Report 2007:6e from the Swedish National Council for Nuclear Waste

KASAM
STATENS RÅD FÖR KÄRNAVFALLSFRÅGOR
National Council for Nuclear Waste

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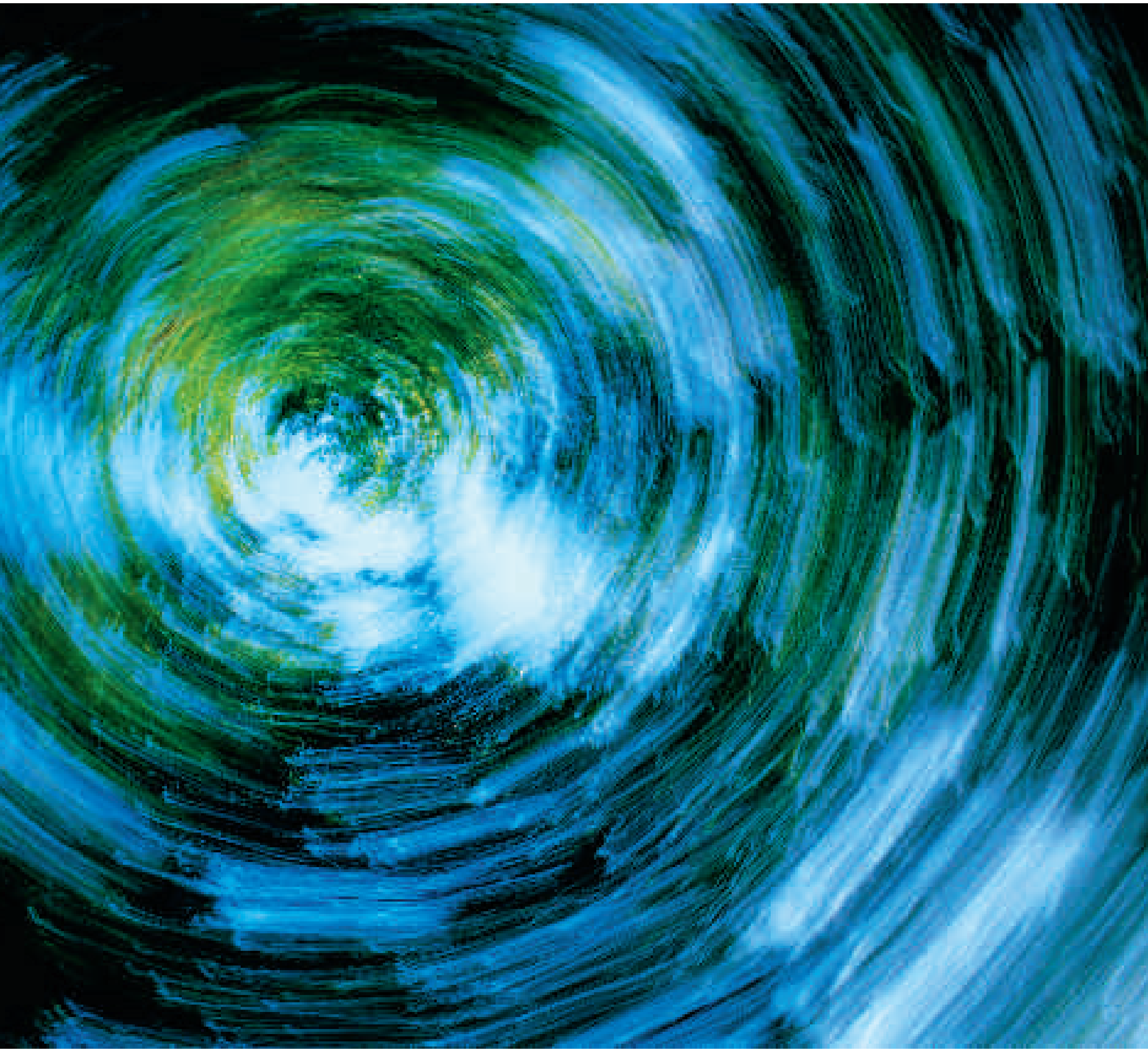

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An alternative for final disposal of spent nuclear fuel?

Report from KASAM's question-and-answer session on 14–15 March 2007

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Swedish National Council for
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Preface

In the autumn of 2006, the Swedish Nuclear Fuel and Waste Management Co (SKB) applied for a permit to build an encapsulation plant, and is planning in 2009 to apply for a permit to build a final repository for spent nuclear fuel. This is an important point of departure the Swedish National Council for Nuclear Waste (KASAM) in its activity planning, so that the Council can provide active and effective support to the Government in its processing of these applications.

An important part of this work is identifying the vital issues from different perspectives and making arguments and other information transparent by clarifying technical issues and values for decision-makers and the public. Furthermore it is very important to bring about a dialogue on these issues between the actors who are of central importance for the preparation of the application and the actors who are otherwise affected by the decision. This dialogue is important from both a knowledge perspective (identifying important issues and making sure they are analyzed and discussed) and a democratic perspective (concerned actors must be given an opportunity to make their voices heard and the issues must be explained in a way that is comprehensible to all categories of actors).

In the autumn of 2006, KASAM therefore initiated a transparency programme aimed at accumulating knowledge and strengthening KASAM's role as an advisor to the Government by making strategic issues transparent. The transparency programme should also serve as a resource for other stakeholders in the future licensing process.

The first step in the programme was to meet different actors in the nuclear waste field to solicit viewpoints on what issues should be addressed in the programme. The result was a list of issues varying in nature (everything from detailed scientific issues to issues of principle in the decision process).

"Deep boreholes" has recently received attention in the public debate as an alternative to the KBS-3 method for disposing of the spent nuclear fuel. In accordance with the wishes of the municipalities of Oskarshamn and Östhammar, SKB and the Swedish NGO Office for Nuclear Waste Review (MKG), KASAM therefore decided that these matters need to be made more transparent. The Swedish Nuclear Power Inspectorate (SKI) and the Swedish Radiation Protection Authority (SSI) also lent their support to this theme for the question-and-answer session.

On 14–15 March 2007, KASAM therefore held a hearing for the purpose of thoroughly examining deep boreholes as a method for the final disposal of spent nuclear fuel. Some of the questions that were raised were: What are the technical, geological and hydrological premises and possibilities? What are the risks from different viewpoints and what values underlie different views of the potential and suitability of deep boreholes?

This hearing is the first in a series of seminars and question-and-answer sessions within the framework of the transparency programme. A programme for future transparency projects is available on KASAM's website www.karnavfallsradet.se.

Stockholm, August 2007

Torsten Carlsson
Chairperson

Contents

1 Introduction

The KBS-3 method has been developed by SKB over a period of some 30 years and is the method for final disposal of spent nuclear fuel which the industry advocates and for which SKB will seek the necessary licence and permits. The method was accepted by the Government in a decision from 2001 as a "planning premise" for the site investigations which SKB is conducting to find a site for a final repository for Sweden's spent nuclear fuel (Government decision of 1 November 2001). The same decision also underscored "that final approval of a specific method for final disposal cannot be given until a decision is made on applications under the Environmental Code and the Nuclear Activities Act for a permit to build a final repository for spent nuclear fuel". But the Government statement from 2001 has given the KBS-3 method special status in the method selection process.

"Deep boreholes" has recently received attention in the public debate as the main alternative with which the KBS-3 method should be compared. In 2006, SKB and the Swedish NGO Office for Nuclear Waste Review (MKG) published separate reports on deep boreholes in which they arrived at different conclusions in the question of whether development work should continue on this alternative.

Since one of KASAM's tasks is to provide information and create arenas for critical scrutiny and discussion of various aspects of the final disposal issue, a hearing on deep boreholes was held on 14–15 March 2007. The purpose was to thoroughly examine the concept as a method for final disposal and to discuss how far development in the area had come and whether further research is desirable. Both facts and values behind the arguments for and against the concept were to be discussed. Presentations would also provide information on the technical, geological and hydrological premises and possibilities. A further intention was to discuss what risks may be associated with this concept.

This report is a summary of the seminar. KASAM has made a selection of contributions and questions from the debate that took place on the basis of their relevance to the purpose of the seminar.

The report generally follows the chronological lecture-and-debate format of the seminar, but has been edited according to different issues rather than according to when different persons spoke.

Chapter 2 describes a number of premises and criteria in the Environmental Code's and the Nuclear Activities Act's requirements on alternatives reporting. The chapter also contains a description of what the deep borehole concept entails and a discussion of the geoscientific premises. In addition, the chapter describes how different values can influence the choice of final disposal method.

Chapters 3–6 describe and discuss technology and long-term safety, the viewpoints of the supervisory authorities on deep boreholes and safety philosophy via lectures followed by questions by KASAM's questioners and the audience.

On the evening of 14 March, representatives of the seven parliamentary parties discussed their preparations and standpoints for an upcoming national debate on the final disposal of nuclear waste. This discussion is also reproduced in the report as Chapter 7.

The main points from a concluding panel debate and discussion are presented in Chapter 8.

In conclusion, Chapter 9 contains some reflections on various arguments proffered during the question-and-answer session, questions on which agreement seems to exist, and where there are differences of opinion.

Speakers' presentations and other contributions are available on KASAM's website: www.karnavfallsradet.se.

2 Background: Formal requirements, values and geological prerequisites

2.1 Requirements on alternatives reporting

Tuija Hilding-Rydevik, KASAM

In 2006, KASAM held a seminar on what Swedish legislation requires when it comes to alternatives reporting and a seminar on decision processes leading to the construction of a final repository for spent nuclear fuel.[1] Tuija Hilding-Rydevik summarizes the results of the seminars:

The decision process is mainly governed by two laws: the Environmental Code and the Nuclear Activities Act (the provisions of the Planning and Building Act are not discussed here, but must also be complied with). The regulations issued by the Swedish Nuclear Power Inspectorate (SKI) and the Swedish Radiation Protection Authority (SSI) are also applicable. SKI has also issued general recommendations and SKI guidelines on their regulations.

The Environmental Code is based on a number of general rules of consideration and talks about what material is required as a basis for decisions, in particular the environmental impact statement (EIS) that is to be appended to an application for a building permit or an operating licence. There are provisions stipulating that the environmental impact statement must contain an account of "alternative sites, if such are possible" for the activity or the

[1] Nuclear waste – which alternatives should be reported? (KASAM Report 2006:1, in Swedish only), and Final disposal of spent nuclear fuel – regulatory system and roles of different actors during the decision process (KASAM Report 2007:1e).

measures to which the application pertains, as well as accounts of “alternative designs”. Furthermore, the environmental impact statement must contain an account of the consequences if the proposed activity or measure is not implemented, i.e. the zero alternative. The provisions concerning alternatives reporting are, however, designed so that they allow room for economic reasonability assessments – the costs of different alternatives may need to be considered in relation to their benefit. Accounts of different alternatives can, particularly when it comes to large projects, be regarded as an aid, a kind of pedagogical instrument or frame of reference, for the decision-makers. They are intended to provide information to enable the decision-makers to make a carefully considered decision from a holistic perspective where various factors have been weighed in.

The Nuclear Activities Act does not contain any requirements on reporting of alternatives in conjunction with an application for a permit to build a final repository for spent nuclear fuel. It does, however, contain provisions requiring the Swedish Nuclear Fuel and Waste Management Co (SKB) to submit a comprehensive research programme regarding questions relating to final disposal issues every three years. According to the Ordinance (1984:14) on Nuclear Activities, the programme shall be submitted to the Swedish Nuclear Power Inspectorate who, after circulation for comment, reviews it and refers it to the Government for a final decision. In these programmes, SKB has described different alternative methods for final disposal. Both SKI and the Government have commented on the alternatives reports and stipulated requirements on them on different occasions. SKI has furthermore issued regulations containing requirements made on the final repository, for example regarding a multiple barrier system, use of best available technology, and preparation of safety assessments and safety analysis reports. SKI’s general recommendations to these regulations state that the repository site and repository depth should be chosen so that the geological formation provides sufficiently stable conditions for a sufficiently long time.

Regulations issued by the Swedish Radiation Protection Authority (based on the Radiation Protection Act) also contain provisions regarding final disposal, for example when it comes to use of best available technology and application of the concept of optimization of the radiation protection.

"There are some different possible interpretations of how different regulations and laws exactly relate to each other. At KASAM's seminar, the environmental lawyers also expressed different opinions as to exactly what rules apply in the final repository issue," says Tuija Hilding-Rydevik.

How the basic purpose of the final repository is formulated is of great importance for how alternatives are reported in accordance with the Environmental Code.

"What should be included as far as alternatives are concerned is not concretely defined. The question of what the environmental impact statement, including the alternatives report, should look like when SKB applies for a permit to build a final repository is the subject of discussion," Hilding-Rydevik points out.

The purpose or aim of a repository has been formulated by SKB (see Fact box 2.1), but we will not know whether that description agrees exactly with what the public authorities think until an application has been examined. Formulations in different bills may not provide sufficient guidance, according to Hilding-Rydevik. There has, for example, been a change in that the possibility of designing a final repository in such a way that it is technically possible to retrieve the spent nuclear fuel is now being discussed. That possibility hardly occurred to the legislator when the Nuclear Activities Act was enacted.

Fact box 2.1

How SKB describes aim and purpose[2]

SKB's purpose is that a final repository for nuclear fuel from the Swedish nuclear reactors should be created within Sweden's borders and with the voluntary participation of the concerned municipalities. The final repository will be built, operated and closed with a focus on safety, radiation protection and environmental considerations. The final repository will be designed to prevent illicit tampering with nuclear fuel both before and after closure. Long-term safety will be based on a system of passive barriers. The final repository will be established by those generations that have derived benefit from the Swedish nuclear reactors and designed so that it will remain safe even without maintenance or monitoring.

[2] From SKB's application for the encapsulation plant, Appendix A, 3.1 "Aim and purpose", p. 7, in Swedish only.

The KBS-3 method fulfils this purpose. SKB will thereby apply for permits under the Nuclear Activities Act and the Environmental Code for the facilities that require a permit and that are a prerequisite for the final disposal of spent nuclear fuel according to the KBS-3 method.

When it comes to alternatives, the Environmental Code says that direct and indirect effects on human health and animals shall be identified for the alternatives (see Fact box 2.2).

Fact box 2.2
Chapter 6 of the Environmental Code, "Environmental impact statements and other supporting material" (excerpt)

Section 3 The purpose of an environmental impact statement for an activity or measure is to identify and describe the direct and indirect effects of the planned activity or measure on people, animals, plants, land, water, air, the climate, the landscape and the cultural environment, on the management of land, water and the physical environment in general, and on other management of materials, raw materials and energy. A further purpose is to permit an overall assessment of these effects on human health and the environment.

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Section 7 An environmental impact statement shall, to the extent necessary with regard to the nature and scope of the activity or measure, contain the information that is needed for the purpose referred to in Section 3.

If the activity or measures … can be assumed to lead to significant environmental impact, the environmental impact statement shall always contain

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4) an account of possible alternative sites, if such are possible, and alternative designs, together with an explanation of why a given alternative has been chosen, and a description of the consequences if the activity or measure is not implemented.

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At KASAM's seminar entitled "Nuclear waste – which alternatives should be reported?"[3] it emerged that there are different interpretations of the Environmental Code's requirements on an account of alternative sites. Tuija Hilding-Rydevik summarizes:

- The point of departure must be that a site will be selected within Sweden's borders. But it is not clear that merely presenting a comparison between Forsmark and Oskarshamn is sufficient. If there are sites that are more suitable, they may need to be presented.
- The fact that a positive attitude exists among the population in certain municipalities is not in itself sufficient reason to restrict the account to sites in these municipalities.
- Alternative sites must be described on a comparable level, and all the alternatives that are described must be suitable for achieving the purpose of the final repository.
- The choice of site must always comply with the fundamental requirements of the Environmental Code on suitability, but the greatest room for political standpoints is in the choice of site.
- Applicants must explain why certain sites that were being considered have since been rejected.

Both the Environmental Code and SKI's and SSI's regulations require that the best available technology, BAT, is to be used. BAT refers to technology that is industrially available and is not in the experimental stage. It does not have to be on the market in Sweden right now, however. If there is any technology that achieves the purpose better than the KBS-3 method, then it can be expected that a permit will not be given to a repository of the KBS-3 type. The provisions of the Nuclear Activities Act concerning a comprehensive research programme can be interpreted as requiring SKB to develop new technology, if existing best available technology is not considered adequate for achieving the purpose of a repository. A reasonability assessment must, however, be made comparing the benefit with the extra cost of the alternative technology.

SSI's regulations from 1998 say that in connection with the final disposal of spent nuclear fuel, optimization must be performed and the best available technology must be taken into consideration. The concept of "optimization" refers to "keeping the radiation doses to

[3] Kärnavfall – vilka alternativ bör redovisas? (KASAM Rapport 2006:1).

humans as low as reasonably achievable, economic and social factors taken into account." The guidelines issued by SSI in 2005 concerning how these regulations should be applied state that optimization and the best available technology should be used in parallel to improve the protective capability of the repository. They also say that in the event of any conflicts between application of optimization and best available technology, priority should be given to best available technology.

