now and in the previous review, is that it is necessary to investigate and describe the composition and properties of the surrounding biosphere to asses the protective capabilities of a repository and the possibility of complying with the requirements that SSI stipulated (in the SSI FS 1998:1 regulations with a background and comments in SSI Report 99:03). Furthermore, in KASAM's opinion, as in its previous review of the RD&D programme, the importance of present-day local biospheric conditions and discharge areas to site selection must be illustrated.

12.2.4 Need for Greater Knowledge of Hydrological Relationships

In KASAM's view, a deeper understanding of the hydrological relationships between a deep repository for spent nuclear fuel and ecosystems concerned is very necessary. This knowledge is necessary in order to make a reliable assessment of the transport pathways and transfer rates to the biosphere in the calculation models. Such an account should specify the areas where surface water or groundwater can be assumed to be affected by releases from the repository. The report should also contain an analysis of radionuclide transport from the bedrock to the soil (from geosphere to biosphere).

12.2.5 Terrestrial and Aquatic Ecosystems

SKB states that the terrestrial ecosystems: agricultural land, forest and mire, are characterized by the fact that they have a groundwater level that is near the ground surface. Therefore, the dominant transport processes from the groundwater up to these systems are root uptake, capillary force and the fluctuation of the groundwater level. Together with wells, mire and other wetlands are important recipients at the sites under consideration. In a very long-term horizon, which is the case with a repository for spent nuclear fuel, major changes will occur at the repository site. This applies to soil layers, hydrological conditions and the biosphere.

In KASAM's view, the proposed ecosystems (forest, mire and sediment) are well justified with respect to these changes as well as possible accumulation effects and increased exposure. However, in the continued discussion, attention should be focussed on the need to improve knowledge of other ecosystems, particularly agricultural land.

The agricultural ecosystem is of considerable importance for the transfer of radionuclides to humans via foodstuffs. Uptake in forestry products, such as fungi (primarily mycorrhizal) and wild animals can result in significant radiation dose contributions via foodstuffs. Mosses and sediments belong to systems where there is a reason to expect radionuclide enrichment.

In connection with previous reviews, KASAM pointed out the importance of studying the variations in biosphere parameters over time and of better describing what happens during the initial years after the closure of a spent nuclear fuel repository.

In RD&D Programme 2004, SKB states that the SAFE Project has developed time-dependent biosphere models and made a first attempt to describe the first 1,000 years.

The section on new knowledge specifically discusses the development of a new type of transport model, which is based on growth, uptake of nutrition and evaporation from the plants as alternatives to root uptake factors. This is an interesting

development, but it could also be dangerous and provide results that are directly misleading. For example, in addition to the factors mentioned, the cesium uptake is also regulated by the potassium concentration in the soil, the strontium uptake by the availability of calcium and the radium uptake by the barium levels etc.

The aquatic ecosystems comprise running water, lakes and seas. In the discharge areas, the radionuclides will pass through sediment layers and will, themselves, become sedimented. In the short term, this can reduce the radionuclide flow but, in the long term, radionuclides can accumulate only to be released later. Considerable basic research is being conducted into water chemistry, seasonal dynamics, the development of system ecological models, stirring of the sediment caused by animals, inventories of fauna and flora on shallow bottoms, models of sedimentation environments etc.

12.2.6 Importance of the Choice of Ecosystems

In KASAM's view, the ecosystems proposed in RD&D Programme 2004 are important from the standpoint of radiation protection. In KASAM's opinion, deeper knowledge should be gained about agricultural lands (including land used for the cultivation of energy crops) as ecosystems, particularly taking into consideration future cultivation of previously accumulation bottoms in watercourses, lakes and seas as well as the use of mire which can contain increased quantities of radionuclides. In the rest of the report, it is important for all relevant main types of ecosystems to be included in order to create the largest possible basis for selecting ecosystems for further evaluation.

12.2.7 Radionuclides and Other Substances

Released radionuclides can affect the entire biosphere. The safety assessment also takes into account other parts of the biosphere apart from humans, now in the form of more realistic process-oriented descriptions than before.

KASAM assumes that the overall environmental impact statement which will be prepared in accordance with Chapter 6 § 5 of the Environmental Code will also contain a quantification of the risks associated with chemical-toxical effects of leaching substances.

In RD&D Programme 1998, SKB stated that it had not managed to present a realistic description of the risks that a deep repository for spent nuclear fuel would entail for humans and the environment. In RD&D Programme 98, KASAM would have liked to see an analysis of causes and a proposal for what SKB intended to do to rectify this situation. KASAM also noted that SKB's work in the area of biosphere studies had until then been limited and emphasized the importance of presenting a clear description of the biosphere, particularly with respect to the interest of the general public in this aspect.

KASAM finds that RD&D Programme 2004 is clearer with respect to further investigations into the biosphere. However, attention should be drawn to the need for clarity in continued risk communication with the public.

12.2.8 Application of the Biosphere Models

SKB is currently conducting extensive development work into biosphere modelling. KASAM notes that the biosphere models should be applied to radionuclide turnover as well as to other substances which, for example, through their chemical toxicity, can affect the environment. KASAM has also noted that the reporting of results from the biosphere studies should be designed with respect to public interest in understanding the

risks associated with a deep repository for spent nuclear fuel compared with other risks in society.

