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KASAM
STATENS RÅD FÖR KÄRNAVFALLSFRÅGOR
National Council for Nuclear Waste

STATENS OFFENTLIGA UTREDNINGAR

Safety assessment of final disposal nuclear waste

– role, development and challenge

An in-depth report supplementing KASAM's Nuclear Waste State-of-the-Art Report 2007 (SOU 2007:38)

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Swedish National Council for Nuclear Waste (KASAM) M 1992:A

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Preface

The Swedish National Council for Nuclear Waste (KASAM) has deemed it appropriate to treat the safety assessment in an in-depth report supplementing KASAM's Nuclear Waste *State-of-the-Art Report 2007 (SOU 2007:38). The report is entitled Safety assessment of final disposal of nuclear waste – role, development and challenge.*

This in-depth report contains contributions from individuals active within KASAM. The report was prepared by a working group consisting of Kjell Andersson (consultant), Sören Norrby (consultant), Eva Simic (secretary) and Clas-Otto Wene (member of the Council).

KASAM has not issued a detailed judgement of the contents of the in-depth report, but finds on the whole that it provides a complex and fascinating picture of the complex of problems surrounding the nuclear waste.

Stockholm, May 2007

Kristina Glimelius
Chairperson

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1 Introduction

The safety assessment has the main role in demonstrating the long-term safety of a final repository in Swedish bedrock for spent nuclear fuel and high-level radioactive waste. The nuclear power industry's joint company, Svensk Kärnbränslehantering AB (the Swedish Nuclear Fuel and Waste Management Co), intends to submit its application for a permit to build a final repository in 2009. The safety assessment of the planned repository on the proposed site will be one of the most important components of this application. It will be reviewed by the Swedish Nuclear Power Inspectorate (SKI) and the Swedish Radiation Protection Authority (SSI) in their capacity as regulatory authorities[1], presumably with the support of extensive national and international expertise. The decision to grant or deny a permit will be made by the Governtment. It is a political decision with great consequences for both the concerned municipalities and national energy policy. A political decision of this scope requires the broad participation of all concerned parties, which means that the content of the safety assessment must be explained and discussed outside the circle of experts. This booklet is an attempt to explain the fundamental features of the safety assessment.

When SKB performs its safety assessment for the application in 2009 and when SKI and SSI review it, they will profit from an international method development effort that has been going on for over three decades. Method development of the safety assessment has been pursued in most nuclear power nations with a continuous exchange of experience between researchers and

[1] The SKI and SSI were in July 2008 merged into a new authority – the Swedish Radiation Safety Authority. As this report was written in 2007, it refers to the old situation before the merger. However, the two separate sets of regulations and guidance documents that relate to the Nuclear Activities Act and the Radiation Protection Act are still valid. Now they shall be coordinated within the new authority instead of between the two separate authorities SKI and SSI.

experts, both by direct cooperation and via the OECD's Nuclear Energy Agency (NEA).

In response to the requirements (an "absolutely safe" final disposal) in the Stipulations Act of 1977, the safety assessment work got under way early in Sweden with the involvement of both the nuclear power industry and the regulatory authorities. SKI in particular, but also SSI, was a driving force behind the international development work as well. Sweden has constantly been in the forefront and occasionally a leader in the development of safety assessment methods.

The challenges to be met by the safety assessment are many. It must judge and bring together information from a very large number of scientific fields. The information is used to evaluate the risks of harm to man and the environment caused by the final repository during an extremely long period of time – up to a million years. This involves identifying all processes and events during this long period of time that could pose a threat to the ability of the different barriers to prevent or retard the transport of radionuclides from the fuel to man and the environment. The properties of the fuel itself, including its low solubility in groundwater, constitute the first barrier to dispersion, while the copper canister is the second one – as well as the most important "engineered barrier". The rock is the most important "natural barrier". The safety assessment must – based on the properties of the barriers and the processes and events that can affect these properties – identify all possible pathways over which radionuclides can be transported. The safety assessment also includes evaluating, by means of various calculation methods, the probabilities of harmful effects on man and the environment. The transport pathways in the biosphere can dilute the radionuclides, but also concentrate them, so that even a small leakage from the final repository can have consequences for life and health.