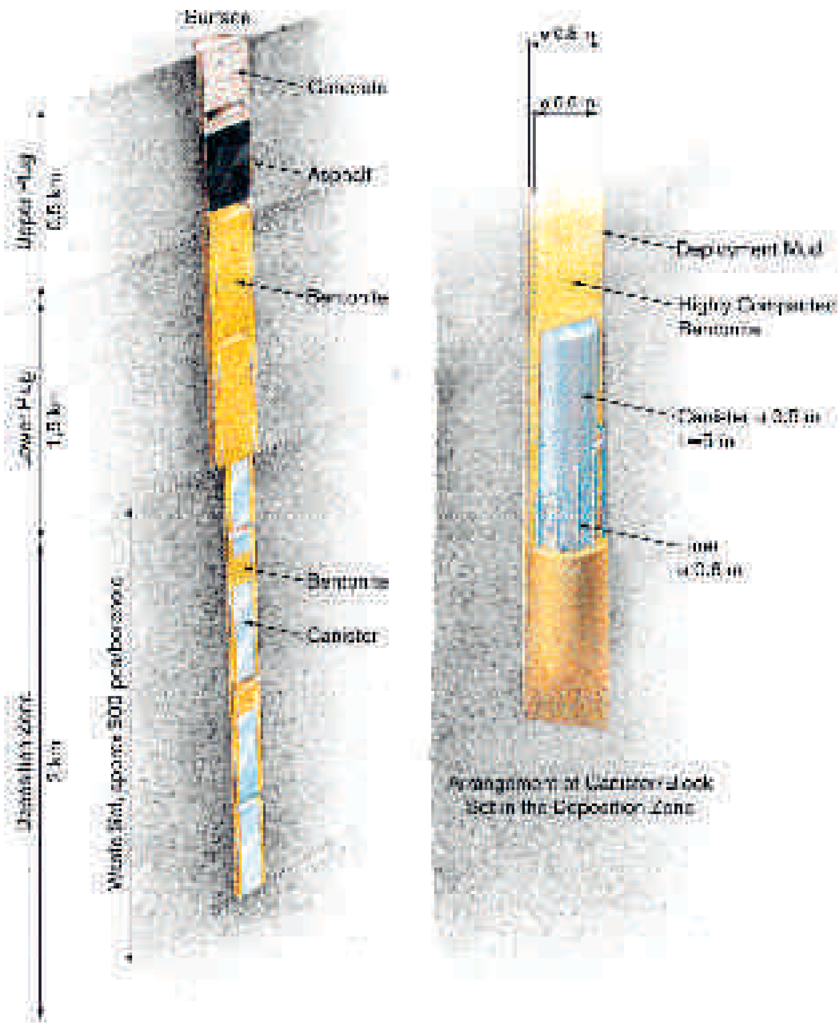
It is not clear in all respects exactly how these provisions are to be applied. In the report on the decision process, KASAM has identified questions in four main areas that need to be further elucidated (KASAM Report 2007:1e, pp. 62–68). Among other things, the areas have to do with coordination of the preparation of the matters within and between administrative authorities, environmental courts and the Government Offices, and the use of certain important expressions and terms such as alternative methods, alternative designs, best available technology, alternative sites, suitable site and best site. Further discussions are also needed on how to describe the underlying purpose of a final repository. However, it may not be possible to achieve clarity in all questions until an application has been received.

2.2 What is meant by deep boreholes?

The deep borehole concept for final disposal of spent nuclear fuel entails drilling a number of holes in the bedrock to a depth of about 4,000 metres (see Figure 2.1). Canisters with nuclear fuel, five metres long and one and a half metres in diameter, are deposited in the boreholes at a depth of between 2,000 and 4,000 metres and interspersed with bentonite clay. The boreholes are then sealed with concrete.

A more detailed account of the technological aspects is provided in Chapter 3.

Figure 2.1 Schematic design of disposal in deep boreholes as developed in the PASS study[4]



[4] "Project Alternative Systems Study – Pass. Analysis of performance and long-term safety of repository concepts," SKB rapport TR-92-43.

2.3 Geological prerequisites for deep boreholes

Jimmy Stigh, KASAM

A repository site with deep boreholes requires a relatively large area, perhaps more than 10 km^2. Jimmy Stigh assumes that while it is possible to construct deep borehole repositories all over Sweden, it is presumably preferable for logistical and cost reasons to dispose of the waste in one place. The choice is then between a "high-temperature repository" and a "low-temperature repository". In the high-temperature case the holes are drilled relatively close together, and the rock is heated by the heat emitted by the spent nuclear fuel. This is regarded as an advantage by some, while others are concerned about the possible consequences of the high temperatures. The alternative is a greater distance between the holes, resulting in a lower temperature. The repository will then require a larger area.

The point of final disposal in deep boreholes is that the groundwater at this depth is stagnant, as well as chemically stable.

"No matter what final disposal method is chosen the waste must be kept isolated for a very long time. We are still talking about over 100,000 years here, in which case the deep boreholes method does not differ from the KBS-3 method," says Jimmy Stigh. But he also points out that KBS-3 is a highly technological project based on the canister lasting 100,000 years. In the case of deep boreholes, the rock is instead assumed to act as the sole protective barrier after the canister has broken apart, which is assumed to take place within a much shorter time than 100,000 years. Then the chemically stable water and stagnant flow are very important factors.

The water flow in the bedrock is expected to decrease with the depth, and the water is virtually stagnant at great depths. Salinity also increases with depth – at 4,000 metres the water is virtually like brine.

Temperature and pressure also increase with depth, as do the stresses in the rock. The temperature increases with the depth at a rate of about 15°C per kilometre. At a depth of 5,000 metres the temperature is between 60 and 105°C.

Stigh shows that fracturing in the rock is greater at the surface, causing high permeability. At greater depth the water flow is mainly restricted to larger, but fewer, fracture zones. At greater depth there are also more shear movements and faults.

"The deep borehole concept is based on a safety strategy where a greater emphasis is placed on the geological barrier in relation to the engineered barriers included in the KBS-3 alternative," says Stigh. At the same time, he says, the body of knowledge on deep boreholes is very limited. This knowledge is based on information from a few deep boreholes at Lake Siljan in Sweden, on the Kola Peninsula in Russia and in the USA.

Stigh asserts that there is no established technology today for depositing canisters of spent nuclear fuel in deep boreholes. Nor is there any technology that can verify that the canisters remain intact, or show what properties the rock has as a buffer around the canisters once they are in place.

"This means that it is not possible today to judge and quantify the barrier function of the canister and the rock with any credibility," he says. Stigh also does not believe the KBS-3 method can be compared with the deep borehole concept without first drilling a hole with the required diameter to the appropriate depth in suitable bedrock in order to obtain fundamental data.

He says that a great deal of research has been done on KBS-3 but very little on deep boreholes. We should therefore discuss whether it is possible, and if so how detailed feasibility studies can be carried out and how accurate position determinations can be performed during the actual drilling.

"There is a big difference between intact and disturbed rock. The rock is damaged in all drilling work. We create transport pathways that didn't previously exist in the rock."

2.4 Groundwater chemistry at great depths

Professor Emeritus Gunnar Jacks of the Department of Land and Water Resources, KTH

Salinity, pH and oxygen are key factors in determining how the environment in the bedrock could affect a final repository for the nuclear waste. These factors are in turn dependent on the inflow of groundwater. According to Gunnar Jacks, a great deal is known about water inflow conditions down to a depth of a few hundred metres, but not at greater depths.

"The water residence time in virgin rock at a depth of 400–500 metres may be thousands or tens of thousands of years, as measured by the carbon 14 method. Down at a depth of 2,000–4,000 metres the water flux is much slower still," says Jacks.

Salinity is a factor that changes greatly with depth. Ordinary rainwater has a salinity of about 10 mg/litre, while it can be ten times as much in a ten-metre deep dug well. In a drilled well at a depth of 100 metres the salinity is around 500 mg/litre.

"At a depth of 1,000 metres the water is like brine, with a salinity of around 50,000 mg/litre. This can be compared with seawater, which has a salinity of 35,000 mg/litre," says Jacks.

He describes the change in pH as much less dramatic. Acidity decreases from a pH of 5 in rainwater to a pH of 8 at a depth of 1,000 metres.

Oxygen is important in this respect. Rainwater is saturated with oxygen, but the concentration decreases rapidly with depth. There is little oxygen in a dug well, while there is hardly any oxygen at all in a drilled well. At a depth of a thousand metres there is an oxygen deficit; the environment is completely oxygen-free at this depth.

We also find different populations of bacteria at different depths in the bedrock. At the surface there are heterotrophic bacteria that live on photosynthesis. Further down the bacteria are autotrophic and live on hydrogen and carbon dioxide.

"These bacteria cannibalize each other and each other's products. They obtain carbon from carbon dioxide and emit methane. They are not as efficient at decomposing substances as the aerobic bacteria," says Jacks. He also points out that the temperature rises with depth and is about 100 degrees at a depth of 5,000 metres. Here conditions are more or less sterile.

Why is the groundwater so saline deep down in the bedrock? Extremely deep groundwaters are often characterized by high concentrations of calcium, sodium and chloride, with a calcium concentration that is often higher than the sodium concentration in Swedish rock types since they are often dominated by calcium chloride. According to Jacks there are several explanations for the high salinity. There may be bubbles in the rock that are filled with fluid and have burst due to movements in the rock so that the saline liquid in the bubbles has leaked out into fractures.

"But there may also be evaporites – sedimentary rocks formed during the dry geological periods by evaporation of the water in seas and lakes and precipitation of poorly soluble salts. These explanations are the most widely accepted ones." According to Jacks it is also possible that salts come from evaporites from rocks that have eroded away. A fourth explanation is that they are residual solutions that have been frozen out of the continental ice sheet.

The reason the pH is relatively stable in the bedrock is that there are buffering minerals in fractures, such as calcium carbonate, that have been formed during the approximately 2 billion year history of the bedrock.

The way different substances are broken down and react with each other (for example by redox reactions) is of great importance in determining the chemical environment in the bedrock. This environment is of great importance for a final repository for spent nuclear fuel, since it will determine how long the canisters may remain intact. Gunnar Jacks explains the connections:

While pH has to do with the flux of hydrogen ions, the redox processes have to do with the flux of electrons that move from one substance to another. An example of a redox reaction is when groundwater, which has high concentrations of dissolved iron (in the form of Fe^{2+}) and has been transported under reducing (i.e. oxygen-poor) conditions, subsequently emerges from the ground and is oxygenated. The dissolved iron is then oxidized (i.e. the iron loses an electron) to iron in the form of Fe^{3}, which forms oxides and hydroxides, which are not water-soluble but are precipitated.

"This is certainly something you have seen in forest streams or springs in the woods. It is thus iron-rich oxygen-poor groundwater that is flowing out, and when it comes into contact with oxygen the iron is precipitated. Rust-red precipitates are then formed, and the water surface may have a blue shimmer like an oil film."

All living organisms – humans, mice, elephants and most bacteria – get their energy from biological decomposition of the organic matter formed by photosynthesis in plants. Decomposition can take place aerobically (in the presence of oxygen) or anaerobically (in the absence of oxygen). In aerobic decomposition, oxygen is the oxidant (the substances that receives electrons), while anaerobic decomposition requires the presence of another substance that acts as an oxidant. Most organisms use oxygen as an oxidant to release energy from the organic substance. When the oxygen runs out, other organisms (bacteria) take over and move electrons to other substances than oxygen.

Gunnar Jacks describes this as a redox stairway that illustrates how different redox and decomposition processes succeed each other with increasing depth in the bedrock, but where and at what depths the different processes occur varies widely, notes Jacks.

"Different steps in the stairway may be only millimetres away from each other. One process may occur in one fracture while a completely different process is taking place a few centimetres deeper in the rock."

According to Jacks, the copper canisters in a KBS-3 repository can be attacked in an oxygen-rich environment as well as one where hydrogen sulphide is present. On the other hand the environment is more favourable for copper if dissolved iron is present. It is in such iron-rich environments that SKB plans to build a KBS-3 repository.

"The chemical environment at the depth for a KBS-3 repository is suitable, at least under undisturbed conditions. The circumstances may of course change when the repository is built. Compared with deep boreholes, the water flux is higher, however," says Jacks. Thus, deep boreholes have lower or no water flux, but much higher salinity, resulting in a more aggressive and corrosive environment.

"Deep boreholes also have a shorter disturbance period, since it is presumably possible to drill a hole, deposit the waste and seal the hole in roughly one year – as compared to 60 years for the KBS-3 system. This is an advantage, since conditions in the rock, including the water flux, are undisturbed over a longer period of time."

2.5 Choice of method depends on facts and values

Carl-Reinhold Bråkenhielm, KASAM

"There are numerous cases where the nuclear power industry and the environmental movement facts argue based on values instead of facts," claims Carl-Reinhold Bråkenhielm. He takes as an example the formulation of the purpose of an encapsulation plant found in SKB's application for a permit for the plant (see Box 2.1).

"The quote first contains a summary of how SKB has interpreted requirements and principles in the legislation, after which SKB makes a clear value judgement in stating that the KBS-3 method fulfils this purpose. Whether the purpose is actually fulfilled is the question to be examined by the regulatory authorities and decided by the Government," he says.

Other actors assert that the purpose may perhaps best be fulfilled by another alternative method, such as final disposal in deep boreholes. The Swedish Society for Nature Conservation and the Swedish Environmental Movement's Nuclear Waste Secretariat (MILKAS) have, for example, questioned SKB's formulation that the selected method fulfils the purpose of the repository. An editorial in the Swedish Society for Nature Conservation's magazine *Sveriges Natur* describes the KBS-3 method as a "superficial" repository (see Fact box 2.4). Such a choice of words also implies a value judgement, says Bråkenhielm, and also says that it is doubtful from a scientific perspective to call KBS-3 a "superficial repository". Saying that it would be irresponsible of the industry to apply for a permit for the method without investigating other alternatives is an even clearer value judgement, he says.

Fact box 2.4
From an editorial in Sveriges Natur *no. 2, 2007*

The nuclear power industry's proposal of a superficial repository (at a depth of 500 metres) is highly dubious from an environmental and scientific point of view. Since the method was launched in the 1970s, safety problems have been revealed and alternatives proposed. At a depth of 3–5 km, there is no mobile water and durability is much greater. But the industry is nevertheless applying for permits without thoroughly investigating other alternatives. Irresponsible!

Bråkenhielm illustrates the distinction between values and facts with an example from upper secondary school philosophy:

"Imagine the words: 'Dusk is the most beautiful time of day.' This is not a statement of fact since the beauty of dusk is not something we can investigate with our senses or prove scientifically. Saying that dusk is the most beautiful time of day expresses a value and the sentence is a value statement."

There are however things we like or dislike, appreciate or dismiss, and there are facts of life that exist whether we like them or not. Bråkenhielm describes facts as objective circumstances that can be established by scientific research. Values, on the other hand, express our likes or dislikes.

"Furthermore, values can be divided into ethical values, which have to do with people, our obligations and motives, and non-ethical values, which relate to objects, processes, states or systems. The statement that SKB is irresponsible is an ethical value judgement. A statement that the disposal method involving deep boreholes is better than KBS-3 is, on the other hand, an example of a non-ethical value judgement."

He asks himself whether the disagreement that exists between SKB and other actors concerns facts or values. Is there disagreement with regard to ethical values or non-ethical values? Superficially, there appears to be disagreement regarding facts, but after having studied various statements from SKB and the environmental movement he says there is in fact agreement regarding facts, but disagreement regarding values.

The factual claim in the quoted editorial in *Sveriges Natur* that there is no mobile water in a borehole repository is followed by a statement by Professor Karl-Inge Åhäll in a report to MKG (see Fact box 2.5). Åhäll writes that deep boreholes are drilled at a depth in the rock where the repository would be surrounded by stably density-stratified groundwater. SKB has investigated deep boreholes on different occasions since the 1990s and most recently through the consulting firm Kemakta. SKB's calculations also show that the deep borehole concept entails very long calculated travel times for groundwater from great depths to the surface.

Box 2.5

Karl-Inge Åhäll in an MKG report[5] *:*

An advantage, compared with a near-surface final repository of the KBS-3 type that is now being planned in Sweden, is that a borehole repository is potentially more technologically robust. This is due to the fact that the deep borehole concept appears to permit such a deep deposition of the nuclear waste that the entire repository area would be surrounded by stably density-stratified groundwater without contact with near-surface levels, while a KBS-3 repository would be surrounded by mobile groundwater in contact with near-

[5] From the summary in Slutförvaring av högaktivt Kärnavfall i djupa borrhål, MKG-rapport 1, 2006.

surface levels. This hydrological difference is of great importance for safety, which is particularly clear in scenarios with leakage of radionuclides.

"There is no real disagreement when it comes to e.g. basic facts about stagnant groundwater at depths of 3–5 kilometres. It can instead be assumed to be a question of values," says Bråkenhielm. The editorial in the Swedish Society for Nature Conservation's magazine says that SKB is irresponsible because they have not examined alternative methods. SKB is on the contrary of the opinion that they have investigated deep boreholes in various studies.

Bråkenhielm also takes up SKB's comments in a television debate in October 2006 when they claimed that disposal in deep boreholes is difficult to check and that the canisters are difficult or impossible to retrieve. SKB also said that the environment is unfavourable for the canister; high salinity and the fact that there is no clay buffer mean that the canister is exposed to a corrosive environment that shortens its life. Nor does SKB believe that the method meets the law's requirement on multiple barriers, since the rock is the only barrier.