12.2.9 Monitoring in and around the Repository

In its review of RD&D Programme 1998, KASAM referred to SSI which, in its review of the programme, noted that monitoring of a closed repository was still an open question. SKB had mentioned very little about the control of repository performance. KASAM considered this to be an important issue in terms of providing factual information to the public and considered that it was important for the authorities to formulate their requirements on the issue.

12.3 KASAM's Conclusions

- KASAM supports the overall goals of the biosphere programme to describe, with a modern knowledge base, the most important processes in the biosphere from a radiological standpoint as well as to provide adequate scientific support to judge the environmental consequences of the construction and operation of a repository.
- In KASAM's opinion, the biosphere models should be applied to the turnover of both radionuclides and other substances that, for example, through their chemical toxicity, can affect the environment.
- In KASAM's view, RD&D Programme 2004 is clearer than previous programmes with respect to further studies of the biosphere.
- KASAM considers that SKB must, as soon as possible, clarify the importance that biospheric conditions will have in a siting discussion. The integration of the biosphere into the other parts of the safety assessment is not clear.

- KASAM shares SKB's view that it is important to convey the company's knowledge to both Swedish and international research groups in order to obtain viewpoints and the necessary independent peer review.
- It is positive that SKB is raising its ambitions. However the fact that society is gaining fewer and fewer opportunities for independent review of results is a threat to credibility. The Government should, as soon as possible, focus its attention on the ongoing funding of Swedish research in the area and the consequences that this will have, in the near future, for independent research opportunities and independent review.
- KASAM also considers that the results from the biosphere studies should be presented taking into account the public's interest in understanding the risks associated with a deep repository for spent nuclear fuel compared with other risks in society.
- In KASAM's opinion, it is important that an environmental monitoring programme for the control of the repository environment should be established.

13 Climate

13.1 Background

The climate changes continuously. It is often difficult for us to distinguish temporary changes from long-term changes. Also short-term changes can affect precipitation and the groundwater level as well as the water levels in the oceans and, thereby, the shoreline. More drastic changes can result in permanent ground frost (permafrost) and inland ice. On the timescale that is relevant here, namely hundreds of thousands of years, the Scandinavian climate was previously characterized by recurrent ice ages. The climate has varied between 1) glacial conditions, 2) permafrost and 3) temperate/boreal conditions (as is the case now). An important part of SKB's work is to attempt to analyze and understand the future environmental and climate changes in the Nordic region and how these can affect the planned spent nuclear fuel repository. Since RD&D Programme 2001, SKB has initiated studies of the bottom conditions and hydrology of the Scandinavian continental ice sheet and has conducted studies into shoreline displacement since the last ice age.

13.2 KASAM's Considerations and Evaluation

KASAM's comments mainly refer to Chapter 21 of RD&D Programme 2004.

The impact of climate changes on conditions down to repository depth and, thereby, on the risk of radionuclide transport to the biosphere, is of interest to assess with respect to different siting alternatives.

The work on climate issues has so far primarily concentrated on long timescales of up to 100,000 years or more. KASAM would like to point out that climate changes in a shorter time frame of a few hundred years or up to 1,000 years could also be of interest, bearing in mind the risk of global warming and the rising water level in the oceans. A climate study for the Olkiluoto region in Southwestern Finland shows that, with the worst case scenario, the sea water level will increase by 10 m in 1,000 years, which will only be partially compensated for by land uplift. This could have a significant impact on a coastal repository and could be one reason for investigating an inland siting of a repository in parallel (for example, in Hultsfred). Increased precipitation also results in rising groundwater levels.

The studies conducted on long timescales have focused on the effects of glaciation. Numerical ice sheet modelling is a key project in SKB's programme. This work is being conducted with a high level of ambition and in a professional and effective manner.

However, it might be possible to deal with some of the details in another manner than at present. It is understandable that SKB has chosen the Weichsel period as an analogue for possible future glaciations and climate scenarios since this period represents the most recent ice age and we therefore have most of our information from this period. However, Marine Isotope Stage (MIS) 11 is the climate period that is most similar to our current period with respect to insolation and, thereby, also future glaciation scenarios (and carbon dioxide concentration, CO_2). This interglacial (namely, the period between two ice ages), about 400,000 years back in time, can now be analyzed in greater detail than before, due to fact that the new EPICA ice core drill in the Antarctic has gone down to a depth representing more than 700,000 years. It is understandable that these data,

which were published in 2004, have not been included in the report. However, SKB should nevertheless have pointed out that the last ice-age cycle deviates considerably from the forthcoming insolation cycle. Due to the relatively weak future insolation, climate factors can therefore play a considerably greater role than they did during the Weichsel period. Therefore, KASAM expects SKB to discuss MIS 11 in future scenarios.

With respect to shoreline displacement and an improved understanding of the earth's crust, ice loading, sea water levels etc., KASAM considers that it is not sufficient to only analyze these variables using mathematical empirical functions. This does not teach us anything about the underlying processes. Instead, more advanced geophysical modelling is necessary, where geophysicists, in co-operation with geologists and glaciologists, prepare an overall model. This work must be based on a geophysical/glaciological model which is shown to be suitable for the Fennoscandinavian geological data available from the last ice-age cycle. It is worth pointing out that, in recent years, new shoreline displacement curves have been and will be published, not only from Uppland but also from Norrland, almost directly in connection with the land uplift centre.