The quality of the safety assessment in SKB's application must be checked very carefully. This includes the completeness of the description of processes, events and barrier properties that might possibly affect the performance of the repository. The calculations of, for example, water movements through the repository must be verified, in other words it must be checked that the applicant has calculated the effects of all natural processes that affect water movements on the selected site, with the properties the repository will have after closure. The regulatory authorities establish criteria and norms which the repository must satisfy to be considered safe, and an important part of regulatory review is verifying that SKB has interpreted and applied these criteria and norms correctly. But the interactions between barrier properties, processes and events during the long period of time are very complex. Even after three decades of extensive research and development, considerable uncertainties remain with regard to the description of processes, events and barrier properties, as well as with regard to the calculations of the repository's ability to prevent radionuclides from escaping and harming man and the environment. It is the applicant's responsibility to identify these uncertainties and show that, taken together, they do not comprise an obstacle to the safety of the repository.

Responsibility for the review of the safety assessment rests with SKI and SSI, who have prepared for this task by initiating their own method development and conducting their own safety assessments, as well as by building up an extensive network of national and international experts. However, as has already been pointed out, responsibility for the decision to build or not to build the repository rests with the country's political bodies, and ultimately with the Government. Even if the review requires complex analyses, the actual review process must therefore be clear and transparent so that it can be followed by affected citizens, who must also have opportunities to pose questions during the process.

The following chapter discusses the role and development of the safety assessment from the mid-1970s until today. Chapter 3 describes how the safety assessment is conducted today, and Chapter 4 gives the regulatory requirements on the assessment. Conclusions and reflections are presented in Chapter 5.

2 Three decades of safety assessment

2.1 The strategic role of the safety assessment has driven its development

The mid-1970s is a natural starting point for a discussion of the development of the safety assessment for final disposal of spent nuclear fuel and high-level nuclear waste. The division of responsebility between state and reactor owner was regulated in such a manner that the industry was given clear responsibility for final disposal of the nuclear waste, with SKI and SSI as supervisory authorities. A new regulatory authority, as of 1985 named the National Board for Spent Nuclear Fuel (SKN), was given the task of reviewing the industry's research and development programme for final disposal[1]. SKN was disbanded in 1992 and most of its activities were transferred to SKI.

The Stipulations Act made demonstration of an "absolutely safe" final repository a prerequisite for commissioning nuclear power plants and raised the status of the safety assessment to a strategic issue for the nuclear power industry from the start. The requirement of guaranteeing an "absolutely safe" final repository prior to a Government decision has disappeared, but the requirement of demonstrating a *sufficiently* safe final repository is unchanged, and the safety assessment remains a strategic activity.

The *focus* of the activity, i.e. the special questions which the safety assessment is supposed to answer, has shifted during the three decades that have passed since the mid-1970s from questions relating to the possibility of building a safe final repository

[1] The authority had originally been established in 1982 under the name "National Board for the Management of Spent Nuclear Fuel" (NAK). Its main task was to administer the government financing system that had been introduced at that time. But NAK also followed the industry's research and development work on the nuclear waste issue.

somewhere in Swedish crystalline bedrock to the prioritization of research and development (R&D) and design of a final repository on a selected site. The division of responsibility between state and industry has been the same during these three decades, but the roles of the actors in the safety assessment process have varied. In addition to national politicians and decision-makers in regulatory authorities and industry, municipal authorities and local citizens are now also considered to be important stakeholders. During the first few years, the nuclear power industry took the initiative in the development of safety assessment methodology, but during the 1980s and 1990s the regulatory authorities took over much of the methodology development work. The industry took back the initiative during the late 1990s.

The methodology development discussion is simplified if it is kept in mind that a safety assessment contains three elements around which the development work is concentrated:

- *A normative part*, which defines the norms and criteria that are to be satisfied.
- *A descriptive part*, which identifies features, events and processes that control the evolution of the repository.
- *A calculative part*, which makes it possible to obtain a conceivable picture of the repository's evolution over time.

The purpose of the calculative part can be said to be to tie together the normative and descriptive parts by showing that a repository that is controlled by the identified features, events and processes either satisfies or fails to satisfy the defined norms and criteria. The contents of the descriptive part and the calculative part are the responsibility of the applicant; SKB can be said to "own" these two parts of the application. The regulatory authorities review the two parts, for example the completeness of the descriptive part and the correctness of the calculations, and approve or reject SKB's work. The normative part, however, is owned by society – political decisions have assigned SKI and SSI the task of administering ownership of this part. They do this by setting up criteria and norms for the final repository based on science and proven experience and the regulatory authorities' interpretation of the risks which society considers acceptable. Given criteria and norms are interpreted by SKB and the regulatory authorities review and correct this interpretation. An interesting question is how the normative part is to be regarded when the regulatory authorities finally refer the matter to the Government for a decision. Responsibility for the next step in the decision process is hereby shifted to the political system (the Government), which decides whether construction of the proposed final repository is compatible with the risks society considers acceptable. After making a decision, the Government can give the regulatory authorities a renewed mandate to administer the normative part (e.g. issue conditions). This procedure clarifies the role of the political system in defining and legitimating the risks which society can accept from a final repository.