Bråkenhielm believes that each of these points is worth studying. Most of them give expression to non-ethical values. But the claim regarding difficulties in retrieving the canisters is associated with the value ascribed to retrievability. The freedom of choice of future generations can be weighed against the desirability of hindering illicit intrusion.

"Åhäll's study for MKG expresses fears similar to those expressed by SKB regarding the fact that deposition in deep boreholes is difficult to check. Åhäll says that research and technical development are needed to prevent problems."

According to Bråkenhielm, there does not seem to be any disagreement between the environmental movement and SKB regarding whether it is difficult to retrieve the canisters from deep boreholes either. The question is instead whether an ethical value judgement is to be considered a valid objection to the deep boreholes alternative.

"There are big differences in what value the actors ascribe to retrievability. Is it good that the freedom of choice of future generations is greater, or does retrievability entail a risk of illicit intrusions that could have severe consequences, leading for example to nuclear weapons proliferation?"

However, he points to deep factual disagreement between the environmental movement and SKB with regard to whether it is possible to obtain reliable data on safety conditions in the deep boreholes. SKB does not believe it is possible to assess safety, while Åhäll is more optimistic about the possibilities of obtaining data.

"When it comes to barriers, SKB writes in the aforementioned commentary that the deep borehole concept does not meet the legal requirement on multiple barriers and that the rock constitutes the sole barrier. However, it can be noted that other judgements are expressed in SKB's other studies (see Fact box 2.6) and that it will be interesting to see whether deep boreholes will be regarded as a single- or multiple-barrier system when SKB submits its application for a final repository in 2009," says Bråkenhielm.

Fact box 2.6
SKB about barriers and deep boreholes[6]:

Even though the real long-term safety in the concept lies in the function of the rock, there are other barriers. The canister will be designed to resist the mechanical force that arises at a depth of four kilometres. The main function of the buffer is to fix the canisters in their positions after deposition. As in KBS-3, several barrier functions are utilized, but the emphasis on the barriers is different. In KBS-3, isolation is guaranteed by the engineered barriers, the canister and the buffer, in combination with the bedrock. In deep boreholes it is primarily the bedrock that guarantees that radionuclides will not reach the ground surface. As at a depth of 500 metres, groundwater is present at a depth of 4,000 metres as well. But it has much higher salinity and lower mobility."

Bråkenhielm thus finds some agreement on the facts, but thinks that the KBS-3 critics perhaps downgrade the possibilities and the value of being able to retrieve the waste and instead emphasize the advantages of stagnant groundwater at great depths. For its part, SKB emphasizes the technical difficulties, deficiencies in safety assessments and the costs of studies of deep boreholes.

[6] Försvarsalternativet djupa borrhål, SKB Rapport R-00-28 p. 7 (in Swedish only).

The differences in opinion regarding deep boreholes seem to stem from a more fundamental disagreement, says Bråkenhielm and points to conflicting perspectives.

"Which facts and values are most important? The conflict may be an ideological one, which is more difficult to solve than simple questions of fact. What is most important: stagnant groundwater conditions or multiple barriers? What is decisive: the impossibility of retrieval or the possibility of retrieval? And what is most desirable: one robust natural barrier or a combination of natural and engineered barriers?

3 Technology and long-term safety

3.1 Deep boreholes – drilling technology

Professor Leif Bjelm (Dept. of Engineering Geology, Lund University) and Gunnar Nord (Atlas Copco) spoke about where drilling technology for deep boreholes stands today and how drilling of large-diameter deep holes is done. Fact box 3.1 summarizes Bjelm's and Nord's presentations. The complete presentations are available at www.karnavfallsradet.se.

Fact box 3.1
Technology for drilling of deep holes

Important parameters in the choice of drilling technology: The crucial parameters are canister diameter, borehole length and minimum deviation from the plumb line.

Drilling methods: Percussion drilling entails that a drill string is rotated at the top while a medium (air or water) is injected into the hole and powers a hammer mounted in the drill string. The hammer hits while the drill rotates. In *rotary drilling*, which is normally used in the oil industry, a heavy drill rod is used. A load is applied to the rotating drill rod to provide force. The two methods have different capabilities today. The percussion drilling method can be used to drill holes with the necessary diameter, but not to the requisite depth. Rotary drilling, on the other hand, can achieve the intended depths, but not the desired diameter. A deep hole can be drilled with a combination of different methods depending on what rock types are encountered. Percussion drilling is normally used in crystalline rock, while rotary drilling is traditionally used in sedimentary rocks. There are other drilling technologies, but they are not relevant for deep boreholes.

Lining of the hole: If the stability of the hole is judged to so poor that there is a risk the hole might collapse, the hole can be lined with steel tubes called casing. Drilling is then interrupted at the predetermined hole depth and steel casing tubes are lowered to the bottom. The tubes are grouted to the rock by cement paste that is injected down to the drill bit and up between the steel tube and the rock wall. There must be liquid in the hole to maintain the hydrostatic pressure to prevent the hole from collapsing.

Hole deviation means that the hole deviates from the plumb line and can occur due to the structure of the rock. If the hole is drilled sharply in towards a foliation (the plane of weakness in the rock), the hole will deviate perpendicular to the foliation. If the hole is drilled in at a low angle to the foliation, the hole tends instead to follow the foliation direction. A hole for a final repository may not deviate more than 1 % from the plumb line. A deviation of 0.5 % means 20 metres in a hole at a depth of 4,000 metres. The amount of deviation has a bearing on how far apart two boreholes must be spaced.

Quantity of waste: There were about 4,500 tonnes of spent nuclear fuel in Sweden in 2007. SKB estimates that the Swedish nuclear power programme will result in a total of about 9,000 tonnes of spent nuclear fuel.[1] The number of canisters required depends on how much waste each one holds, but according to SKB report R-06-58 approximately 13,000 canisters will be needed, which means about 45 boreholes with 300 canisters in each.

Costs: Great uncertainty exists concerning what a borehole would cost to drill. An estimate is that the cost of a borehole could be on the order of SEK 100 million. At the present time there is no other known industry where there is a demand for this type of borehole. The final disposal industry therefore has to conduct the development work and pay the costs.

[1] Table 2-2 in Plan 2007.

According to Gunnar Nord, the technology for drilling a deep borehole repository does not exist today, but it is conceivable with today's knowledge. Leif Bjelm says that the necessary equipment with the required performance already exists, but no proper analyses have been conducted of feasibility. He estimates the cost of a study leading to alternative drilling programmes for different waste parameters to be USD 3–4 million.

3.2 SKB on deep boreholes

3.2.1 Background

Saida Lâarouchi Engström, SKB

SKB has been investigating different methods for the disposal of spent nuclear fuel and publishing the results for more than 20 years. A unique feature of the nuclear waste programme is the research and development programmes which SKB has published every three years since 1986 and which are now called RD&D programmes (Research, Development and Demonstration). The programmes, which are submitted to the Government, describe the research situation and plans for continued research.

"Regulatory authorities, organizations, the Government and others review the RD&D programmes and give their comments. SKB then receives directives from the Government on how we should conduct our further research."

When it comes to other methods for final disposal of spent nuclear fuel, she mentions numerous different studies which SKB has conducted[2] and particularly emphasizes the system analysis that sheds light on different methods and how the method considered to be the most promising for the future (the KBS-3 method) has been selected.[3] Thus, within the framework of its research programmes, SKB has been studying other methods such as deep boreholes for a long time.

[2] RD&D-Programme 86 and RD&D-Programme 89; PASS (Project on Alternative Systems Study) 1993 (TR-92-43); Systemanalys. Val av strategi och system för omhändertagande av använt kärnbränsle, 2000 (R-00-32); Förvarsalternativet djupa borrhål. Innehåll och omfattning av Fud-program som krävs för jämförelse med KBS-3-metoden, 2000 (R-00-28); Djupa borrhål – Status och analys av konsekvenserna vid användning i Sverige, 2006 (R-06-58).

[3] Systemanalys. Val av strategi och system för omhändertagande av använt kärnbränsle, 2000.

"SKB takes its responsibility to investigate alternatives very seriously, and we will submit information on this, including deep boreholes, in our application for the final repository in 2009," she says.

Engström notes that new knowledge has emerged, particularly on drilling technology, but claims that the deep borehole concept is nevertheless associated with fundamental weaknesses which SKB does not believe can be altered by further research and development.

"Locating the final repository deeper down in the bedrock is not a guarantee for greater safety," she says.

Society and SKB share a common view of the principles for disposal of spent nuclear fuel, she points out. Final disposal must be done safely; it must be accomplished within the country's borders; illicit tampering with nuclear material or nuclear waste must be prevented; safety must rest on multiple barriers; undue burdens on future generations must be avoided; and the disposal process must be controlled at every step.

"We have to know what we are doing at all times. In the case of disposal in deep boreholes, we don't know for sure whether the canister and the buffer are intact after deposition and whether they are emplaced in the right position. It is further important to be able to correct mistakes or errors that have occurred during the operating period. It should therefore be possible to retrieve deposited canisters in order to check or repair them."

She does not think that the possibility of controlled deposition or repairs of deposited canisters is satisfactory with deep boreholes.

"If it is later discovered that something may be wrong with one of the canisters that has been lowered into a hole to a depth of 4,000 metres, it is impossible to get it up. We have to reckon with the human factor and assume that things can go wrong. It must be possible to correct mistakes."

Lâarouchi Engström believes that the KBS-3 method fulfils the purposes which society stipulates for a final repository in laws and regulations. The purpose may also be fulfilled by other methods, but SKB believes the KBS-3 method is best.

3.2.2 SKB's point of view

Erik Setzman, SKB

SKB assumes that the Swedish nuclear power programme will be operated for around 40 years. Then a borehole repository would have to have about 50 deep boreholes if each hole holds about 300 canisters in order to dispose of the spent nuclear fuel.

Erik Setzman compares the KBS-3 method with deep boreholes. A KBS-3 repository will be located at a depth of between 400 and 700 metres, while deep boreholes will be drilled to a depth of 2,000–4,000 metres. He asserts that the deep borehole concept entails uncontrolled deposition, while the KBS-3 method entails controlled deposition. In deep boreholes there is only one barrier, while KBS-3 has multiple barriers, both engineered and natural. This repository is also built to withstand external disturbances, unlike the deep borehole concept, which is sensitive to such disturbances. Furthermore, the KBS-3 method is ready to be implemented after 30 years of research, while deep boreholes requires further development.

According to SKB, the final repository will not be safer just because it is located deeper down in the bedrock. On the contrary, the deep boreholes concept involves technical difficulties with drilling technology and deposition, which can perhaps be solved by research, but the difficulties with long-term safety will not be altered by further research.

"The advantage of a KBS-3 repository is that we can see what the rock looks like down in the tunnels, including in the actual deposition holes. We can therefore see where it is suitable and unsuitable to deposit the canisters. In the alternative with deep boreholes, it is not possible to reject unsuitable canister positions, and it is difficult to avoid unsuitable bedrock," says Setzman. He also points out that it is not possible to obtain the same knowledge of the rock around the deep boreholes, and that inspections cannot be performed to the degree long-term safety requires.

"The canister can get stuck in the hole and end up at the wrong depth. It can be damaged when it is deposited, and the risk of this is relatively great. We will therefore not know with certainty whether the canister and the buffer are intact and whether they are in the right position," he says.

The environment at the depth entailed by the borehole alternative is troublesome and aggressive. The salinity is higher, which is on the one hand an advantage in that the groundwater is stagnant at the present time, but can also cause trouble, just like the high temperature and the rock stresses. There is a risk that the canisters will corrode and the function of the buffer will be impaired. There is also a risk of rock breakout, which is when the rock breaks apart so that pieces come loose that could damage the canister. All in all, this means that the repository only has one barrier, the rock.

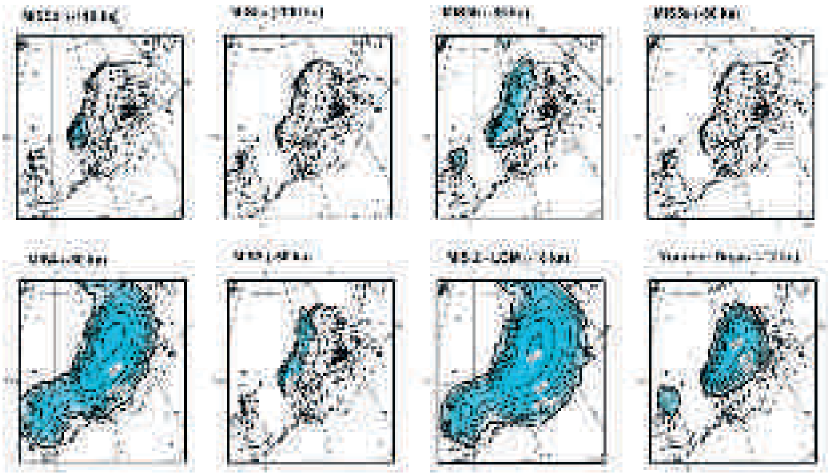
According to Setzman, it is also not known how earthquakes and glaciations will affect the rock and the groundwater, which is currently stagnant. He also points out that if the borehole, the buffer or the canister is damaged, the borehole could become a transport pathway for radioactive material up to the surface.

3.2.3 How can deep boreholes be affected by glaciation?

Jens-Ove Näslund, SKB

"Glacial domain is defined here as when an ice sheet covers the site of the repository. Such a widespread glaciation of Sweden must be taken into consideration when a repository for spent nuclear fuel is built," says Jens-Ove Näslund. This is true no matter what method is chosen. SKB judges that the bedrock will be the only protective barrier left if the deep borehole concept is used when the next ice sheet comes, in perhaps 20,000 to 50,000 years. Clay buffer and canisters in the repository will then be broken apart by the aggressive conditions at such great depths in the bedrock.

Figure 3.1 Extent of ice sheet during the latest glacial cycle in Fennoscandia



Source: SKB 2006. Climate and climate related issues for the safety assessment SR-Can. SKB TR-06-23, Svensk Kärnbränslehantering AB.

Caption: An ice sheet can advance and withdraw several times during the lifetime of a final repository.

The most important processes associated with glaciation are changes in groundwater flow and earthquakes. There is mobile groundwater in the bedrock down to between 500 and 1,000 metres. At great depths, more than 3,000 metres, the groundwater is saline and much less mobile. There is a transition zone between the mobile and the stagnant groundwater, but what this transition zone looks like we don't know. It is very possible that a glaciation would affect the transition zone by moving the zone downward, but we know little about how much it would be affected, according to Jens-Ove Näslund.

"We don't know much about how glaciation affects water flows at great depths," he says and refers to simulations that have been done of sedimentary bedrock showing that the groundwater flow increases during a glaciation at a depth of 2–3 kilometres. Crystalline rock, the kind of bedrock in which a KBS-3 repository is planned to be built, would probably not be affected as much, but model studies indicate that groundwater at great depths may be affected.

"What we know is that the biggest effects on a repository occur during glaciations, regardless of disposal method. During a glaciation the groundwater flow increases compared with periods when no ice sheet is present. This is particularly true when the steep face of the ice sheet passes over the repository, but also when the ice retreats."

According to Näslund, the ice sheet may advance and retreat several times over a repository during a period of 100,000 years. If the transition zone is thereby displaced, groundwater that was previously stagnant may be mobilized. In such cases, the ice sheet affects the borehole repository's only barrier – the rock.

"The greatest uncertainties occur when the repository has become a single-barrier system, with the rock as the only protective barrier. These uncertainties stem from expected changes in groundwater flow in the upper part of the geosphere," he says.

According to Näslund, data compiled from the Swedish national seismic networks show that more earthquakes occur far down in the rock than closer to the Earth's surface. Today around 5–6 times more earthquakes occur at a depth of 2.5–6 km than at depths of less than 2.5 km. Most big earthquakes take place at great depths today as well.

"According to many studies, more earthquakes also occur when an ice sheet advances and retreats. It's probably the same under these conditions, that more earthquakes occur further down in the rock than at the surface, so that a glaciation would give rise to even more earthquakes at depth. The proportion of big earthquakes would also increase." Näslund says that seismologists at Uppsala University expect that the bigger glacially induced earthquakes would usually take place at depths greater than 1–2 km. A repository according to the deep borehole concept is therefore more exposed to earthquakes than a shallower repository, since it is closer to the point of origin of most quakes.

What can earthquakes do that affects a repository? Näslund says that earthquakes cause a volume change in the bedrock due to compression and extension of the bedrock and its fracture system. Observations from Iceland show that because of this, earthquakes can lead to groundwater movements. Theoretically, this should also apply to deep-lying saline groundwaters. In other words, earthquakes can result in the formation of new fractures and transport pathways for the deep-lying saline groundwaters to the ground surface.

"Theoretically, earthquakes could also give rise to a transport of deep-lying saline groundwater towards the surface. Radionuclides could thereby be transported to groundwater flowing near the surface or to the ground surface. A borehole repository, with the rock as the only protective barrier, should therefore be more sensitive to the effects of earthquakes than a KBS-3 repository, which is designed with multiple barriers that keep the spent nuclear fuel isolated from the groundwater and the ground surface in the event of an earthquake."