KASAM finds it surprising that the geophysicist, who has the greatest knowledge of the Fennoscandinavian region's response to glaciations, Kurt Lambeck in Canberra, is not cited in the geophysical sections. Of those who have attempted to model the varying ice cover in the last ice-age cycle, he is the one who has taken geological data into account to the greatest extent. Lambeck and his group are also the geophysicists who have published the most on the Scandinavian continental ice sheet. It should therefore be possible to make much better use of their unique geological knowledge than has so far been done. It is also difficult to understand that SKB has not continued to become involved in building a Nordic shoreline database. Data currently exist which indicate young (less than 9,000 years) substantial land uplift anomalies in Southern Sweden. This should be of

interest for SKB. The confirmation and detailed mapping of such faults require a large shoreline database.

Another aspect that should be investigated is how fast climate changes alter repository conditions. It is known that the climate change seen over the past 100 years is not, in any way, unique. Severe and more rapid changes have been seen since the last ice age, not to mention further back in time. Therefore, it is also excellent that SKB now supports research on climate evolution over the past 2,000 years.

An additional task of interest for researchers in this area is to investigate the likelihood of human activities delaying future glaciation phases. This could be done by using different CO_2 scenarios versus future insolation levels in the Northern Hemisphere. Another question of interest is: What is the likelihood of vertical mixing of the oceans being interrupted, with the result that glaciation starts in Northwestern Europe while global temperatures are high? This scenario has been formulated by model developers as a possible consequence of a substantial increase in CO_2 levels.

13.3 KASAM's Conclusions

- It is satisfactory that SKB really wishes to investigate issues relating to subglacial drainage/hydrology and permafrost. With its work, SKB can contribute to new research findings in this area.
- KASAM would like to point out that climate changes in a shorter time frame of a few hundred years or up to 1,000 years could also be of interest, bearing in mind the risk of global warming and the rising water level in the oceans, increased precipitation and rising groundwater levels.
- Traces of ice ages besides the most recent, should also be studied and taken into account in SKB's continued work on the climate issues.

14 Social Science Research

14.1 Background

Since RD&D Programme 2001, a separate chapter, "Social Science Research" has been added to SKB's report.

RD&D Programme 2004 specifies eight research projects in four research areas that SKB considers to be relevant to the nuclear waste issue and the municipalities.

A committee of social science and behavioural science researchers was appointed to be responsible for the scientific quality and relevance of the projects and to ensure that the projects are awarded to suitable researchers.

According to SKB, the purpose of this research is to:

- Obtain a broader perspective of the societal aspects of the nuclear waste programme.
- Provide deeper knowledge and a better body of data as a basis for site- and project-related studies and analyses.
- Contribute data and analyses to research on the societal aspects of large industrial and infrastructure projects.

According to SKB, the main focus is applied research and, preferably, it must be possible to use the results practically, for example, as a basis for licence applications and environmental

impact statements in connection with the licensing of the nuclear waste facilities that SKB plans to construct.

SKB states that scientific publication will be achieved and that the research results will also be reported in an easy-to-read, popular form.

14.2 KASAM's Considerations and Evaluations

KASAM's comments mainly refer to Chapter 22 of RD&D Programme 2004.

In its review of RD&D Programme 2001, KASAM indicated the need for qualified social science research on nuclear waste issues. KASAM's judgement was based on the feasibility study municipalities' request that SKB should pay more attention to the societal and democratic aspects of the nuclear waste issue. Therefore, it is with satisfaction that KASAM now notes that SKB, in autumn 2004, has initiated a social science research programme.

14.2.1 SKB's Social Science Research Programme

The research programme focuses on four areas, which have been identified by researchers and different reviewing bodies as relevant and central to the continued work on the nuclear waste issue, especially with respect to the preparation of the Environmental Impact Statement (EIS). The four themes that have been highlighted are:

- Socio-economic impact.
- Decision-making processes.
- Public opinion and attitudes – psychosocial effects.
- Global changes.

In the first phase, eight different projects relating to these themes are being financed.

In KASAM's view, it is a deficiency that the theme of global changes is only being investigated to a limited extent in the first phase. This is particularly the case, in view of the fact that SKB, in the plan of action presented in Appendix A, talks about rapid, radical and unpredictable societal changes which should be taken into consideration in connection with disposal safety. Furthermore, it is unclear to which extent the societal research programme is related to existing knowledge gaps that are relevant for the Environmental Impact Assessment (EIA) – the process of preparing the Environmental Impact Statement. However, since the first final reports from these research projects are not expected to be ready until autumn 2006, it is not meaningful to present further viewpoints on the individual research projects at this stage.

KASAM has noted that SKB has made an official announcement concerning the availability of research funds for the social science research programme. This approach is in agreement with KASAM's view. Competition among researchers for research funding is an accepted way of enlisting the best expertise to resolve a research problem.

Bearing in mind the interest that KASAM has shown for a long time in societal research relating to the nuclear waste issue, it is natural for KASAM to follow the continued development of SKB's social science programme with interest. In a proposal from December 2003, prior to the research policy bill that was submitted in spring 2005, KASAM emphasized the need for social science research in the interface between environment, sustainable development, town and country planning and decision-making processes. There is every need to, once again, emphasize this.

14.3 KASAM's Conclusions

- KASAM is satisfied to note that SKB has initiated a social science research programme and will follow SKB's work in this area with great interest.
- KASAM would like to see SKB provide an account of how the results from the social science research programme will contribute to filling the need for knowledge in the nuclear waste area, for example, in helping to prepare the Environmental Impact Statement. (See also KASAM's conclusions in Chapter 3.)