The unique requirement on a final repository is that it must be safe for an exceptionally long period of time, up to a million years. This long timespan results in large *uncertainties* depending on whether all natural processes have been included and correctly described, whether events with low probability but large consequences have been taken into consideration, whether the calculations are correct and whether the given norms and criteria are relevant. The discussion of the effects of these uncertainties is a part of the safety assessment, while studies of different ways to handle the uncertainties are a part of method development. We will return to this in Chapter 3.

An overview of the different phases undergone by the safety assessment during the past three decades is presented below. It is hoped that this overview will provide a background for a better understanding of the discussions of the current situation regarding methodology and regulatory requirements in the two following chapters.

2.2 The "pioneer period" – identification of processes and rock properties

The period from the mid-1970s to the early 1980s was characterized by an attempt to develop a legitimate and effective concept for a final repository. SKBF (SKB's predecessor) led the use and development of safety assessment. The goal was to identify processes and properties (features) of the crystalline bedrock that are crucial for the safety of the repository. The analysis included strengths, weaknesses and threats to the different barriers: fuel >

canister > backfill > rock[2]. A milestone was the safety assessment in the KBS-1 report, on which the 1978 application under the Stipulations Act for permission to start the Ringhals 3 reactor was based. This was the first time all available knowledge was gathered in a safety assessment for a final repository. The proposal was based on reprocessing of the fuel abroad and subsequent disposal of the vitrified high-level waste in the Swedish bedrock. During the period immediately following KBS-1, the reprocessing line in the Swedish programme was abandoned in favour of direct disposal of the spent nuclear fuel, i.e. final disposal without prior treatment according to the KBS-3 method.

2.3 Prioritization of R&D – international calculation methods

When permits were to be issued in 1984 for the two last reactors (Oskarshamn 3 and Forsmark 3), the requirement of the Stipulations Act on an "absolutely safe" final disposal had been replaced by a requirement in the Nuclear Activities Act that final disposal should take place in "a safe manner" (Section 10). This change does not reflect a relaxation of the requirements, but was done to arrive at a more scientifically correct and reasonable means of expression. The Government bill on which the Nuclear Activities Act is based states that in order to get a fuelling permit "the reactor owner must have demonstrated an acceptable method with respect to safety and radiation protection for management and final disposal" of the spent nuclear fuel (Gov. Bill 1983/84:60 p. 46). To this was added a section (Section 12) stating that the reactor owner shall have presented a programme for the research and development (R&D) needed to realize a safe final disposal.

Demonstrating an acceptable method (KBS-3) was thus to be supplemented with continued R&D. Expectations were also great on the ability of the safety assessment to provide guidance for prioritization of this R&D. Since then, regular R&D programmes (later called RD&D programmes) have been presented in accordance with the requirements of the act. On certain occasions, SKB has also presented new safety assessments. However, the

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2 This type of analysis is usually called a SWOT analysis (strengths, weaknesses, opportunities, threats).

safety assessment has not provided as clear guidance for the RD&D work as many had anticipated in the mid-1980s.

In the early 1980s, a vigorous effort was commenced at SKI to develop a methodology for safety assessment. The idea was that the safety assessment should be the central instrument where all knowledge of the various aspects of final disposal was gathered for an assessment of its safety. It was particularly important for SKI to have competence and resources in this particular area in order to be qualified to pose the critical questions to SKB. The effort was long-term and was aimed at the examination of an application for the final repository. The intention was also that expertise in safety assessment would also enable SKI to identify particularly important issues in the RD&D review. Through the years, this development effort by SKI has been followed by a similarly strengthened function at SSI as well.

SKI and SSI thus became the driving forces behind the development of the safety assessment. The focus was on the *calculative part* with a series of international projects for validation of calculation models and execution of the whole calculation chain in a safety assessment. These projects – for example HYDROCOIN, INTRAVAL and BIOMOVS[3] – amassed knowledge on the capabilities and limitations of the models while also being an effective means for the Swedish regulatory authorities to improve their competence in this field.