The probability of glaciation-induced earthquakes also makes it more difficult to avoid unsuitable deposition positions. According to Näslund, it is very difficult or impossible to map fracture zones around a deep borehole with the same degree of detail as around the KBS-3 deposition holes.

"In the KBS-3 method we work with respect distances to fractures or fracture zones in order to avoid unsuitable positions. It is very difficult to apply this principle to deep boreholes, since we will not know what the rock in the near-field looks like with the same degree of detail. This, along with the fact that it costs a great deal to drill a new deep hole if the first one should prove unsuitable, means it is difficult to avoid unsuitable deposition positions that could be damaged by an earthquake. In the KBS-3 concept, on the other hand, we can reject unsuitable canister positions before deposition. The conclusion is that glacially induced earthquakes introduce great uncertainties in the function of the only protective barrier in a borehole repository, since the rock is the only barrier at the time of glaciation when the number of quakes is expected to increase."

Earthquakes can lead to damage in a repository, and not just when ice sheets advance and retreat, but also in today's temperate climate, notes Näslund. The aggregate probability that a geological repository will be damaged increases with time. Even if it is 50,000 years until the next ice age, earthquakes are a risk up until then. A KBS-3 repository is designed to withstand such stresses in the best way.

An ice sheet scenario entails risks in the sense of increased stresses for all types of geological repositories in Sweden. In the current situation it is not correct to say that existing data, regardless of method, show that the risks decline the deeper the waste is emplaced in the bedrock. In discussing these risks, it is necessary to distinguish between different types of repository system and evaluate the performance of their barrier systems as a whole, according to Näslund.

He says that according to present-day knowledge and data, it is highly uncertain whether a repository according to the deep borehole concept could ever be shown to be safe during a glaciation, since only the rock can be counted as a protective barrier at that time. It is SKB's judgement that it is possible with today's knowledge to estimate the size of the stresses for a KBS-3 repository so that the engineered barriers can be designed to withstand the increased stresses during glaciations.

The uncertainties are great concerning what can happen with a final repository at a depth of 2–5 km during a glaciation, says Näslund. Since disposal in deep boreholes means that it is difficult to take credit for any other protective barriers than the rock, the disposal concept is sensitive to the impact of glaciations. These uncertainties are due to the combination of the single protective barrier and the expected increase in glacially induced earthquakes, as well as changes in groundwater flow.

3.2.4 Questions and discussion

Kjell Andersson, KASAM: SKB argues that deep boreholes entails a single-barrier principle, but isn't this a difference in degree rather than a difference in kind? Isn't the KBS-3 method also based on a single-barrier principle where a period of 100,000 years can be managed with technology?

Saida Lâarouchi Engström, SKB: The performance of the barrier must be viewed in the long term. Stresses and uncertainties in connection with glaciations are the same for deep boreholes as for KBS-3. It is therefore important to have protective barriers that ensure function even in the face of such uncertainties. In deep boreholes the environment is aggressive to both buffer and canister. If the canisters can be emplaced at all, the rock barrier can only be counted on for a limited period of time. We should instead view the function of the repository as a whole. KBS-3 has a barrier that protects and lives up to the safety requirements, but we cannot draw the same conclusion for deep boreholes. Even if we put barriers in place, they disappear faster than in a KBS-3 repository.

Kjell Andersson, KASAM: Is it a matter of principle that there should be more than a single barrier?

Saida Lâarouchi Engström, SKB: Existing regulations are derived from science, which says that multiple barriers are needed.

Kjell Andersson, KASAM: The requirement of multiple barriers comes from the field of reactor safety and has been applied to nuclear waste. Is it relevant?

Saida Lâarouchi Engström, SKB: Yes, since a final repository is also a nuclear facility.

Claes Thegerström, SKB: The reason multiple barriers are required is that no knowledge of barriers is absolute. If we only rely on a single barrier, the risks are greater than if we rely on several. The philosophy that is applied in nuclear waste disposal is that one barrier should back up another.

Eva Simic, KASAM: If stagnant groundwater conditions prevail at great depths in the bedrock, can't we make lower requirements on deep boreholes than KBS-3 when it comes to reparability?

Saida Lâarouchi Engström, SKB: The same requirements are made on all methods. KBS-3 is SKB's proposed method for meeting the requirements. We cannot dismiss certain requirements that we have on KBS-3 when it comes to deep boreholes. That would not be legally or scientifically acceptable.

Eva Simic, KASAM: Aren't the requirements designed for the KBS-3 method? The KBS-3 concept was developed at a time when the regulatory requirements had not yet been specified.

Saida Lâarouchi Engström, SKB: That's not how I see it. It was known from the start that multiple barriers were necessary. The principles of reactor safety apply here as well.

Kjell Andersson, KASAM: The deep borehole concept is based on the principle that no other barriers than the rock are needed due to the fact that stagnant conditions prevail. Why should reparability be necessary?

Saida Lâarouchi Engström, SKB: You are assuming that no canister ever gets stuck on its way down in the borehole. If we assume that everything ends up where it should be there are no problems, but no one can guarantee this.

Jens-Ove Näslund, SKB: If we have misjudged the function of the rock and it is not what we thought it would be in 5,000 years and we only have one barrier as in the case of deep boreholes, then we won't be able to retrieve the waste. This is why reparability is important.

Jimmy Stigh, KASAM: We're talking about apples and oranges here. SKB has been working very hard to develop the KBS-3 method, but there are great gaps in our knowledge when it comes to deep boreholes. If we had drilled deep holes 30 years ago and had been able to perform measurements, we could have had another discussion. But now the methods are being compared and evaluated anyway. Saida *Lâarouchi* Engström says that KBS-3 entails multiple barriers, but I think this was emphasized to a greater degree before. Now the canister seems to be so much of a barrier that nothing else is needed, but IF anything should happen there are other barriers.

Gert Knutsson, KASAM: I think what is being said about glaciations is contradictory. According to Jens-Ove Näslund, we don't know how glaciations will affect the rock at great depth. At the same time he says there will be disturbances, that changes will occur in superficial groundwaters that should also affect deeper-lying groundwaters. This seems to indicate that things can happen at great depths?

Jens-Ove Näslund, SKB: I said there were uncertainties in the event of glaciation, but that we don't really know what.

Johan Swahn, MKG: It's interesting to see that SKB is constantly backpedalling when new questions come up requiring further studies. But it is doubtful whether the industry should be conducting the studies. These things should be handled independently in the future.

Saida Lâarouchi Engström, SKB: We are not backpedalling, we are researching and studying. The fundamental weaknesses of deep boreholes are the same as before, and new knowledge says that there are additional problems. The concept is based on shaky safety philosophy principles.

Björn Dverstorp, SSI: Why does SKB categorically claim that deep boreholes is a single-barrier system while KBS-3 is a multiple-barrier system? Saida Lâarouchi Engström says that the environment in deep boreholes is aggressive, but the expected temperature and salinity meet the requirements for a buffer. SKB must also explain why the canister in the deep borehole concept is assumed to be poorer than in the KBS-3 alternative. In the KBS-3 case, SKB assumes copper canisters, which last much longer than the iron canisters that are assumed in the case of deep boreholes. The latter rust much faster.

Saida Lâarouchi Engström, SKB: We have not made any in-depth analyses of how long the canisters will last in deep boreholes.

Claes Thegerström, SKB: In a built KBS-3 repository, we will be careful about achieving the initial state we want to have in the barrier system. We can emplace the waste any way we want it. This cannot be done in the deep borehole repository, which I consider a weakness.

3.3 Some reflections on SKB's attitude

Karl-Inge Åhäll, Professor of geology,
Karlstad University, for MKG

According to Karl-Inge Åhäll, it became generally known in Sweden during the 1990s that groundwaters at great depth in the bedrock can remain separate from groundwaters higher up. This was discovered by a compilation of new research data done by Juhlin et al. on behalf of SKB.

Åhäll points out that the permeability of the bedrock and the density of the groundwater change with depth in the bedrock. This also applies to factors such as salinity, temperature and pressure.

There are normally large groundwater flows in the upper part of the bedrock, but below that level down to a depth of 1–1.5 km there is something we call a hydrogeological intermediate zone with decreasing groundwater movements. The flows in this zone are characterized by weak but relatively stable groundwater movements from inland recharge areas to coastal discharge areas.

The fact that permeability declines with depth in the intermediate zone is assumed to be due to the fact that the pressure in the rock increase so much that the fractures are "squeezed shut" below a depth of 1–1.5 km. Data from Swedish bedrock is sparse and Åhäll does not want to state with certainty that these conditions apply generally.

"Further down in the bedrock there are also fractures, but the pressure there is so high that the fractures appear to be permanently squeezed shut. This leads to a considerable reduction in permeability. Older gneiss and granite bedrock of the type that dominates Sweden at depths of more than 1.5 km is therefore characterized by a general lack of significant water flows. There are exceptions, however, where open fracture systems may carry significant flows, at least locally. But the measurement localities are few and far between, so most hydrogeologists are cautious in their interpretations."

Åhäll says that broad agreement now exists that there is a hydrogeological zonation in the bedrock, as a result of which there is, at least locally, a density-stratified groundwater below 1–1.5 km that may remain undisturbed for millennia. But it still remains to be determined whether large enough areas exist with undisturbed density stratification.

If a repository were to be placed in the intermediate zone, Åhäll says that leaking radioactive substances could not be prevented from reaching the biosphere, since the repository would be surrounded by mobile groundwater in contact with near-surface levels. Radionuclides from the repository would then eventually reach regional discharge areas. If such a repository is placed in a recharge area, the travel times until the radioactivity reaches near-surface levels will be longer than if the repository is placed in a discharge area. Based on this, a siting in both Oskarshamn and Forsmark can be questioned, says Åhäll, since the repository would then be located in a coastal area with regional discharge areas. These sites can therefore hardly have been selected on the basis of scientific criteria, he says, noting that this is remarkable.

He advocates maintaining a critical attitude towards the deep borehole concept as well, even though the repository would then be located below the zone with mobile groundwater.

"The concept assumes, however, that it is really possible to identify sufficiently large areas with density-stratified groundwater, and their existence must also be verified," he says.

"In addition to meeting this basic hydrogeological prerequisite for a borehole repository, methods must be developed for depositing the waste in a safe manner and without permanently disturbing the area's stable density stratification. No one knows today whether these prerequisites can be satisfied within the country."

Åhäll describes the prerequisites for a final repository in deep boreholes in nine points, which he says include geological, hydrogeological, technical, economic and political factors.

The following requirements must be met:

- Political and social acceptance for deep boreholes and for the costs incurred during the project exists during a period of 15–30 years.
- A sufficiently large area with stable density-stratified groundwater exists at a depth of 3–5 km.
- Measurement and analysis technology for borehole measurements exists that can identify areas at a depth of 3–5 km with stable density-stratified groundwater.
- Geodynamic and hydrogeological knowledge exists so that areas can be identified at a depth of 3–5 km where the effects of future ice ages do not jeopardize the long-term safety of the repository.
- Technology exists for precision drilling of both narrow boreholes for probing and wide boreholes for deposition.
- Technology exists for safe deposition of the waste containers and for retrieval of containers during the deposition phase for exchange or tests of material and technology.
- Drilling, deposition of waste containers and sealing of all boreholes can be done without long-term disturbance of the density stratification of the groundwater outside the actual repository area.
- The nuclear waste can be permanently stored at a depth of 3–5 km without heat and radiation effects from the radioactive decay of the waste disturbing the density stratification of the groundwater outside the actual repository area.
- Drilling equipment, waste containers and borehole sealing material are chosen so that they do not promote chemical reactions that lead to gas formation in the repository area.

A crucial condition for a repository in deep boreholes is that it can be built in rock with low permeability and stable density stratification.

Åhäll also says that stable density stratification is crucial for long-term safety since it prevents any large vertical movements of groundwater at great depths, provided that there is no energy input to the area that alters the density stratification. Given that normal Swedish basement rock has no energy sources of a volcanic or other geothermal nature at great depths, there is no energy source that could cause a vertical transport of radionuclides to near-surface levels.

"If a repository is to be built in the bedrock, all levels where the groundwater has contact with the biosphere should be avoided. In other words, the minimum depth is 1–1.5 km, but then it is also wise of course to have a wide buffer zone of another 1–1.5 km, since it is not known how much the density stratification might be affected by a future glaciation, for example," he says. This adds up to a depth of at least 2–2.5 km.

Since both drilling costs and safety seem to increase with depth, there is a conflict of interest here.

"I myself would prefer an emplacement depth of at least 3 km. With today's technology it would be too expensive to deposit waste all the way down to a depth of 5 km, but if the technology continues to be developed even that may be possible."

Åhäll therefore says that good evidence exists today for the existence of stable density stratification in normal Swedish bedrock, and that the hydrogeological prerequisites thereby exist for a final repository in deep boreholes. He no longer considers these conclusions to be controversial. He wants to see more research concentrated on areas without deformation zones and younger dolerite dykes that are geochemically unconsolidated, since they would indicate potential zones of weakness in the bedrock. A further prerequisite for the borehole concept is the development of technology for safe deposition, and this technology development should take place in collaboration with other countries.

He summarizes:

There is a hydrogeological zonation in older continental bedrock. This enables groundwater at a depth of 3–5 km to remain density-stratified for several million years. However, we do not know whether there are sufficiently large areas with stable density stratification in normal Swedish gneiss and granite bedrock.

If we compare geological repositories at different depths, deep boreholes has the advantage of being potentially more technological robust compared with shallow geological repositories of the KBS-3 type.

"This is because the entire disposal area for a final repository in deep boreholes would be surrounded by highly saline, stably density-stratified groundwater with no contact with near-surface levels. A KBS-3 repository would instead be surrounded by mobile, low-salinity groundwater in contact with the biosphere."

Åhäll therefore claims that a borehole repository at a depth of 3–5 km is potentially less vulnerable. This is true for both expected events such as changes in groundwater conditions during future ice ages and for undesirable events such as terrorist actions, technological blunders or major earthquakes in the repository area.

In order to shed light on the importance of selecting a robust final disposal method, he recalls previous technological blunders in the nuclear power sector:

"I remember that not even our specially trained engineers predicted the incidents that occurred in Forsmark in the summer of 2006 or in Barsebäck in 1992. The need for a forgiving technology can never be overestimated. There is therefore a fundamental weakness in the KBS concept in that nothing may ever go wrong, since this type of repository would always be surrounded by mobile groundwater in contact with the biosphere."

Åhäll does not advocate a borehole repository. At least not yet. But he adds that he would if the basic prerequisites for the deep borehole concept could be met.

Questions and debate in response to Åhäll's input

Björn Hedberg, KASAM: You say that the density stratification of the groundwater in the rock will not be disturbed if there is no energy input. But isn't spent nuclear fuel a source of thermal energy input?

Karl-Inge Åhäll: Certainly. But when its effects have been analyzed, the conclusion is that this heat input does not cause any real problems, provided the waste isn't spaced too densely. A relatively fresh SKB report comes to this conclusion.

Eva Simic, KASAM: There are requirements that nothing may go wrong with KBS-3, but shouldn't the same requirements be made on deep boreholes, for example that no canisters may get stuck on the way down?

Karl-Inge Åhäll: Naturally such requirements must be made, and when it comes to the deposition technology in particular, a great deal remains to be clarified beyond what is presented in Harrison's SKB report. The difference is that when the waste has come down to the levels for deep boreholes without disturbing the density stratification, there is greater tolerance for both foreseen and unforeseen events in that the repository would then not be surrounded by mobile groundwater. But there are risks before the waste canisters have arrived in position.

Jimmy Stigh, KASAM: Do you think the high water flows in Gravberg[4] are due to the drilling?

Karl-Inge Åhäll: I think we should be careful about drawing conclusions in this case, since the drilling in Gravberg was not a scientifically controlled project but a speculative financial venture. And as long as there is only data from a single well indicating such a large deviation for the depth to a saline groundwater, it is also conceivable that there are other parts of the Caledonides that do not have as much impact on nearby groundwater flows.

Kjell Andersson, KASAM: It doesn't seem as though MKG's and SKB's reports differ so much scientifically. But value-related arguments are made such as that it is difficult to retrieve a canister in a deep borehole once it has been deposited. This argument is construed as an advantage in MKG's argumentation but a disadvantage in SKB's. The argumentation is value-based and is an expression of what different groups are out to prove. We know what SKB wants – to get its application approved. But what does MKG want?

Karl-Inge Åhäll: I can't answer for MKG. But in general it can be said that you cannot compare different methods in a qualitative sense without first defining the performance criteria for final disposal. Today we have conflicting performance criteria: we are talking about keeping the waste separated but at the same time retrievable. But how should we balance these conflicting requirements? Before this has been established we can't decide which method is better. Thus, the strengths and weaknesses of different methods can be discussed, but absolute value judgements cannot be made. So in order to be able to make more precise comparisons, a clarifying discussion is needed regarding the performance criteria for a Swedish final repository, and KASAM should therefore push to get this discussion going.