15 Alternative Methods

15.1 Background

The Swedish strategy for the management of spent nuclear fuel is direct disposal. Therefore, the main work in the area focuses on developing and building a geological repository where the spent nuclear fuel can be isolated from the biosphere (the living environment of humans and other living creatures) for hundreds of thousands of years, namely until the radioactivity has decayed. This is the basis of the Swedish KBS-3 concept. The Government has stated that SKB should use this method as a premise for planning the site investigations that SKB has been conducting for more than three years.

The Act on Nuclear Activities (1984:3) stipulates that anyone who has a licence to conduct nuclear activities is to be responsible for ensuring that measures are adopted to safely manage and dispose of nuclear waste arising in the activity. The Environmental Code (1998:808) stipulates that the best available technology should be used (Chapter 2 § 3) as well that alternative methods should be investigated and reported in the Environmental Impact Statement (Chapter 6 § 7) which should be submitted along with the applications for evaluating permissibility/licensing in accordance with the Environmental Code and the Act on Nuclear Activities.

Already at an early stage in the development process for disposal, it was clear that alternatives were necessary if the

KBS-3 concept, for some reason, could not be implemented. In its decisions on SKB's research programme, the Government pointed out that SKB should continue to monitor technological developments concerning different alternatives for the management of spent nuclear fuel. In its decision concerning RD&D Programme 2001, the Government has also assumed that issues concerning the alternative to be reported in the Environmental Impact Statement should be subjected to in-depth consideration in connection with the consultation stipulated by Chapter 6 of the Environmental Code.

In its review to the Government on RD&D Programme 2001, KASAM stated that the evaluation of the alternative issue requires that the basis for decision-making should be well supported, including an evaluation of partitioning and transmutation (P&T) as a possibly comparable method, which in turn assumes an up-to-date status report on P&T. KASAM stated that it was important for SKB to actively take developments into account and proposed that the Government request that SKB present a more detailed basis for evaluating SKB's financial support for research and knowledge acquisition in the P&T area. KASAM also considered that SKB should be open to the possibility that such increased work within EU-financed research on P&T, which was discussed at the time, could lead to an increase in Swedish work. KASAM also proposed that the Government should examine the possibility of revoking § 6 and modifying § 5a of the Act on Nuclear Activities with the aim of promoting research in the nuclear area, which could contribute to alternative solutions for the management of spent nuclear fuel.

15.1.1 SKB's RD&D Programme 2004

SKB plans to continue to follow and support, with about SEK 5 million per year, basic research in P&T which is being conducted in Sweden (at the Royal Institute of Technology,

Stockholm, Uppsala University and Chalmers Institute of Technology). SKB also intends to follow international research in this area. The Swedish researchers involved are also participating in several EU-funded research projects on P&T. SKB has indicated the possibility of participating in international projects, especially EU projects.

15.2 KASAM's Considerations and Evaluation

KASAM's comments mainly refer to Chapter 23 of RD&D Programme 2004.

15.2.1 Premises for P&T

In "Nuclear Waste State-of-the-Art Report 2004" (SOU 2004:67), KASAM dealt with the issue of P&T as an alternative to disposal. The account is intended to show how P&T could be used in different ways to treat spent nuclear fuel from Swedish nuclear power plants. According to the account, the following conditions must be met for it to be possible to apply the method in Sweden:

- The Swedish policy on the use of nuclear power and disposal of nuclear waste as well as the Act on Nuclear Activities must be changed, or Sweden must rely on purchasing these services from abroad.
- The development of P&T into an industrial technology requires extensive work over a long period of time (at least 30 years, according to the EU's research and development plan). The development work must therefore be conducted through international co-operation. This also applies to the Swedish research and development work.
- Four completely new types of nuclear facility must be developed: an accelerator, a reactor, a reprocessing plant and a fuel fabrication plant. All of these facilities must work

efficiently together (with efficient separation of short and long-lived radionuclides), with a high level of safety for personnel and the environment and at a reasonable cost.
– Only when prototypes of these facilities are in operation, in 20 to 30 years, can a more exact evaluation be made of efficiency, safety, cost etc. Only after this is done, is it meaningful to decide whether P&T is of interest as a method on which to focus.
– P&T requires the construction of at least two reactors of a new type in order to manage to transmute Swedish nuclear waste for a reasonably long period of time (100 years).

15.2.2 Advantages and Disadvantages of P&T

Focusing on P&T would mean concentrating on nuclear technology and this has associated advantages and disadvantages.

Advantages:

– P&T is based on known principles and scientific facts. No scientific breakthrough, such as in the case of fusion (hydrogen power) is necessary.
– For most of the transmuted nuclear waste, it is assumed that the radioactivity will be able to decay to non-hazardous levels within about 1,000 years. This can be compared with the several hundred thousand years needed for spent nuclear fuel which has not been reprocessed or transmuted to be equally as non-hazardous. This simplifies the construction of a nuclear waste repository and reduces the risk of radioactive releases from the repository. This line of reasoning assumes that remaining quantities of long-lived radionuclides in the main fraction will be very small. However, it should be emphasized that also, in the case of P&T, facilities of the same type as in the current Swedish nuclear waste

programme will be needed even if the repository can be made considerably smaller and not require the same level of sustainability over time.
– Focusing on P&T means that nuclear competence can be maintained for a long time.
– Through the transmutation process, the quantity of plutonium that could be used for nuclear weapons manufacturing is used up at the same time that the energy can be used. (However, compare with the following point).

Disadvantages:

– P&T technology, in the form that includes plutonium combustion in the form of MOX fuel, requires reprocessing before combustion. This increases releases to the environment and increases the risk of nuclear proliferation. The Swedish policy is not to reprocess spent nuclear fuel.
– The new reactors could be constructed in Sweden. However, it is uncertain if this would be acceptable during a period when nuclear power is being phased out. The new reactors could also be constructed outside Sweden, although this would assume that another country is prepared to support such an arrangement. Such a move could be perceived as a departure, to some extent, from the principle that each country must manage and dispose of its own waste.
– It is hardly technically or economically feasible for Sweden to construct the partitioning facility or facilities required for P&T. One premise is therefore that partitioning can be carried out jointly by countries in a number of European facilities.
– The quantity of material transported within Sweden and abroad will increase. This could result in increased risks.
– The management of high-level waste would increase, which means risks for increased radiation doses for those working in the facilities.

– In order for P&T technology to be reasonably cost-effective, the reactors that are constructed must also be used to generate and deliver electricity. However, P&T can be expected to result in a significantly more expensive management of nuclear waste than the direct disposal that is now being planned, even with power production. Swedish estimates show that if the cost of direct disposal is about 5 % of the cost of the produced power, the corresponding cost for waste management through P&T would be about 30 % of the electricity production costs. According to the same source, the subsequent higher electricity production cost would roughly correspond to the cost of alternative energy sources such as wind and biofuel.

15.2.3 KASAM's Overall Evaluation of P&T

The use of P&T for the management of Swedish nuclear waste is a question for future generations. With present-day knowledge of this technology, it is not acceptable to interrupt or postpone the Swedish disposal programme on the basis that P&T is a possible alternative. On the other hand, this potential alternative for the future reinforces the requirement that the repository should be designed so that retrieval of the waste is possible. According to the ethical principles that KASAM and others have established, each generation should manage their own waste and not force future generations to develop new technology to solve the problems. Therefore, it is reasonable for resources to be set aside for further research on P&T. This research can also result in exchange which is of value within other areas, such as nuclear physics. Swedish P&T research should be co-ordinated with the research and development that is being conducted in other countries. To allocate resources for further P&T research at this stage would also be in line with the approach that our generation should give future generations the best possible conditions to decide whether they would like to choose P&T as a method to

manage spent nuclear fuel instead of restricting the choice to direct disposal alone (in accordance with the KBS-3 method).

15.2.4 Deep Boreholes

In connection with the review of RD&D Programme 2001, KASAM stated the opinion that disposal in deep boreholes (at a depth of between 2 and 4 km in the bedrock) was not a realistic method. The possibility of retrieving the spent nuclear fuel with such a disposal method would be almost non-existent and, therefore, demonstrating such a disposal method would also present significant difficulties. As SKB states in RD&D Programme 2004, it would also be difficult to assess the thermal conditions and the hydraulic transport conditions at great depths.

15.2.5 KASAM's Overall Evaluation of Alternative Methods

In connection with its review of RD&D Programme 2001, KASAM stated that disposal in deep boreholes cannot be considered to be a sufficiently realistic alternative for environmental licensing. Furthermore, P&T can hardly be used in this context, since technical assessments of what can be achieved will not be available within the next two decades. It is important for SKB to consider other alternatives to the KBS-3 method which can be expected to be technically feasible and it is important that this can be demonstrated in connection with environmental licensing.

KASAM has previously stated its opinion that alternatives – which are to be described in the Environmental Impact Statement in accordance with Chapter 6 § 7 of the Environmental Code – to the KBS-3 method should be identified from within the category of repositories built in the

uppermost kilometre of the bedrock. KASAM still upholds this conclusion.

15.3 KASAM's Conclusions

- In KASAM's opinion, with present-day knowledge of possible alternatives to the KBS-3 method, there are strong reasons to continue current research and development work focusing on direct disposal in accordance with the KBS-3 method. In KASAM's view, it is not acceptable to postpone the Swedish disposal programme on the basis of the specified alternative methods as possible technologies.
- With respect to possible future progress in P&T research, SKB should, in the continued RD&D programme, focus its attention on the possibility of designing the repository so that the spent nuclear fuel can be retrieved.
- KASAM considers that it is reasonable that SKB is following, with great attention, and supporting ongoing research and development work on P&T in and outside Sweden.
- It is important for SKB to study alternative methods that can be expected to be technically feasible and that this can be shown in connection with environmental licensing.
- KASAM would like to remind the Government of the revision of the Act on Nuclear Activities that KASAM proposed in "Nuclear Waste – Research and Technique Development; KASAM's Review of the Swedish Nuclear Fuel and Waste Management Co's (SKB's) RD&D Programme 2001" (SOU 2002:63, pp. 106-111).

16 Decommissioning

16.1 Background

The planning of a future decommissioning of Swedish nuclear power plants is dealt with in general in Chapter 24 of SKB's RD&D Programme 2004. According to this chapter, a timetable for the decommissioning of nuclear power plants has not been established and the owners of nuclear power plants are currently planning for operating the plants for 60 years or more. It is also stressed that the estimates of the cost of decommissioning are updated on an annual basis and that SKB is using a reactor operating lifetime of 40 years as a basis for the estimates (with the exception of Barsebäck 1).

Chapter 24 of RD&D Programme 2004 also contains the conclusions that SKB has drawn from the viewpoints expressed in connection with the review of the corresponding chapter in RD&D Programme 2001, as well as new knowledge gained in recent years.