Johan Swahn, MKG: The industry has now taken upon itself to define the societal purpose on behalf of all of us. MKG takes no stand on whether deep boreholes or KBS-3 is preferable. The environmental movement has worked for years to try to get more

[4] Exploration wells were drilled in Gravberg in the Siljan Ring in the mid-1980s in a search for natural gas.

studies done. We have seen fundamental hydrological possibilities and potential advantages with deep boreholes and would therefore like to know more about this alternative. We are critical to the fact that this responsibility has been given to the nuclear industry with the support of the Nuclear Activities Act. If the industry doesn't gather sufficient information, we wonder how we should go about getting more information.

Saida Lâarouchi Engström, SKB: I would like to emphasize that during the operating period, reparability – and retrievability as an element of this – is important. We are not talking about retrievability for the purpose enabling future generations to extract energy from the deposited fuel.

When it comes to performance requirements, the regulatory authorities impose requirements on SKB and these requirements serve as a basis for our safety assessments. We in the industry do not define these performance requirements.

4 Have new facts emerged that support or alter previous standpoints regarding deep boreholes? Some reflections

Björn Hedberg, KASAM

"Claes Thegerström has stressed in various contexts that it is SKB's task to come up with a method that SKB believes in. This is perfectly in line with the Environmental Code and the Nuclear Activities Act, which place the responsibility on SKB. Thegerström says that SKB must be allowed to discharge this responsibility and should therefore not pursue any new studies of alternatives. Karl-Inge Åhäll said almost the same thing: that it is unreasonable to demand that SKB should study the alternatives to a reasonable level."

We have also heard from SKB that it would take 30 years and cost at least SEK 4 billion to study deep boreholes to the same level as KBS-3 is at today. Leif Bjelm has stated that there is drilling technology that SKB has not taken into consideration. There appears to be technology for studying the concept to a better level than now, but not to the same level as KBS-3. According to Bjelm, such a study would take about 1.5 years and cost USD 3–5 million, in addition to the cost of the actual borehole.

Karl Inge Åhäll

"Deep boreholes is not an alternative today because it is not possible to judge the concept. It could perhaps be an alternative in the future, but further studies are needed in order to make this judgement. In other words it is important to refine the discussion of alternatives."

Ever since the 1986 R&D programme, SKB has presented alternative designs and methods, but at a varying level. In its reviews, the Government has provided information and viewpoints on the research and has dismissed both a method with long tunnels under the Baltic Sea and deep boreholes. Subsequently the Government has urged SKB to give accounts of both deep boreholes and transmutation. In this way the Government has provided direction.

A consensus exists on many points. Hydrologists and geologists at least agree in some sense as to how we should interpret existing databases. No one actually advocated deep boreholes 5–10 years ago, and perhaps no one does today. But there is a potential in deep boreholes that is worth considering and that is attracting interest today. Some of the objections from 10 years ago are gone, such as that the drilling capacity didn't exist. There is no doubt that the drilling industry has the capability. An interesting formulation by Gunnar Nord is that "the technology is conceivable with today's knowledge". Another is that it is "a very big challenge".[1] There is confidence that this can be managed. Nor is the cost picture any longer an argument against deep boreholes, compared with KBS-3.

It remains to determine whether the basic prerequisites for deep boreholes exist. The politicians said yesterday that there is a need to study alternatives to the same level as KBS-3, but we should proceed stepwise instead. If the basic prerequisites on which the concept must be based do not exist in reality, there is no reason to go any further.

Johan Andersson, SKB

"From what is being said here it appears as if safety is entirely dependent on the canister in the KBS-3 concept. SKB realized back in the early 1980s that there were uncertainties, which is why we included several barriers: copper canister, buffer and good rock, which should interact. Since then we have learned a great deal about the complexity of the system, and today we have a more realistic view of its different parts. This indicates the importance of not selecting a technology based on only one advantage."

[1] SKB Report R-00-35.

I have become increasingly worried about the deep borehole concept. It emerged yesterday that the salinities found in deep boreholes are not much higher than at the depths we are considering for KBS-3. Is the density stratification really as stable as some think? Many water-conducting fractures have also been found 3–4 km down in the basement rock in Lund. In other words, much more thorough investigations than I thought are needed to determine whether the elementary prerequisites exist for deep boreholes.

Olle Olsson, SKB

"We have learned more about drilling. It is possible to drill down to relevant depths with smaller diameters, but we also have to check the reliability of the drilling. Technical problems have so far been common, and a large number of holes would not have been approved for deposition. But in the future it will undoubtedly be possible to increase the diameters to what is needed to emplace canisters."

Building a final repository involves more than just being able to drill; a safe concept entails that radionuclides must not reach the ground surface. We still claim that deep boreholes is essentially based on only one barrier: the rock. We don't know much about this barrier at the present time and will never be able to know much about it at these depths.

Stagnant water means very high salinities. If we look at Laxemar, we see a very saline water, about 8 % at a depth of 1.2 km. Analyses indicate that salinity increases steadily with depth. But at depth we have also seen from isotope analyses that there is some glacial water content. In other words, the water is still flowing. Despite attempts to map the upper boundary for immobile water, we have difficulty finding it.

We have two observations in the country of highly saline water at great depth, in Laxemar and in Gravberg at a depth of 5 km. Should we base our concept on this evidence and be able to confirm from this that it really holds up? We need several decades to get a good idea of deep saline waters, and it will cost more than SEK 4 billion before we know for sure.

We have also worked with the question of earthquakes and want to base the repository on knowledge of the rock in the vicinity of the canisters. We do this in order to be able to check them as well as the buffer and the rock. We want to avoid bad canister positions, which cannot be done in the deep borehole concept, no matter how much we drill and investigate.

There are other weaknesses with deep boreholes as well. We cannot emplace buffer in the hole with the same high density as we can with KBS-3 to protect the canister.

Greater depth does not guarantee greater safety. We can show that KBS-3 is safe and meets the stipulated requirements. In our application we will present alternatives that we have studied and argue that we should let the matter rest there and proceed with KBS-3.

Johan Swahn, MKG

The Swedish Society for Nature Conservation and MKG do not recommend any specific method but want to have the method with deep boreholes more thoroughly studied, since there are researchers who say that deep boreholes could provide better long-term environmental safety than the KBS-3 method. Furthermore, the method could provide better long-term protection against nuclear weapons proliferation. The organizations do not think industry-independent studies of the deep borehole concept are needed. It has emerged that the industry, represented by SKB, has not done its job over the years. An example of particulars that the industry has not determined in a fair manner is what ground surface area would be required for a deep borehole repository. With modern drilling technology, the spacing between the holes at emplacement depth can meet the safety requirements, even if several holes are drilled from the same site.

In the opinion of the industry, further studies are not needed to be able to compare deep boreholes as an alternative to the KBS-3 method so that the alternative method is ready for an application. MKG believes that in order to permit a fair comparison as a basis for decisions by environmental courts, regulatory authorities and the Government, satisfactory answers must be found to fundamental questions relating to long-term safety, reliable technology, and the necessary costs and time. To start with, an independent feasibility study should be done to determine how much time a comprehensive study would take and what it would cost. MKG wants KASAM and the authorities to bring up the question of the need for an independent feasibility study with the Government, for example in connection with the review of the next RD&D-programme submitted by the industry in the autumn of 2007.

Kjell Andersson, KASAM

On MKG's website there is a text that clearly accentuates the advantages of deep boreholes, but not the disadvantages. Nor does it take up the advantages of other methods, so is it not only natural that you are perceived to be advocates of deep boreholes?

Johan Swahn, MKG

Yes, I think we provide a nuanced picture of which questions demand answers.

Saida Lâarouchi Engström, SKB

When SKB submits its background material with the application, it will contain technical advances that have been made with regard to drilling technology as well as our fundamental safety philosophy evaluations on which KBS-3 is based. This material will then be reviewed. It is SKB's mission to do this job, and I don't understand why we shouldn't be allowed to do it or to have the matter examined?

5 What the regulatory authorities think of the deep borehole concept

5.1 Swedish Radiation Protection Authority

Criteria for judging the final repository, SSI

SSI has issued regulations that define a risk standard for the protection of human health. The risk standard contains a quantitative measure, a level that a final repository must not exceed. The annual risk that people will suffer harmful effects, such as cancer, may not exceed one in a million. The safety assessment provides figures for the risk, but the calculations will always be associated with uncertainty.

"It is difficult to extrapolate data and models to a distant future and to know how the people of the future will live. Nor is there any way for us to check how it actually turned out," says Björn Dverstorp. He says that it is not enough for SKB to report dose and risk, the company also has to furnish arguments to convince regulatory authorities and decision-makers to issue permits for the final repository. SKB must, for example, be able to show that they have quality-assured the calculations adequately and used scientific methods.

"How do we know that SKB has adopted all measures and checked all alternatives? How do we know that no shortcuts have been taken?" asks Dverstorp.

This is where SSI's requirements on optimization of the radiation protection and application of the best available technology, BAT, enter the picture. SKB must give an account of the selected site and method in the application. Alternatives must be considered and described. The principle is that SKB should, wherever possible, select the alternative that gives the best radiation protection.

Dverstorp describes SSI's tool for assessing the long-term radiation protection, optimization, that SKB is supposed to use for its calculations. In optimization, the results of the risk calculations are used to evaluate which technical solutions or alternatives best minimize the risks.

"For very long times, especially after a glaciation, a greater emphasis should be placed on best available technology, BAT. This makes it possible to focus on robust indicators or measures of barrier performance, for example how many canisters can break apart or how much radioactive material leaks from the repository. SKB should select the alternative that best minimizes releases from the final repository."

Dverstorp also points out that a reasonability assessment must be made, since BAT cannot be taken to the extreme. Society imposes restrictions in the form of, for example, political decisions. One such restriction is the principle of voluntary municipal participation, which means that SSI cannot require SKB to look for sites in municipalities where the inhabitants are against a repository. There are financial limitations, such as how much money the Nuclear Waste Fund contains. Finally, there are technical limitations, such as the availability of technology or the feasibility of developing technology at reasonable costs.

How are the requirements on optimization and BAT judged?

"There are no quantitatively detailed criteria for such judgements, since we cannot foresee what problems will arise in permit applications and what industry will present," says Dverstorp.

The purpose of alternatives reporting according to the requirements on optimization and BAT is to support the choice of main method by showing that there are no better alternative methods.

Two situations could arise. If an alternative is equivalent to the main alternative, SKB can freely choose between them. If instead the alternative has significant advantages from the viewpoint of radiation protection, the principle is that SKB should recommend it. But here it is nevertheless possible for SKB to choose the poorer alternative, as long as SSI's risk criteria are fulfilled.

"But then a convincing argument must be made explaining what considerations have motivated this choice. Then it is up to SSI to judge the reasons given by SKB, and in the end it is the Government that has to decide whether they are acceptable," says Dverstorp.

"In studying the state of knowledge concerning deep boreholes, SSI has found preliminary indications that the geosphere can provide a very good protective capability. More analyses are required, however," says Dverstorp. "The drilling technology does not appear impossible to develop, but there are some difficult questions concerning how canisters are to be deposited," he says.

In summary, SSI thinks it is worth gathering further material on deep boreholes in order to permit comparison with KBS-3, but this does not mean a fully developed implementation alternative is required. In its permit application, SSI wants SKB to calculate the repository's protective capability based on existing geodata and informed assessments of feasibility, including deposition.

"We also want to have a comparative evaluation against the KBS-3 method with regard to basic protective functions. It is then important to take uncertainties in both concepts into consideration, even though KBS-3 has come further," says Dverstorp.

SSI has not performed a review, but has made a preliminary evaluation of the study SSI contracted Kemakta to conduct.[1]

"It appears to be a good assessment of the basic disposal functions of deep boreholes (VDH), but there are questions that could be clarified better. One question is what why the design life of the canister has been limited to 1,000 years for the borehole repository when the design life of the canister in the KBS-3 method is much longer," says Dverstorp.

He also believes that Kemakta has overrated the protective capability of the repository in other cases. In order to simplify the calculations they have used a small model domain that shuts out large regional flow patters that could bring radioactivity even from deep boreholes up to the ground surface.

"In contrast to what we have heard before, I don't think we can know for certain that the water at great depths is stagnant just because it is saline. There may be other reasons it is saline; it may have been in the rock and been transported for a long time."

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[1] Djupa borrhål – Status och analys av konsekvenserna vid användning i Sverige; SKB-rapport R-06-58.

SSI would also like to see a systematic comparison with KBS-3 regarding long-term radiation protection, risks and feasibility. The Authority therefore has some expectations on SKB's RD&D programme this autumn:

"We think SKB should take a stand on the recently published studies and findings. They should also announce what further reports are planned so that we know what we can expect of an application."

SSI also thinks it's too early to dismiss deep boreholes as an alternative. The Authority needs additional material prior to SKB's application to be able to compare deep boreholes with KBS-3.

Dverstorp also mentions a method that is used in the USA for strengthening the evaluation of uncertainties regarding drilling technology and deposition: question-and-answer sessions with experts.

5.2 Swedish Nuclear Power Inspectorate

Öivind Toverud, SKI

Öivind Toverud describes what conclusions SKI has reached regarding SKB's studies of various alternatives and system solutions for a final repository.

SKI accepted the industry's plans during the 1990s. The Inspectorate found that in order to be able to reject an alternative, SKB should show that the alternative was either less suitable than the main alternative or that the cost of studying whether the alternative was suitable was unreasonably high in relation to the expected benefit. SKI did not believe it was reasonable that SKB should conduct parallel technical development of alternative methods and SKI wrote in some commentaries that the research programme had to be increasingly focused on one method and one system design.

"Even though SKI realized that a great deal of technical development and testing work remained to be done, they believed that the evidence indicated that the KBS-3 method was technically feasible," says Toverud. He points out that in review statements on RD&D programmes, SKI has thought that SKB has presented good accounts of the deep borehole alternatives, but that SKI has not considered it to be a realistic alternative to KBS-3.

"In the 1990s we said that KBS-3 was judged to be most suitable and the only realistic planning premise for the site investigation."

In the 2000s it was SKI's opinion that SKB should continue its programme concerning different alternatives for the disposal of nuclear waste with essentially the same direction and scope as before. At the same time there was a need to clarify the account of deep boreholes, and this is what SKB contracted the consulting firm Kemakta to do. Deep boreholes was to be compared with KBS-3 at a level that utilized previously applied safety assessment methodology.

What does SKI think of deep boreholes today? Öivind Toverud says that a great depth ensures slow water flow and long transport pathways to the biosphere for any escaped nuclides. The waste is also inaccessible with a low risk of inadvertent intrusion into the repository.

"But considerable efforts are required to develop drilling and deposition technology, and great uncertainties will exist when the waste is to be deposited," says Toverud. He also thinks it is difficult, costly and risky to retrieve the fuel if anything goes wrong during deposition. Furthermore, there are considerable difficulties in evaluating long-term safety, since a limited amount of relevant data is available on the rock.

"After only a thousand years it is likely that the rock will be the only barrier due to the corrosive environment, the high temperature and the high rock pressure at great depth," he says, also emphasizing that post-closure retrieval would entail high costs.

Toverud also notes that SKI's regulations are based on a repository having several barriers to ensure safety despite deficiencies in an individual barrier.[2]

KBS-3 is based on multiple barriers, and it takes a long time for the engineered barriers to be broken down, unlike in the deep borehole concept, he says.

Nor does he think that the industry can be expected to set aside resources to study other alternatives; there are no funds in the Nuclear Waste Fund set aside for this purpose. Both incurred and future costs to be paid for from the Fund are based on the KBS-3 concept.

[2] Section 7, SKIFS 2002:1.

"Studies of other alternatives will have to be paid for by the electricity consumers or the state."

Toverud also observes that if the alternatives are to be studied, the disposal programme will be delayed by 20–30 years, at great additional costs for all parties concerned.

5.3 Questions and discussion

SSI wants deep boreholes to be further studied.
What is SKI's stand on this?

Öivind Toverud, SKI: We have told SKB that we want the next RD&D programme to include an account of where SKB stands on the issue of alternative methods, and we would like to have a historical account of how they have arrived at this stand.

Is there a difference between SSI and SKI when it comes to whether they consider the deep borehole concept to be a single- or a multiple-barrier system?

Öivind Toverud, SKI: It is our definite opinion that the disposal canister used in deep boreholes has a short life. Whether this life is 1,000 years, 5,000 years or longer is a matter of dispute.

Björn Dverstorp, SSI: I can only state that the matter has not been studied. The canister will rust apart in a few thousand years if it is made of iron, but there are other materials, such as copper, which is used in the KBS-3 canisters. The choice of canister needs to be justified more thoroughly for deep boreholes as well. The chemical and thermal parameters do not differ so dramatically between deep boreholes and KBS-3. At least it appears possible to meet the requirements on salinity and temperature which SKB has itself set up for KBS-3.

Are best available technology (BAT) and best radiation protection the same thing?

Björn Dverstorp, SSI: The requirements on optimization of radiation protection and BAT are both ways to judge the protective capability of the repository and have different time perspectives. They have the same purpose: to ensure as good protection as reasonably possible for human beings and the environment in the future. The reason we include both principles in our guidelines is that it is difficult to calculate credible risks in a distant future. Assumptions must be made about the state of the environment and how people live in order to arrive at risk figures. In the long run, risk is not a good measure of the repository's protective capability. Then we should instead rely on more robust criteria according to the best available technology principle, such as estimating how many canisters can be expected to fail.

Are there other factors from a societal perspective than radiation protection and risk that can be weighed into the question of what the best solution is, and if so who decides this?

Björn Dverstorp, SSI: Many other aspects enter in, and SSI oversees the radiation protection aspect. Examination under the Environmental Code entails consideration of other aspects.

6 Safety philosophy for final disposal

6.1 Viewpoints of the actors

The safety philosophy for the KBS-3 method, Allan Hedin, SKB

"The safety philosophy is based on a collection of principles which are adhered to in the safety work, sort of like a life philosophy that you live your own life by," says Allan Hedin.

Two principles apply to the KBS-3 method: the multiple barrier principle and the passive barrier principle. The basic idea is that the final repository should isolate the spent nuclear fuel from man and the environment for a million years. If the barriers should for any reason be breached, the final repository system as a whole will retard radionuclide transport so that the radionuclides decay before they reach the surface. Safety may not be dependent on a single component of the repository system. Instead, multiple barriers contribute individually and jointly to isolation and retardation.

"The barriers are supposed to function passively, in other words intervention in the repository should not be necessary in the future. The repository should be designed to function for a very long time," says Hedin.

Another principle for SKB is that long-term safety should be based on scientific understanding. This requires a repository environment where it can be claimed on scientific grounds that the repository is located in rock that has the properties that are necessary for long-term safety.

"The conclusion is then that the waste is emplaced at great depth in a stable, known geological environment that protects against the impact of societal changes and direct effects of long-term climate changes on the surface," he says.

In order to be able to claim that the system is safe in the long term on scientific grounds, it is important that the engineered barriers consist of naturally occurring materials. Conventional knowledge about the processes that can affect the properties of the barriers is also needed.

The third principle for SKB is safety and control in all handling steps. It must be possible to verify the properties of the rock and the barriers initially and when the repository is closed.

A deep repository principle that says that radiological accidents shall be prevented by multiple barriers and that reliable and proven equipment shall be used applies during both the construction phase and the operating phase.

Johan Swahn, MKG

Johan Swahn prefers to approach the issue of safety from a broader perspective and independently of the choice of method. He wants to discuss the question of retrievability linked to long-term environmental risks in such a way that the long-term environmental risks must be minimized and take precedence over any advantages of retrievability. He says that this is of course a question of values.

Swahn believes that a natural barrier, such as the salinity gradient barrier that can prevent groundwater from deep boreholes from reaching man and the environment, can be preferable to methods that are dependent on artificial barriers for long-term environmental safety. He refers to other countries' main alternatives. Germany has salt domes, whereas France, Belgium and Switzerland are currently considering clay formations. The USA is considering disposal in the desert.

As far as multiple barrier systems are concerned, he is not convinced that deep boreholes would not entail multiple barriers:

"When it comes to materials for the canister, we have only the industry's choices and calculations to rely on. I don't consider that satisfactory."

Swahn also wants to analyze the possibilities of retrieving canisters in connection with deposition if something goes wrong. It may also be possible to make repairs during the operating period in the deep borehole alternative, he says. Perhaps even after closure.

He also believes that deep boreholes provides greater safety against nuclear weapons proliferation in the very long term.

"In about 10,000 years we may have completely different societies. Then 21st century technology will be required to retrieve the material from deep boreholes, while 19th century technology suffices to get at the waste in a KBS-3 repository," he says.

SKI's safety philosophy, Stig Wingefors, SKI

Stig Wingefors starts by pointing out that it is really the industry's, SKB's, responsibility to develop a safety philosophy for the final repository. SKI's safety philosophy in this context could be said to be the idea behind SKI's regulations concerning final disposal. The Nuclear Activities Act requires that measures be taken to prevent unacceptable release and dispersion of radioactive substances. Stig Wingefors describes that the Inspectorate's safety philosophy includes both the choice of method and how the method is to be realized, as well as the connection between the two.

SKI's safety philosophy requires that the final repository be designed with a system of interacting barriers with different functions that contribute to safety.

"The rock isolates the waste from man and the environment, the canister contains the waste, and the buffer and the rock retard releases if the containment is damaged," he says. The barriers are not independent of each other, but may also protect each other. No barrier should be more important than any other one in the sense that if anything goes wrong, the safety of the repository must not be jeopardized by a defect in a single barrier, as far as is possible. This is also stated in the IAEA's latest proposed regulatory framework.

The barrier system should be passive, i.e. it must not require human intervention and maintenance to work. Safety must be built into the repository when it is closed.

"In other words, safety is based on the construction and operation of the repository, including the fabrication of all its parts. Careful control is also required during operation," says Wingefors. He sees a need for feedback from assessments of long-term safety and a need for experiments on different scales in order for the final repository to be designed and operated safely. The safety assessments provide the design premises, which are translated into technical requirements and requirements on control when the repository is built. This is an iterative process.

"All repositories, without exception, stop functioning sooner or later. When safety is assessed, we must therefore base it on the function of the barriers during different time periods," says Wingefors. Over short periods, under 10,000 years, the risk picture is dominated by relatively short-lived nuclides. It is important that the barriers function completely satisfactorily. Multiple barriers are needed to guard against unforeseen events and processes, Wingefors says. All the barriers interact during these times.

According to Wingefors, the rock plays increasingly less role as a barrier over long periods of time, more than 10,000 years, since the long-lived nuclides can nevertheless reach the environment. In this perspective, the canister eventually adopts the role of the only significant barrier. In the case of deep boreholes it can be difficult to guarantee the life of the canister, even over very short spans of time. We then have only a single barrier, the rock, right from the start.

"When safety is assessed for long periods of time, it cannot be based merely on dose estimates. Other parameters, such as concentrations and flows of nuclides in the ground, can be used as safety indicators and be compared with natural concentrations and flows," he says.

International development trends indicate that an increasing emphasis is being placed on choice of method and processes in the development of the final repository. According to the IAEA's proposed safety standard for final disposal,[1] a step by step approach is required with periodic reviews by regulatory authorities and other concerned parties. Periodic safety assessment covering all aspects, including principles for construction and operation, is also required. The Swedish process complies with most of these modern requirements, says Wingefors.

Safety and radiation protection, Mikael Jensen, SSI

The standard for safety can be said to have been formulated in 1977 by the then Fälldin Government, which submitted the bill for what eventually became the Stipulations Act. This required an

[1] IAEA, Safety Requirements: Disposal of Radioactive Waste (2006).

"absolutely safe" solution to the nuclear waste issue in order for additional reactors to obtain fuelling permits.

"It's easy to make fun of Fälldin's requirement, but it was the start of a very important debate about what safety entails," says Mikael Jensen.

Sweden got the Nuclear Activities Act in the 1980s, which said that safety should be assessed by the regulatory authorities, but it was still not clear how safety should be described or quantified. There were at that time in the USA criteria that were based on individual barriers and barrier functions. For example, it should take at least a thousand years for the water from the repository to reach the environment. After some time, requirements were also issued on how individual barriers should be designed, but these requirements were increasingly questioned. In 1992 the U.S. Congress passed the Nuclear Energy Act, which instructed the Environmental Protection Agency (EPA) to consult the National Academy of Sciences (NAS) in the matter of a standard for releases or requirements on individual barriers. Questions were also posed having to do with intrusion and preservation of information.

The International Commission on Radiological Protection (ICRP) has defined a maximum dose and risk level. This is also specified in the IAEA document mentioned by Stig Wingefors[2].

The USA, the UK and Sweden apply a dose-risk standard. Finland has a standard defined in terms of releases, but the releases are defined in terms of dose. In general, a dose and risk standard thus applies. The Swedish risk standard can be found in SSI's regulations SSI 1998:1.

Jensen then discusses the concept of BAT and the difficulties of quantifying risk. Optimization is needed, since we have to attach great importance to the handling of uncertainties. It is obvious that a given dose value cannot be predicted 100,000 years in the future. Nor is it possible to say what the probability is of forgetting a scenario in the safety assessment. That is why BAT has to be applied, says Jensen.

When it comes to risk philosophy (including the risk limit), SSI says that the limit value should be applied in parallel with BAT and optimization. A risk value must be quantified based on illustrative scenarios, which should be credible, with reasonable expectations on climate etc. However, these are not an absolute prediction of

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[2] IAEA, Safety Requirements: Disposal of Radioactive Waste (2006).

what will happen, so we come back to the importance of applying BAT.

Marika Dörwaldt, MILKAS

"MILKAS is sceptical of the deep borehole method, since, just like KBS-3, it does not take sufficient account of geodynamic forces beyond human control, such as earthquakes," says Marika Dörwaldt. She believes that the concept of responsibility is crucial to a discussion of safety and that a possible definition of responsibility is to be willing to accept the consequences of one's actions. Here she is referring to the decision to use an energy source whose waste causes severe problems for hundreds of years.

"Is society willing to accept the consequences of this action? Unfortunately, the answer seems to be no. We judge the stress that characterizes the decision process in the nuclear waste issue to be due to an attempt on the part of the industry and non-socialist parties to cover the tracks of their historic mistake of backing nuclear power and then trying to force more nuclear power on us," she says.

MILKAS finds that the regulatory authorities have a number of laudable principles, but that the principle stating that the waste may not be handed over to the next generation is instead an encouragement for nuclear power.

"Since it is completely impossible and wishful thinking to imagine that we can avoid handing over the problem to future generations, no matter what we do, we believe than in order to really take responsibility we must not conceal the scope of the problem for future generations. They are entitled to benefit from our knowledge and mistakes, and we must not prevent them from learning new lessons."

MILKAS therefore wishes to urge the industry, the regulatory authorities and KASAM to dare to take their responsibility and stop rushing the decision process in the nuclear waste issue.

"Wait instead for new knowledge to become available so that we can investigate more alternative disposal methods."

6.2 Questions and discussion

Claes Otto Wene: Johan Swahn wants to give priority to natural barriers over engineered ones.What is wrong with the concept of redundancy proposed by SKB?

Johan Swahn, MKG: Great uncertainties exist concerning the future in these time perspectives. As a result, all assessments of engineered or man-made barriers require that we haven't thought wrong in order for this to work. Natural barriers are an entirely different matter.

Claes Otto Wene, KASAM: But isn't copper a natural substance as well as an element, which is fabricated into a tube in KBS-3?

Johan Swahn, MKG: There are many elements. The idea is that a final repository should function interactively and be able to protect against various events. We need to understand how the environment affects these kinds of barriers, compared with a natural barrier. The industry itself has moved away from regarding the rock as an important part of the safety concept. In their most recent safety assessments, long-term safety is dependent on the copper canister.

Allan Hedin, SKB: 500 metres of granitic rock is a considerable barrier in the KBS-3 concept. We have done an analysis where we conducted the thought experiment of taking away the buffer and the canister in all deposition holes for the repository site we know best, Forsmark. The result was that with only the fuel and the rock, we get doses far below the doses caused by background radiation. A warning however: it was a simplified calculation.

Johan Swahn, MKG: The rock differs a great deal between Laxemar in Oskarshamn and Forsmark, where the rock has proved to be more or less free of fractures. Hedin's argument that the canister can be taken away does not apply in Laxemar. It will be interesting to see how the industry chooses between the two sites.

Tuija Hilding-Rydevik, KASAM: The environmental movement speaks about the risk of nuclear weapons proliferation as an important criterion in the choice of method. The regulatory authorities and SKB speak about science, such as the engineered barriers. The difference in focus is clear between a technical safety philosophy on the one hand

and a decision-making philosophy and requirements on alternatives from SSI on the other. A question to MKG: Do you have any objections to the safety philosophy formulated by the regulatory authorities and SKB? And I would like to pose this question to the regulatory authorities and SKB: what clear differences do you see in the different methods for illicit intrusion?

Johan Swahn, MKG: We see that the regulatory authorities have different safety philosophies due to the fact that they work with different issues, SKI with technical systems and SSI with protection of man and the environment. I hear that SKI is mimicking the industry's safety philosophy directly here at the seminar, and we are not satisfied with that. A safety philosophy has been developed in Sweden over the past 30 years that is suited to one method and has been developed in collaboration with the regulatory authorities. SSI has a more general view of the safety issues, and we consider that to be more relevant.

Lena Jarlov, SNF: I would like to see a discussion of the history and the future of the safety philosophy. Social science and societal thinking should balance the scientific safety discussion. It is a question of what kind of society will manage the waste, and we know nothing about the future. Iran is not being allowed to have nuclear energy because the west is worried they will develop nuclear weapons. What they're saying indirectly is that nuclear energy is only compatible with a peaceful, democratic society. What do we know about what society will be like in twenty, a hundred or a hundred thousand years? Questions such as these are extremely important to address before making a decision on the repository.

Mikael Jensen, SSI: Both the issue of inaccessibility or intrusion, which has to do with retrievability, and the issue of retrieving the waste for weapons manufacture are purely political issues and must be decided by the Riksdag. The regulatory authorities have not legal support today for putting barriers in place for future generations. If the regulatory authorities are to deal with these matters, we must have a solid legal footing in the form of a change in the law. The same applies to the environmental court. They do not take the question into account unless there is a legal basis. If the environmental movement wants something, lobby for a change in the law. But purely technically speaking, it is more difficult to retrieve waste from a depth of 4 km.

Lars Persson, Environmentalists for Nuclear Power (MFK): MFK thinks that KASAM's principle should be followed, i.e. that a final repository should be designed so that monitoring and controls are unnecessary, but so that it is still possible to monitor and control the repository if this should prove necessary. The organization believes that a final repository of the KBS-3 type should be created and that society's efforts on behalf of final disposal should not be overdone. These efforts should be considered in relation to other environmental problems.

"MFK believes that there is no hurry, and that infinite safety does not have to be achieved. We do not think that exaggerated efforts should be made for a safe final repository. It is enough to prescribe a low risk for the final repository in relation to other risks in society, as in the radiation protection area," says Lars Persson.

Anders Andersson, Energy for Östhammar: This non-profit organization was formed when Östhammar was asked if they wanted to host a final repository and advocates a scientific approach to the final repository issue. The association wants to have more research on both transmutation and deep boreholes. According to Anders Andersson, SKB should not be prevented from building its KBS-3 repository. However, at the time the final repository is to be closed, which will be in 30 to 50 years, the Government should consider whether the transmutation alternative might be preferable to a deep repository.

"We have time before repository closure to study the alternatives and learn more about them," says Anders Andersson.

7 Concluding panel debate and discussion

Moderator: Göran Skytte. Panel members: Stig Wingefors (SKI), Leif Bjelm (drilling expert), Björn Dverstorp (SSI), Claes Thegerström (SKB), Johan Swahn (MKG), Jacob Spangenberg (Östhammar Municipality)

7.1 Technology

Göran Skytte: What are the technical options for carrying out the kind of drilling required for the deep borehole concept?

Leif Bjelm: A firm professional order must be made for a given type of drilling to a depth of 4,000 metres in order for this type of drilling to be done.

Gunnar Nord: That means starting with a known technology and solving technical problems that arise along the way. Only the nuclear waste industry could be interested in this type of hole.

Göran Skytte: Does everyone feel comfortable with the fact that we will be drilling holes 4 000–5,000 metres down into the ground when this has never been done before?

Gunnar Nord: It has been done. Drilling has been done in Germany and other places down to 9,000 metres. But I pointed out that the diameter of the holes was considerably smaller than is required for this project. I expressed it by saying “the technology is conceivable”.

Kenneth Gunnarsson, OSS Östhammar: If we are confident that the regulatory authorities and SKB have the technical know-how for a KBS-3 repository, we must be confident that they can manage a deep borehole repository as well.

Claes Thegerström, SKB: If I understand Gunnar Nord correctly, a great deal of work will be required to develop the drilling technology, and as an amateur it seems to me that this type of drilling may be possible in the future. However, just the fact that the drilling is possible not nearly enough to ensure that the concept is feasible. But technology development is continuing for both deep boreholes and KBS-3.

Leif Bjelm: The methods do not have to be placed in opposition to each other. There is no conflict in pursuing development work on deep boreholes in parallel with KBS-3 in order to have flexibility in 20–30 years.

Torsten Carlsson, KASAM: According to previous RD&D programmes and various authorities' statements of comment, there will be a trial operation period. New options may emerge during such a period which the industry should consider. Will SKB have such a trial operation period when the repository is built and will an evaluation be done afterwards?

Claes Thegerström, SKB: When SKI has issued SKB with a licence to start operation, a trial operation will first be done. Experience and results from this period will be evaluated before we get a licence for regular operation. During the process that is currently under way, technology development is taking place and we will put this to use in our ongoing work.

Stig Wingefors, SKI: There is nothing in the legislation that says that the responsibility to conduct research ends when a permit is obtained to build a final repository. Continued requirements will be imposed to improve the method that is used, improve safety assessments and study what methods other countries are using. This is needed to obtain ample information as a basis for the decision to finally close the repository. We then need to know that the method meets the BAT requirements.

7.2 Hidden agenda and division of roles

Göran Skytte brings up the question of whether the industry and other actors have a hidden agenda, namely to expand nuclear power. He refers to Marika Dörwaldt from MILKAS, who has expressed scepticism towards deep boreholes and has said that it is a way for the non-socialist parties to promote increased use of nuclear power.

Marika Dörwaldt, MILKAS: I wasn't referring specifically to deep boreholes, but was reacting to the rush to find a solution as quickly as possible, that we can't continue to conduct research and wait for a better alternative. Now a commitment has been made to one alternative for the next 30 years, and we believe other alternatives should be researched more thoroughly. It's no secret that the non-socialist parties are more positive to nuclear power than the others.