Under the heading, "Programme", three overall goals are specified for SKB's work in the decommissioning area. These can be summarized as follows:

– Ensure that knowledge and technology for decommissioning are developed in good time before detailed planning of the decommissioning work starts.

- Carry out costs calculations, as a basis for accumulating funds for dismantling.
- Ensure that the radioactive waste from decommissioning can be properly managed, transported and disposed of.

The focus of the programme for the forthcoming six-year period will mainly be the following:

- Studies regarding the disposal of whole reactor pressure vessels and other large components.
- An update of decommissioning studies previously carried out. A more extensive, total decommissioning study is being conducted.
- Estimates of the dose budget for the decommissioning of nuclear power plants.
- The management of inactive waste (quantities, disposal, reuse).
- An overview of decommissioning logistics. Examine the consequences of extending operation from 40 to 60 years. Plan for the phase-out considering the fact the resources for the phase-out will be limited.
- Preliminary safety assessments of a repository for short-lived decommissioning waste (coordination of final repository for operational waste with the final repository for short-lived decommissioning waste).
- Work on a preliminary evaluation of long-term safety in the disposal of long-lived low and intermediate-level waste will begin at the end of the period.

16.2 KASAM's Considerations and Evaluation

KASAM's comments mainly refer to Chapter 24 of RD&D Programme 2004.

A decision to close operations at a nuclear power plant leads to extensive measures, including the decommissioning/

dismantling of different systems and buildings as well as land remediation. The planning of the future use of the area is decisive for the extent of the restoration work. Various alternatives may be relevant, from continued electricity production, other industrial activities or housing construction to land cultivation such as agriculture and forestry. However, regardless of the future land use, the operator must adopt measures so that anyone coming to the area in future does not run the risk of harm from radiation originating from the nuclear activity previously conducted.

KASAM observed, in its review of the corresponding account in RD&D Programme 2001, that issues relating to the decommissioning of nuclear power plants are not controversial from a technical/scientific standpoint (SOU 2002:63, p. 113). KASAM still upholds this view.

On the other hand, KASAM is critical to the fact that more attention has not been given to decommissioning issues in RD&D Programme 2004. This particularly applies to issues concerning cost estimates for the decommissioning of nuclear power plants that must be prepared some time in the future.

These issues have come more into focus as a result of the Government's decision in December 2004 that the right to operate the nuclear power reactor, Barsebäck 2, to generate nuclear energy should be revoked at the end of May 2005. These issues are also discussed in the final report of the Commission of Inquiry into Financing "Responsibility for Paying for Nuclear Waste" (SOU 2004:125) and in KASAM's review statement on the final report.

Surveys conducted by the IAEA and the OECD/NEA show that a large number of nuclear power plants around the world will reach the 40-year operating lifetime in the period of 2015-2025, and that issues concerning different aspects of decommissioning have consequently gained increased international attention. Decommissioning of nuclear power plants is currently being implemented in several countries, such as Germany. KASAM assumes that SKB and the Swedish reactor

licensees will successively acquire knowledge from such ongoing decommissioning work.

There are a number of more general aspects of decommissioning issues for which in-depth studies must be carried out in the next few years. Some of these issues are of such a nature that initiatives should be taken by the Government, and in other cases by the reactor licensees.

One issue concerns requirements, in accordance with EC directives and the Environmental Code, concerning the preparation of Environmental Impact Statements in connection with the phase-out of nuclear power and the forthcoming decommissioning of nuclear power plants. According to the Ordinance (1998:899) on Environmentally Hazardous Activities and Health Protection, a licence is required in accordance with Chapter 9 of the Environmental Code (1998:808) for "activities through which nuclear power plants or other nuclear reactors are decommissioned or dismantled, from the time that the reactor is shut down to the time that the reactor has ceased to exist through the permanent removal of all nuclear fuel and other radioactive material from the site." In accordance with Chapter 6 of the Environmental Code, an Environmental Impact Statement (EIS) must be attached to an application for such a licence. The EIS must be prepared in consultation with specially affected individuals, the general public and affected municipalities, authorities and organizations.

In the Government's decision of December 2004 concerning the revoking of the right to operate Barsebäck 2 to generate nuclear energy, the Government found that it is neither up to the Government nor the operator to ensure the preparation of an EIS as a condition for the closure of the reactor. On the other hand, it is clearly stated in the decision that the operator must prepare an EIS as a basis for decommissioning or dismantling the reactor.

In KASAM's view, it is obvious that a large-scale nuclear phase-out, which includes the decommissioning of nuclear power plants, will have environmental consequences. The issue

of whether or not an EIS is needed covers both energy policy and legal aspects. In KASAM's view the Government should take the initiative to ensure that relevant environmental policy, energy policy and legal issues are investigated in greater depth.

The Government also has overall responsibility for ensuring that universities have access to the educational and research resources that are needed to ensure that the decommissioning of nuclear power plants can be conducted in a safe manner. The same also applies to the other parts of the programme for the management of radioactive waste, transportation of nuclear waste and nuclear substances and for the management of accidents, terrorist threat and terrorist action directed at nuclear facilities.