Bengt Barkman, Environmentalists for Nuclear Power: It isn't just the non-socialist side that wants nuclear power. Electricity-intensive industries have long said they need it. The trade union IF Metall is for nuclear power, as are certain social democrats.

Göran Skytte: But Dörwaldt says that the non-socialist parties are doing certain things because they really want something else: namely, to cover the tracks of nuclear power because they want to increase this energy form.

Marika Dörwaldt, *MILKAS*: The nuclear power industry has a double role when it is also in charge of the process with environmental impact assessment and consultations. They are supposed to lead this process, at the same time as they are a concerned party with vested interests. Having vested interests is not bad in itself, but we think an independent party should lead the consultation process.

Claes Thegerström, SKB: I think the clear division of roles that exists now is good. It is good to know who is responsible for what. If Marika's line is to work, the laws have to be changed, and I think the roles will then be less clear. Today the reviewers can clearly see that SKB and no one else is responsible for the material that is presented.

Johan Swahn, MKG: There doesn't have to be any hidden agenda, but the industry has double interests in this case: building a final repository and bolstering public confidence in nuclear power by showing that it can work. In most cases where environmental impact statements are to be compiled for applications to environmental courts, the system where the activity operator has the responsibility works well, even though it is the activity operator who compiles the environmental impact statement. But this applies to projects that are not controversial. If it is a big project, like this one, and a conflict arises, it can be a good idea for the environmental impact assessment to be carried out by an independent party. We at MKG notice that the industry doesn't listen to us when we ask them in the consultations to include certain issues in the environmental impact statement, which entails a risk that environmental courts, regulatory authorities and the Government will not have a complete body of material on which to base their decisions. Who will listen to us if the industry doesn't?

Claes Thegerström, SKB: It is important that we do what we believe in and can take responsibility for. We cannot act as an organization that does what others say we should do, since we have responsibility. Nor can we excuse ourselves by saying someone else told us what to do. The division of roles is such that we take responsibility for the task we have been assigned and propose solutions that we believe in. This doesn't mean we implement them; the matter first has to be examined by the supervisory authorities and the environmental court. This is the clarity in our regulatory system.

Göran Skytte: There are also claims among those who are positive to KBS-3 that the environmental movement has a hidden agenda; that the environmental movement does not really want to continue studying the issue, but is demanding further studies in order to stop nuclear power.

Johan Swahn, MKG: We hear this being said, but the environmental movement has worked with these issues for many years and we don't feel we have gained a hearing for our standpoints when it comes to sufficiently comprehensive studies. Our criticism has been met with silence, for example from SKI. It is not until we obtained additional resources recently that we see new information emerging. We are interested in arriving at the best solution for the environment. There is a further need to discuss what is best.

Jonas Forsberg, MILKAS: Accusations of a hidden agenda lead to an unnuanced debate. People are acting from different rationales and everyone one would gain from a more nuanced debate.

Karl Inge Åhäll: The discussion of a hidden agenda does not focus on the real problem, namely that we have a strong actor who has access to large information resources. Many have expressed a desire for impartial information on discovering that SKB is a party. No one meets the need for comprehensive and relevant information. The regulatory authorities are limited to the exercise of their authority and have difficulty answering questions which some other public body should have been able to answer.

Claes Thegerström, SKB: The important thing is that our material is subjected to expert review by different parties. We would like to see a heavy mobilization on the part of the regulatory authorities for the upcoming comprehensive review. It is in our interest that it be competent, well organized and expert.

Kristina Glimelius, KASAM: It is SKB's obligation to inform and discuss with the public, which they do well. At the same time, independent organizations or knowledge organizations should analyze and review that which SKB produces. A competence building programme needs to be developed in Sweden. Regulatory authorities and other reviewing bodies need additional resources and expertise. We at KASAM have a special responsibility for research and competence building.

Jacob Spangenberg, Östhammar Municipality: The municipal leadership in Oskarshamn has written to the Government demanding sufficient resources for the reviewing authorities to deal with SKB's applications. This is crucial to enable the municipalities to continue the process in a satisfactory manner.

Saida Lâarouchi Engström, SKB: SKB has not only the right but also an obligation to inform and maintain a dialogue with interested persons in the matter. The environmental organizations say they want the public to have a say, but I can't see how this can happen unless SKB takes full responsibility for information, consultations and dialogue.

Miles Goldstick, OSS Östhammar: The problem is that SKB's information is not objective, but attempts to advertise or sell a concept.

7.3 How do we obtain studies of the deep borehole alternative? Who will foot the bill?

Göran Skytte notes that different wishes have been expressed for additional studies. But how do we obtain studies of the deep borehole alternative? How big should the studies be and who will pay for them?

Björn Dverstorp, SSI: The regulatory authorities cannot at this time demand that SKB should do anything to study the deep borehole alternative. We can tell them what material we expect to get before the permit application and warn SKB if we think that the material in the application will be insufficient before it comes in. In evaluating the permit application, we may have to make tricky judgements as to whether SKB has done enough. But to go so far as to demand that SKB should develop new drilling technology in order to implement deep boreholes is going too far. We want to have an assessment at a sufficiently high level so that we can judge whether another alternative is appreciably better from a radiation protection viewpoint and it is therefore worth stopping the main alternative.

Kenneth Gunnarsson, OSS Östhammar: Only a political decision at the municipal or national level can force the industry to study alternatives. The voluntary municipalities can make demands, which can grow and become requirements at the national level. The municipalities can demand that the alternatives be more fully investigated than today and claim that they will only approve the best method. Both municipalities could demand this without playing against each other.

Jacob Spangenberg, Östhammar Municipality: Gunnarsson is overestimating the municipalities' competence. We are not capable of determining whether KBS-3 or deep boreholes is the best method.

Kenneth Gunnarsson, OSS Östhammar: It is up to SKB and the authorities to find the best technology. The politicians have to assign responsibility in relation to the political goals expressed in the environmental legislation. In order to take responsibility the municipal politicians have to make demands that lie on another level than the technical aspects, obtain information and make a decision with the help of the regulatory authorities.

Jacob Spangenberg, Östhammar Municipality: I cannot judge where that quality level is, but we can refer these matters to the national politicians so that resources are allocated to enable decisions to be made on the basis of optimal knowledge. But it isn't today, but when SKB has submitted its application and the regulatory authorities have made their decision, that the municipalities can made demands based on our special situation. Before then we can have opinions about RD&D Programme 2007.

Claes Thegerström, SKB: The system whereby SKB submits RD&D programmes will continue even after 2009 (when SKB has submitted its application for a permit for a final repository system). We see it as an important instrument for society to issue directives to SKB. The Government has previously said that we should go ahead with our plans and in other cases urged us to take a special look at certain questions. The next RD&D programme will be submitted in September 2007, and then everyone can express an opinion.

Arnold Unge, Östhammar: RD&D Programme 2007 is important because it is the last programme before SKB submits its application. Does SKB feel after this seminar that they should do something about the issue of deep boreholes? If so, will SKB have time for this before submitting RD&D Programme 2007?

Claes Thegerström, SKB: Deep boreholes will be included in RD&D Programme 2007. We will describe where we stand today, and how we intend to go ahead and work further with the alternative. More information is always a good thing, but it costs money, takes time and resources and can affect the focus of the programme. We are obligated to consider these factors and we are obligated to decide what we think is enough information for the various alternatives.

Lars Högberg, former director-general of SKI: Is one borehole to a depth of 4,000–5,000 metres enough to obtain significantly better data on hydrogeological conditions, chemistry, water flow, etc.?

Gunnar Jacks: It's a good start, but we will have to decide when it is interesting to continue drilling more holes. If the water's residence time is only 10,000 years it is not interesting. At a residence time of 100,000 years it is somewhat interesting, and at 1 million years definitely interesting to drill more holes to collect more data.

Karl Inge Åhäll, MKG: The step-by-step approach is wise and does not cost too much to begin with. The presence of saline water must be determined, but also whether the saline water has been isolated from the biosphere, which requires sophisticated studies. Geophysicists are needed to judge the data.

Kristina Glimelius, KASAM: I don't think one borehole will be enough; we need more to find out what the saline stratum looks like. The question is very interesting from a basic research perspective, but one hole cannot answer the alternative question.

Göran Skytte: Is there any reason not to drill a hole in parallel with the continued research on KBS-3?

Claes Thegerström, SKB: We don't plan to drill a hole with a depth of 5,000–6,000 metres in the RD&D programme, but we would like to see it done.

A discussion arises between Leif Bjelm and Claes Thegerström, where Bjelm judges SKB's data on deep boreholes to be inadequate in the sense that the environmental court may very well demand more data on deep boreholes. Thegerström claims that they are studying deep boreholes, but not to the level that would make it possible to decide to use this method for the final repository. That would require another 30 years of studies and several billion kronor, he says. Bjelm thinks that SKB is giving a warped picture of reality and that so much money does not have to be spent to find out whether it is technically possible to drill deep boreholes; that would require 3–4 million dollars. Thegerström says that SKB is listening to everyone's experience from proceedings in environmental courts to provide such a good body of material that they get a permit to build the final repository.

Kurt Angéus, Östhammar Municipality: People at Atlas Copco and Sandvik know how much time it took to develop Swedish tunnelling technology even though there were companies that were willing to invest money in the work. During the seminar it was said that SKB may be interested in this kind of boring technology. Lots of mistakes can be expected during the development work. Is the uncertainty level such as it is portrayed with regard to technology development realistic? I think it is greater.

Gunnar Nord: I don't see any other industry who may be interested in this kind of hole. The geothermal industry might possibly have an interest and maybe the mining industry, but this is just a guess.

Johan Swahn, MKG: The foreign nuclear waste industry may also be interested. There is a discussion of deep boreholes in the UK, maybe also in the USA. Perhaps the development costs can be shared with others.

Saida Lâarouchi Engström, SKB: We are following carefully what the British Committee on Radioactive Waste Management and NIREX are saying. They make roughly the same judgements as we, and the Committee will recommend that the UK build a KBS-3 type repository.

Göran Skytte: Who would be in charge of any boreholes?

Gert Knutsson, KASAM: The Geological Survey of Sweden, SGU, could be in charge and collaborate with researchers and engineers. SGU cannot finance the project but could request special appropriations.

Roland Davidsson, Hultsfred Municipality/SERO: Who will foot the bill? SKB gets money from the Nuclear Waste Fund, and that money comes from us consumers. We should tell SKB that we are prepared to pay to have the alternatives studied. Considering how much money SKB has got from the Nuclear Waste Fund it is not unreasonable to let Lund University and Atlas Copco have money from the Fund to drill a hole.

Other voices were heard that the price of electricity can be raised to pay the bill.

Göran Skytte: What are SSI's limits for when it is too early to dismiss deep boreholes and when it is worth going further?

Björn Dverstorp, SSI: There is of course no exact answer. A lot depends on SKB's new studies of drilling technology and implementation of deposition. If additional calculations of the long-term radiation protection indicate that the deep borehole alternative has significant advantages compared with the KBS-3 method – then we will have to decide whether to demand new data on deep boreholes. We are not there today. We should, however, proceed step by step and fill the knowledge gaps that don't cost many millions. With that knowledge we can re-assess the situation. The RD&D process is an instrument for this, and SSI and SKI will review RD&D Programme 2007 before SKB submits its application. If we see the need for more data we will present this request to SKB.

7.4 Multinational repositories

Christina Larsson, OSS Östhammar: I think every country should dispose of its own waste. Many countries are conducting research on superficial geological repositories, but many have a bedrock that makes these repositories unsuitable. If it turns out that deep boreholes works better than KBS-3, how would the discussions of multinational repositories develop? Would they continue to be discussed or do you think each country could more easily dispose of its waste if deep boreholes works?

Claes Thegerström, SKB: The discussions in the major European nuclear power countries have to do with how they should proceed in the siting process and gain access to sites to investigate. All of them have geological repositories as a main alternative and not deep boreholes. Finland, Sweden and to some extent France have come farthest in their siting processes. But the basic principle in all countries is that they will dispose of their own waste. According to international conventions, no country can be forced to accept waste from another. But some private initiatives have exploited countries in Africa and Asia to propagate for multinational repositories. This has led to strong reactions, however. What cannot be ruled out, on the other hand, is that small European countries with problematical geology will band together and decide under democratic forms to do something jointly.

Stig Wingefors, SKI: You would have to be a geologist to answer the question whether realization of deep boreholes changes the premises for the discussion of international repositories. But I imagine that the need would rather decrease, since the possibilities of a local solution would be improved.

Saida Lâarouchi Engström, SKB: Ethical aspects are also involved here. I am Swedish, but also Moroccan, and would not like to see a repository in the Atlas Mountains where there is no nuclear power. It is only fair that those who enjoy the benefits of nuclear power should also have the disadvantages.

7.5 Is it better to wait to build a final repository until the technology has been further developed?

Börje Bergman, Scandinavian Water Environment Council: All rock cracks, and if a repository is to function for 100,000 years things will undoubtedly happen that no one could have foreseen. Land uplift creates stress in the rock, the Earth's crustal plates move. Isn't it better to build a repository that will be safe for 100 years and during that time concentrate all the world's research on solving the problem?

Claes Thegerström, SKB: But in 100 years we may be in the same situation. The argument is circular, but naturally new knowledge will emerge as time passes. 25 years ago we had a discussion regarding how the repository for low- and intermediate-level nuclear waste should be designed and sited. The repository was built and is being used, but we haven't had any discussion about why we didn't wait instead. Sometimes you have to decide to do something, otherwise it never gets done. If this line of reasoning is linked to deep boreholes, there is an argument in favour of KBS-3: with KBS-3 we get a long-term safe repository where we don't have to do anything more, but if our view of the nuclear waste changes in 100 years it can be retrieved.

Miles Goldstick, OSS Östhammar: Deep boreholes has been a new issue for 10 years now, and it isn't a question of starting from the beginning; the matter needs more time to be studied. It isn't reasonable to say that we have to act now.

Rigmor Eklind, Oskarshamn Municipality: The spent nuclear fuel is being temporarily stored in Clab in Oskarshamn. The municipality accepted the siting based on the assumption that it would operate for 40 years and not be transformed into a final repository. During that time a final repository solution would be arrived at. Now 20 years has passed. If we want a repository that is not accessible, then Clab is not a good solution, it is merely temporary.

Nils Axel Mörner, MILKAS: That is precisely why we are proposing a dry repository according to the DRD method down in the rock so that it will be protected against bombs while at the same time being accessible. Technological development will hopefully make transmutation possible, which can be used for energy extraction. Of 5,000 canisters, 500 will remain with real waste, and these could fit in only two deep boreholes.

Johan Swahn, MKG: I am an optimist regarding the potential of transmutation, but that use of the technology can only be considered in the long run and when global nuclear power has been phased out. The current legislation is designed for a continuation of nuclear power, and the industry is following the legislation.

7.6 Timetable for decisions?

Göran Skytte: What is the timetable for the upcoming decision process?

Claes Thegerström, SKB: We plan to submit an application at the end of 2009. The most important laws under which the application will be examined are the Environmental Code and the Nuclear Activities Act. The application under the Environmental Code includes the entire system: encapsulation, transportation and final disposal. A special application will be submitted under the Nuclear Activities Act for the final repository. The application under the Nuclear Activities Act for the encapsulation plant was submitted in the autumn of 2006, and that examination can begin now. The regulatory authorities themselves decide how long it takes to examine the applications, but it will take at least two years after 2009. A positive decision from the Government cannot come before 2012. The most important examination bodies at the expert level are SKI, SSI and the environmental court, and at the political level the municipalities and the Government. The municipalities and the Government will undoubtedly also want to know what judgements the expert bodies as a basis for their decisions.

Sven Bengtsson, Superior Environmental Court: When an application is submitted to the environmental court a number of criteria have to be met, such as an extensive consultation procedure, EIA etc. After the matter has been prepared by the environmental court, it will be referred to the Government for permissibility assessment, i.e. the Government decides whether it is permissible under the Environmental Code to build a final repository in the manner for which SKB has applied. If the Government says no, the matter is ended. If the Government says yes, the environmental court can decide on what conditions are to apply for the activity. Certain conditions may be temporary and apply during a trial period. Then the final conditions are established. Conditions issued by the environmental court in a judgement can be appealed by regulatory authorities, municipalities and concerned parties. Who concerned parties are is determined from case to case. The environmental court's judgement regarding the nuclear power plant in Oskarshamn a while back was appealed to the Superior Environmental Court by a person residing in Vaxholm. That person was judged not to be a concerned party. The environmental court's judgement can be appealed to the Superior Environmental Court, which is a department of the Svea Court of Appeal. The Superior Environmental Court's judgement can in turn be appealed to the Supreme Court, but there a review permit is required. It takes 1–3 years for the environmental court to prepare the matter, obtain the Government's decision in the permissibility question, and if the activity is permissible set conditions for the activity. An appeal to the Superior Environmental Court can take years, and if the matter goes further to the Supreme Court it takes another 1–2 years.

Johan Swahn, MKG: The conditions can be appealed, but can't SKB demand to be allowed to start the activity directly after the Government's decision?