Other general issues should primarily be handled by the reactor licensees. Issues relating to decommissioning logistics are specified as an area for work in SKB's programme for the coming six-year period. KASAM sees a need for SKB to devote increased attention to strategic issues of this type. One example is the question of whether all types of repositories for decommissioning waste should be completed before the decommissioning of a reactor starts. Another example concerns the process for the selection of a site for a repository for decommissioning waste. In RD&D Programme 2004, SKB states that "the short-lived waste from decommissioning of nuclear power plants will be disposed of in an extension to SFR" (p. 326). SKB also states that long-lived decommissioning waste will finally be "emplaced in a special repository, which is planned to be built for example at SFR but at a greater depth" (p. 325). In KASAM's view, SKB should consider whether these plans to extend the operations at SFR are compatible with the regulations of the Environmental Code concerning how the selection of a site for a repository for decommissioning waste should be carried out. SKB should shed light on these issues in RD&D Programme 2007.

As far as the problem of the cost estimate is concerned, KASAM has the following opinion.

RD&D Programme 2004 states that, as an overall goal of the coming six-year period, SKB intends to conduct an update of previously conducted decommissioning studies and carry out a more comprehensive, total decommissioning study. KASAM assumes that these studies will also include cost-related issues. These cost estimates must be of a high quality. They are an essential part of the input data for the annual government decisions concerning fees for the reactor licenses in accordance with the Act (1992:1537) on the Financing of Future Expenses for Spent Nuclear Fuel etc. If the costs are underestimated systematically and for a long period of time, there will be an increasing risk that adequate funds will not be accumulated. If this happens, the financing system will not be able to fulfil its purpose as intended.

There are additional reasons why KASAM emphasizes that it is important that SKB and the licensees should critically evaluate the cost estimate for the decommissioning of Swedish nuclear power plants that the company has so far presented in different contexts and upon the basis of which funds are now being accumulated. International comparisons show that, as a rule, the results of the cost estimates from Sweden, as those from Finland, are based on a far lower cost level than those estimates prepared in other countries. Even if it is very difficult to compare cost estimates from different countries, it is necessary for SKB and the Swedish reactor owners to put more resources into safeguarding the quality of the estimates carried out.

Finally, KASAM has observed that the reference list for Chapter 24 only contains two publications. In KASAM's view, a very relevant reference, namely the report "Structure of the Decommissioning Plan for Nuclear Facilities, "Guideline", SKB R-04-43" is missing from the list. The reference list should also include important international publications focusing on decommissioning issues, especially recently published conference papers and surveys published by the IAEA and OECD/NEA. Examples of this type of publication include the documentation (published in 2003) from an IAEA conference in

October 2002 in Berlin, "Safe Decommissioning of Nuclear Activities: Assuring the Safe Termination of Practices Involving Radioactive Materials". Recently, the OECD/NEA also published "The Decommissioning and Dismantling of Nuclear Facilities – Status, Approaches, Challenges (2002), Decommissioning Nuclear Power Plants – Policies, Strategies and Costs (2003)" as well as "Strategy Selection for the Decommissioning of Nuclear Facilities – Seminar Proceedings, Tarragona, Spain 1-4 September 2003".

16.3 KASAM's Conclusions

- As in its review of RD&D Programme 2001, KASAM considers that issues relating to the decommissioning of nuclear power plants are not an area that is controversial from the technical/scientific standpoint.
- The Government should ensure that greater light is shed on issues relating to the need for Environmental Impact Statements for a large-scale phase-out of nuclear power, including decommissioning of nuclear power plants. The meaning of EC directives and regulations of the Environmental Code need to be clarified prior to the decommissioning of nuclear power plants.
- The Government should be aware of the fact that the ongoing reduction in research resources in certain areas means that there is a risk of a lack of availability of expertise in radiation protection, which is needed in connection with the decommissioning of nuclear power plants.
- Planning by SKB and the licensees now needs to be conducted in greater detail, including within de-commissioning logistics.
- SKB needs to critically evaluate previously prepared cost estimates for future decommissioning work.

17 Low and Intermediate-level Waste

17.1 Background

In addition to spent nuclear fuel, low and intermediate-level waste (LILW) is generated by the operation (and later decommissioning) of nuclear reactors. SKB's facilities for nuclear waste currently comprise the repository for short-lived LILW (SFR), the Central Interim Storage Facility for Spent Nuclear Fuel (CLAB) and the transportation system including the ship, Sigyn. The repository for waste from the decommissioning of nuclear power plants and the decommissioning of other nuclear activities (need to be used in about 2020, according to SKB) will be added at a later stage. The plan is to deposit the short-lived decommissioning waste in an extension of SFR. A separate repository for long-lived waste is planned to be completed by about 2045. An interim storage facility is being planned for core components. Parts of the system for LILW are also being used for waste from Studsvik and other waste suppliers.

In the review of RD&D Programme 2001, a request was made for a better account of how the decommissioning waste will be managed, especially the large quantities of low-level waste that are expected. In the case of long-lived waste, certain nuclides were identified as being of particular interest (such as chlorine-36 and molybdenum-93). The safety authorities considered that the repository for short-lived waste should be ready by 2015.

The authorities also stated that the safety assessment needed to be developed. In its review, KASAM emphasized the importance of SKB conducting the research and development activity necessary in order to characterize (namely identify the properties for) the LILW and to develop safety assessment methodology for these waste types.

17.1.1 SKB's Programme

In RD&D Programme 2004, SKB maintains that many of the studies that are being conducted are applicable to both short and long-lived waste.

In the case of short-lived waste, SKB's premise is that a repository for decommissioning waste would be ready when decommissioning starts on a larger scale (2020).

In the case of core components (containing long-lived radionuclides) a separate interim storage facility is being planned as a complement to CLAB, where such waste can also be stored.

The overall goals of SKB's work on LILW for the period of 2005-2010 are to:

- Put into operation a system for dry interim storage of core components to relieve the load on CLAB.
- Prepare for future safety assessments.
- Develop handling and storage of the waste in co-operation with the nuclear power plants.
- Carry out preliminary safety evaluations for the final disposal of short-lived operational and decommissioning waste in SFR.
- Study the prospects for a shallow repository for very low-level decommissioning waste.

According to SKB, during the period of 2005-2010, research activities will be conducted to provide a basis for future safety assessments. The planned activities focus on the following studies:

- Further studies of diffusion and sorption of radionuclides in high-pH concrete and rock.
- Model development for concrete degradation.
- Reactions between leachate from concrete and the surrounding gravel in the repository.
- Field studies and investigations of natural analogues of alkaline concrete environments.
- Corrosion of metals in concrete environment.

17.2 KASAM's Considerations and Evaluation

KASAM's comments mainly refer to Chapter 25 of RD&D Programme 2004.

As in its review of RD&D Programme 2001, KASAM would like to emphasize that LILW (both short and long-lived) can have highly varying characteristics and the characterization and documentation of these waste types is an important issue. Safety evaluations for LILW can be of a more complex nature than the relatively more homogeneous waste type represented by spent nuclear fuel.

KASAM supports the programme for research that SKB has presented but would like to emphasize that SKB should also focus its development work on safety assessment methodology taking into account the highly varying characteristics that LILW can have. The safety assessment should not only be used to judge the safety of a repository but also as a tool for identifying and focusing on necessary research (for example, the need for further studies of the long-term durability of concrete in different environments, effective methods for handling and cleaning contaminated land etc.).

KASAM would also like to emphasize the need for the planning of siting and facility construction to take into account all of the links between activities and facilities (for example, the timetable for decommissioning and the timetable for the construction of necessary facilities) so that an overall plan that is rational and safety-oriented is achieved.

Although it may seem as though there is much time for this planning, experience has so far shown that siting processes can be more time-consuming than planned. For some of the waste facilities needed, SKB has identified sites. For decommissioning waste, SKB assumes that SFR will be extended. The interim storage of long-lived low and intermediate-level core components is assumed to be carried out in a facility next to CLAB. A site has not yet been identified for a repository for long-lived LILW.

KASAM does not criticize the plan that SKB has so far reported. However, KASAM would like to emphasize the need for taking all aspects into account in connection with planning, especially the links mentioned above. This also applies to safety and radiation protection as well as general environmental aspects on a regional and national perspective, so that an adequate overall plan for the entire waste system can be achieved. In KASAM's view, SKB should present a more in-depth analysis of the reasons behind its plan, for example, with respect to the issue of interim storage of core components. The closure of Barsebäck 2, which has now been decided by the Government, is additional justification for revising the plan.

KASAM also considers that it is necessary to create an effective national system for the disposal of all radioactive waste – nuclear waste and non-nuclear waste ("IKA" waste)[1]. Therefore, it is important for SKB, which is the dominant actor with respect to the management of radioactive waste, to also take into account in its planning the needs that arise in

[1] See also KASAM's statement to the Ministry of Environment, March 23, 2004, dnr 3-04, about the IKA Commission of Inquiry's final report, "Radioactive Waste in Safe Hands" (SOU 2003:122).

connection with IKA waste, even if (the financial) responsibility formally lies with the producers of this waste. For society as a whole, it is also vital to ensure a suitable management of historical waste and waste for which no one is legally responsible. KASAM also considers that other characteristics of the waste besides ionizing radiation must be taken into account by SKB, for example, the biological and chemical aspects of the waste. The extent to which this affects planning should be taken into account.

17.3 KASAM's Conclusions

- KASAM is positive to the programme for research on issues concerning LILW that SKB has presented, but would also like to emphasize the value of safety assessment as an instrument for identifying and focusing the research conducted in the programme.
- KASAM underlines the need for having a system of facilities that are necessary for waste management and disposal, where the links between the parts and activities of the system are analyzed so that planning and siting are conducted in a rational manner.
- KASAM considers that it is necessary for a national system to be created, not only for the sake of waste from nuclear power production but also for radioactive waste from non-nuclear activities ("IKA" waste).
- KASAM considers that also other characteristics besides ionizing radiation, such as chemical and biological characteristics, should be taken into account both for nuclear waste and "IKA" waste.

KASAM

STATENS RÅD FÖR
KÄRNAVFALLSFRÅGOR
National Council for Nuclear Waste

KASAM – the Swedish National Council for Nuclear Waste – was established in 1985 and is an independent committee attached to the Ministry of Sustainable Development.

KASAM's mandate is to study issues relating to nuclear waste and the decommissioning of nuclear facilities and to advise the Government and certain regulatory authorities on these issues.

KASAM's members are independent experts within different areas of importance for the disposal of radioactive waste, not only within technology and science but also within areas such as ethics and the social sciences.

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

An important activity carried out by KASAM is that of providing a forum for diffrent viewpoints and for experts in Sweden and abroad on the topic of nuclear waste and related issues. A number of seminars on various themes 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 and other matters – which the Swedish nuclear power companies present every years. This report is KASAM's review statement on the Swedish Nuclear Fuel and Waste Management Co's (SKB) RD&D Programme 2004,"Programme for Research, Development and Demonstration of Methods for the Management and Disposal of Nuclear Waste, including Social Science Research".

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