Sven Bengtsson, Superior Environmental Court: SKB may not start the activity until the environmental court has determined what conditions are to apply. If the Government decides that the activity is permissible, then the matter is decided. The environmental court cannot re-examine the Government's decision in the matter of permissibility. On the other hand, the

Government's decision in the permissibility question can be appealed to the Supreme Administrative Court (judicial review) if a concerned party claims that the Government has exceeded the bounds of the regulatory framework.

7.7 Input from and questions to Nils Axel Mörner, MILKAS

Nils-Axel Mörner says that we now have a whole new picture of the geodynamic processes that prevail in the Swedish basement rock, which is of crucial importance in judging the alternatives. The old theory from the 1970s on which SKB bases the KBS-3 method is antiquated and has collapsed. It was previously assumed that there was a total stability, that earthquakes were insignificant, that glaciations had no impact.

"Those of us who represent the free research community have arrived at other conclusions than SKB, and we are trying to get a dialogue going," he says.

We have noted 56 major earthquakes while SKB assumes no more than 7 earthquakes during a period of 100,000 years. We have also discovered methane explosions in the rock, which gives a whole new scenario. This should stimulate interest in having a closer look at the alternatives, both deep boreholes and disposal with freedom of choice for the future.

Kjell Andersson, KASAM: It appears as if MILKAS and MKG have different premises when it comes to their safety philosophy. You and MILKAS advocate the DRD method, which is a near-surface repository, and think that you then have the waste under control. MKG instead appears to want to get rid of the nuclear waste. Is there such a gap in viewpoints?

Nils Axel Mörner, MILKAS: Deep boreholes and a dry repository in the rock have both advantages and disadvantages, and not until the alternatives have been studied can a summation be made. That is why it's important that the alternatives be studied to a comparable level. This doesn't take 30 years. There are lots of lessons from KBS-3 that can be directly applied to these two alternatives.

Gert Knutsson, KASAM: By studying superficial effects of earthquakes you have interpreted many more earthquakes that we previously knew about. At the same time you advocate a superficial repository, which seems to be contradictory. Earthquakes always have the greatest effect at the surface. Why do you want a superficial repository?

Nils Axel Mörner, MILKAS: That's because you have to guarantee safety for a long time, and no method can guarantee safety for 100,000 years. So we have to provide freedom of choice so we can exploit technical advances in the future, for example with regard to transmutation. The superficial repository is surrounded by an artificial crushed zone to drain the rock and provide a relatively good seismic barrier.

Björn Hedberg, KASAM: KBS-3 offers better possibilities for retrievability than deep boreholes and you advocate retrievability. Isn't then KBS-3 preferable to deep boreholes?

Nils Axel Mörner, MILKAS: Deep boreholes is preferable if you're afraid of terrorist attacks. If you believe in future technology, the DRD method should be chosen. SKB's method is not preferable for either reason and is the only really bad alternative.

Said Lâarouchi Engström, SKB: You speak about retrievability, but the primary reason for retrieval is to permit repairs. It must be possible to correct mistakes.

Claes Thegerström, SKB: We are caught here between two alternatives advocated by different branches of the environmental movement. You might say that the best aspects are taken from these alternatives and combined in the KBS-3 method. With a built repository at a depth of 500 metres, KBS-3 provides excellent protection against unauthorized intrusion. It's difficult to get down there. It is interesting that we are now discussing at what depth the repository should be located, while 5–10 years ago the discussion was whether it was at all morally defensible to put spent nuclear fuel in the bedrock. We describe how we handle earthquakes in our upcoming application.

Göran Skytte: Nils Axel Mörner says that the premises for the final disposal idea have collapsed. Is there anything to what he says?

Claes Thegerström, SKB: Of course the premises have not collapsed. Then research on nuclear waste would have collapsed all over the world, and that is not the impression I have. It is SKB's task to listen to all the facts, claims and interpretations that are presented to us, and we are trying to do that with Mörner's data as well. But it must be pointed out that there are other scientists who view his data differently.

Allan Hedin, SKB: We have analyzed and taken into account the possibility that future ice sheets can trigger earthquakes when they move. The repository is designed with a view to this possibility. We select canister positions so that the risk of damage due to such an event is minimized. Mörner's estimates have been weighed in among all other experts' judgements that we have used in the safety assessment.

Nils-Axel Mörner, MILKAS: What I talked about as "now the facts collapsed" were the basic facts that once put the KBS-3 method on the track towards being a "safe final repository". These facts no longer exist. Neither should the talk of a safe final repository in 100,000 years.

8 Some reflections

During this hearing on deep boreholes as a method for final disposal of spent nuclear fuel, different actors have presented their viewpoints and arguments, and deep boreholes as a final disposal concept has been compared with the KBS-3 method. This chapter provides some reflections on the arguments offered and issues on which there is disagreement, as well as where there are differences in opinion.

A general impression from the question-and-answer session is that while the argumentation often takes the form of a discussion of factual issues, the arguments are in fact largely based on the different values of the participants. This is illustrated by three themes that dominated the discussion during different parts of the session: the barriers, retrievability and the question of whether new knowledge is needed.

KASAM draws no conclusions of its own concerning the method question in this report – that will be done in other contexts, such as the upcoming review of SKB's RD&D Programme 2007.

8.1 Agreement on fundamental facts and rerequisites

There is no real disagreement when it comes to fundamental facts concerning stagnant groundwater conditions at great depths (3–5 km) and the advantage this entails for a final repository for spent nuclear fuel. SKB's own calculations show that the travel time for groundwater from great depths to the surface is very long and there do not seem to be any driving forces for groundwater movements. The basic idea is that the entire disposal area for a final repository in deep boreholes would be surrounded by highly saline, stably density-stratified groundwater with no contact with near-surface levels.

Like SKB, Karl-Inge Åhäll does not regard the deep borehole concept as a realistic alternative at the present time, since there is no evidence that the hydrogeological prerequisites are satisfied. He stresses that two prerequisites for the concept are that it is possible to identify large enough areas with density-stratified groundwater and that methods are developed to deposit the waste in a safe manner and without permanently disturbing the area's stable density stratification. If these basic prerequisites for the concept are satisfied, he says he could be an advocate of the method. MKG's standpoint is that deep boreholes is not a realistic alternative at the present time, but they are critical of the way deep boreholes has been dismissed as a potential alternative to the KBS-3 method.

The fundamental agreement between SKB and MKG in particular ends here – they then arrive at different conclusions regarding what could be gained from new knowledge, as well as what it would cost to obtain such knowledge.

8.2 The actors' arguments

Importance of the barriers

One of SKB's main arguments against a final repository with deep boreholes is that long-term safety would be dependent on only one barrier – the rock with its stable hydrological conditions. If this is the case, the method does not comply with SKI's safety philosophy and regulations, which require a multiple barrier system. However, SKI's regulations could be revised if the single barrier should prove to be entirely reliable. From a societal perspective it is possible to ask, as Carl-Reinhold Bråkenhielm did initially, what is most important: stagnant groundwater conditions or multiple barriers? And what is most desirable: a robust natural barrier or a robust combination of natural and engineered barriers?

SKB also argues that the deep borehole concept entails uncontrolled deposition, while the KBS-3 method entails controlled deposition. During deposition in deep boreholes the canister can be damaged, and it can get stuck somewhere in the hole at the wrong depth. SKB does not believe it will be possible to check whether the canister and the buffer are intact and in the right place.

Karl Inge Åhäll argues that a deep borehole repository could potentially be less vulnerable than a KBS-3 repository in the face of both expected events, such as changed groundwater conditions during future ice ages, and unexpected events such as terrorist actions, technological blunders or major earthquakes in the area. Regarding the discussion of "one or more barriers", MKG says that it ought to be possible to develop barriers for the deep hole concept as well. Johan Swahn also argues that a natural barrier may be preferable to methods with "artificial" barriers. This argument gets some support from SSI, who said that preliminary assessments show that the geosphere alone could provide very good protective capability in the deep borehole alternative.

Here it may be worth noting how different actors choose to use different concepts depending on what message they want to convey:

- SKB and the regulatory authorities talk about "engineered" barriers, while MKG uses the term "artificial" barriers.
- Karl Inge Åhäll and MKG describe KBS-3 as a "near-surface" repository. Other actors use the term "near-surface" for interim repositories such as CLAB (about 30 m below the surface) or DRD repositories (about 50 m below the surface). SKB has previously called KBS-3 a "deep repository", while the regulatory authorities call KBS-3 a final repository (in accordance with the Nuclear Activities Act).

These rhetorical choices of terms are in themselves clear expressions of different values.

Further research and technology development

SKB asserts that the deep borehole concept is associated with fundamental weaknesses which further research and development work cannot alter. The technical weaknesses in the drilling and deposition technology could be solved with more research and technology development, but the weaknesses in long-term safety will not be altered by this. As a representative of MKG, Karl-Inge Åhäll on the other hand says that there are crucial research questions that could be answered with limited efforts, for example the question of whether there is a big enough area at a depth of 3–5 km with stably density-stratified groundwater. SSI observes that the drilling technology does not appear impossible to develop, but that there are some difficult questions related to canister deposition.

Leif Bjelm points out that the methods do not have to be placed in opposition to each other. There is no conflict in pursuing development work on deep boreholes in parallel with KBS-3.

Opinions differ when it comes to the cost and the time required for new studies as well, even though studies of differing scope are being discussed to some extent. SKB says that the research and study work necessary to bring knowledge to a level comparable with knowledge of the KBS-3 method would take another 30 years and several billion kronor. Leif Bjelm, on the other hand, thinks that SKB is giving a warped picture of reality and that so much money does not have to be spent to find out whether it is technically possible to drill deep boreholes; that would require 3–4 million dollars. Gunnar Nord expresses the situation by saying that "the technology is conceivable". Drilling has been done in Germany and other places down to 9,000 metres, but Nord says that the diameter of the holes was considerably smaller than that required for a final repository.

Here it can be noted, however, that the studies referred to by SKB and Bjelm differ in scope. In order for deep boreholes to be a realistic alternative disposal method, it is not enough to make sure that it is technically possible to implement deep boreholes, which is the study Bjelm is talking about. It is also necessary to verify the basic hydrogeological prerequisites and to identify a large enough area with stagnant groundwater conditions, as well as to develop a reliable deposition method.

If, as SKB claims, deep borehole disposal has serious inherent fundamental disadvantages that cannot be altered by more research, it is only logical to minimize such unnecessary costs. The question is, however, whether these disadvantages (e.g. reduced reparability during the operating period, reduced adaptability to geological conditions on the site, deviation from the multiple barrier principle) are actual disadvantages for all actors or for society as a whole, or whether they serve as arguments for SKB's intentions. It is also, as SKB's representatives expressed it, a question of how far SKB can be expected to pursue an alternative method that they don't believe in. Those who, on the other hand, advocate more research, including drilling of one or more deep holes, need to define what the purpose would be. Is it just to find out what the groundwater conditions are at great depths, or to find out if it is technically possible to drill holes of the size required? What do we do if we get positive answers to these questions? Arguments are offered in this question as well that appear to rest on different judgements of what is possible to do. SKB does not believe drilling a few test holes will permit a better assessment of safety, while Åhäll and MKG are more optimistic about the possibilities of obtaining the relevant information.

Gunnar Nord says that it is the nuclear power industry itself that has to pursue and pay for the technology development that is required. Questions that were discussed during the question-and-answer session and that need to be answered if society wants to go further with deep boreholes are therefore who should conduct further R&D, and how this research and technology development is to be financed.

Retrievability

When it comes to retrievability and reparability, no one challenged the claim that these characteristics would be more difficult to achieve with deep boreholes than with KBS-3, even though very little research on this has been done for deep boreholes. There are big differences in what value the actors place on retrievability. The fundamental question is whether this possibility is something positive, since it would give future generations more freedom of choice, or whether retrievability should be avoided in view of the fact that future intrusions could be intended for making nuclear weapons.

According to SKB, we have to have control over what we do in each step of the handling of the spent nuclear fuel. If deep boreholes are used, the nuclear waste is left to nature after it has been deposited. SKB wants repair and retrieval of canisters to be possible so they can be inspected during the operating period (about 50–60 years). According to SKB, deep boreholes does not provide such possibilities. We have to allow for the human factor and the fact that things can go wrong – it must be possible to correct mistakes.

MKG prefers to approach the issue of safety from a broader perspective and independently of the choice of method. The question of retrievability should be discussed linked to long-term environmental risks in such a way that the long-term environmental risks must be minimized and take precedence over any advantages of retrievability. MKG also says that a deep borehole repository provides greater safety against nuclear weapons proliferation in the very long term. At the same time, MKG believes that retrieval and repair during the operating period can also be possible in the deep borehole alternative and wants this to be analyzed.

MILKAS believes that greater retrievability than can be achieved with KBS-3 is necessary, and is critical of both KBS-3 and deep boreholes and wants to see studies of other methods as well.

Thus, actors who are opposed to greater R&D efforts on deep boreholes use freedom of choice as an argument – more knowledge of the rock will not increase the freedom of choice of future generations. On the other hand, actors who want to see more thorough studies of the method use inaccessibility as an argument – more knowledge could make it possible to realize a method that makes it nearly impossible to retrieve the waste. Here there is also a clear difference between the two environmental organizations, MILKAS and MKG. MILKAS is more critical to both the KBS-3 method and deep boreholes and wants to have full freedom of choice pending new knowledge. MKG, on the other hand, believes that final disposal in deep boreholes could be a way to get rid of the waste permanently.

Societal goals and safety philosophy

According to SKB, the company's view of how the spent nuclear fuel should be disposed largely agrees with society's view. Safety should rest on multiple barriers, undue burdens on future generations should be avoided, and waste handling should be controlled in all steps. SKB has two main arguments against deep boreholes: the method relies on only one barrier, which violates the regulatory authorities' safety philosophy and regulations, and the advantages of stagnant groundwater conditions are difficult to demonstrate with the required certainty.

SKI said that the Inspectorate's regulations are based on a repository having multiple barriers to guarantee safety despite deficiencies in a single barrier. SKI's safety philosophy requires that the final repository be designed with a system of interacting barriers with different functions that contribute to safety.

However, Swahn criticized the safety philosophy that both the regulatory authorities and SKB advocate. He says a safety philosophy has been developed that is suited to one method and that it has been developed in collaboration between the regulatory authorities and SKB[1].

MILKAS says that the waste must not be got rid of, but that responsibility must be taken for it for a long time. A solution to this difficult problem cannot be rushed. MILKAS is therefore sceptical to both deep boreholes and KBS-3 as final disposal methods.

It can be noted that MILKAS and MKG have different premises in their safety philosophies. MKG advocates finding a solution for nuclear waste disposal, but wants to see a minimum of retrievability and therefore says that deep boreholes may be preferable to KBS-3. MILKAS, on the other hand, advocates not looking for a quick solution to nuclear waste disposal, but instead relying on interim storage, for example in a DRD repository, pending a more long-term solution.

8.3 Conclusion

SKB is responsible for preparing an application for a safe final repository. The environmental court and the regulatory authorities will then review the application and recommend what decision the Government should make under the Environmental Code and the Nuclear Activities Act. Ultimately it is the politicians at the national level who will decide whether SKB's application offers a suitable balance between retrievability and inaccessibility and provides an adequate account of alternative designs, and whether the proposed method rests on a proper safety philosophy and is in agreement with the purpose defined by society as a whole. But the

[1] KASAM would in this context like to point out the fact – which was not mentioned during the question-and-answer session – that the multiple barrier principle has broad international support, e.g. IAEA Safety Standards, Geological disposal of radioactive waste, Safety requirements No. WS-R-4.

standpoint arrived at by the council in the concerned municipality, in other words at the local political level, is of crucial importance for the political decision at the national level. There will not be any given answers to these questions, but SKB must do its best to present a solution that is in harmony with the prevailing values in society.

By its continued efforts, KASAM can raise awareness of these matters on the part of all actors, including politicians and private citizens, to clarify both the factual and value issues.

The Swedish National Council for Nuclear Waste (KASAM) has the following composition:

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The Swedish National Council for Nuclear Waste – KASAM – is an independent scientific committee within the Ministry of the Environment. Its task is to advise the Government in matters relating to nuclear waste and the decommissioning of nuclear installations. KASAM's members are experts within different areas of importance for the disposal of radioactive waste, not only in technology and science, but also in such areas as ethics, the humanities and the social sciences.

In the autumn of 2006, KASAM launched a new transparency programme aimed at strengthening KASAM's role as an advisor to the Government by shedding light on strategic issues. Question-and-answer sessions and seminars aimed at clarifying facts and values in current issues will be central features. The programme should also serve as a resource for other stakeholders in the future licensing process.

A feasibility study for the transparency programme revealed high expectations on the part of central actors in the nuclear waste issue. Among other things, an immediate need was found for a thorough elucidation of questions concerning "deep boreholes" as an alternative to the so-called KBS-3 method. KASAM therefore held a question-and-answer session concerning this method on 14–15 March 2007. Some of the questions that were raised were: What are the technical, geological and hydrological premises and possibilities? What are the risks from different viewpoints and what values underlie different views of the potential and suitability of deep boreholes?

This report contains presentations and discussions from the question-and-answer session and concludes with an analysis of the arguments proffered by various actors.

This report and the presentations from the question-and-answer session are available on our website www.karnavfallsradet.se.

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