2.4 Systematization

SKI's effort to develop its "own" safety assessments started with Project-90 and culminated with SITE 94. Through these projects SKI built up an internal capacity in the area. Even though they didn't have all the necessary resources internally, by combining internal resources with Swedish and foreign consultants and other international experts they mastered the entire calculation chain. Success achieved elsewhere, mainly at Sandia National Research Laboratories and the OECD/NEA, could be "brought home" and applied to Swedish conditions. In SITE 94, an attempt was made to transform raw data from test drilling and measurements (from the

[3] This project was aimed at quality assurance of calculation models for groundwater flow and radionuclide migration in the rock and in the biosphere by comparing calculation results with experiments.

site of the Äspö HRL) into input data for the safety assessment models for groundwater flow and radionuclide transport in the bedrock.

A driving force behind SITE 94 was to systematize and formalize the descriptive part and the calculative part as far as possible. One feature, in deference to the international trend in the area, was the introduction of FEP databases, where FEP stands for Features, Events and Processes. The intention is that these databases should contain information on all repository features, events and processes that could possibly influence the evolution and safety of the repository. The relationship between different FEPs can be visualized by matrices or influence diagrams. The FEP databases comprise the basis for the descriptive part of the safety assessment. Methods were also developed to describe the connection between the models that were used to calculate the effect of different FEPs on the repository. The information flow between the models can be depicted in diagrammatic form in an Assessment Model Flowchart, AMF. A big step was also taken towards a systematic handling of different kinds of uncertainties (see next section). The idea was that systematization and formalization of the safety assessment would provide the platform for total quality control of future safety assessments.

2.5 Consolidation – preparations for the real thing

SITE 94 is the latest safety assessment produced by the regulatory authorities. After this, they had to concentrate their resources on reviewing SKB's RD&D programmes and safety assessments as well as SKB's site investigation programmes, which started in 2002. For its part, SKB has, since the start of the 1990s, conducted extensive development work with the ultimate aim of acquiring the knowledge and resources needed to produce the safety assessment that will serve as a basis for an application for a permit to build a final repository – SR-Site. This work has resulted in several important safety assessments and method reports, all of which have been reviewed by SKI and SSI:

- The purpose of the SKB 91 safety assessment was to examine how long-term safety in a final repository is affected by the geological features of the site. The report, which used data from

Finnsjön in northern Uppland, also served as a basis for SKB's continued work to systematize all steps of the safety assessment.

- In SR 95, SKB presented a template for future safety assessments.
- The SR 97 safety assessment came in response to a request by the Government and the regulatory authorities that SKB should present an assessment of the long-term safety of a final repository, the aim being "– to show, in a credible manner, that the KBS-3 method has good prospects of complying with the safety and radiation protection criteria that SKI and SSI have stipulated in recent years"[4]. Geological data were taken from Äspö, Finnsjön and Gideå in Ångermanland. SR 97 received quite a bit of criticism from SKI and SSI, who said that the methodology used in SR 97 had shortcomings, for example when it comes to determining which scenarios should be analyzed. They also said that the connection between safety assessment and site investigations should be improved.
- In 2004, SKB presented an interim report on the safety assessment SR-Can (SKB Technical Report TR-04-11), which was mainly concerned with demonstrating the methodology for the safety assessment on which SKB's application for a permit to build an encapsulation plant for spent nuclear fuel is based (SR-Can).
- In 2006, SKB presented SR-Can (SKB Technical Report TR-06-09), which is an important step along the way towards the final safety assessment SR-Site, on which SKB's application for a permit to build the final repository is based. The regulatory review of SR-Can is still under way in 2007.

The work with SR-Can has proceeded in parallel with the site investigations at Forsmark and Oskarshamn, and the result has been the first site-specific safety assessment where it is possible to compare properties at the different sites and their impact on the calculation results. Thus, the focus has gradually been shifted from R&D and scenarios with generic data (general data obtained under similar conditions at other places) to preparations for a licensing process. The challenge is to use actual data from actual sites in the safety assessment models in a quality-controlled fashion. This has

[4] The Swedish Nuclear Power Inspectorate's evaluation of SKB's RD&D-Programme 98 for treatment and final disposal of nuclear waste, SKI Report 99:31, p. 12.

entailed an emphasis on *the descriptive part* of the safety assessment.

In parallel with SKB's work with SR-Can, the regulatory authorities, particularly SSI, have issued new regulations and general recommendations that affect the form and content of the safety assessment. In other words, the development work in recent years has also been focused on *the normative part.* SKB has developed a concept with safety functions designed to satisfy the criteria and norms stipulated by SKI and SSI.

The improved and increasingly detailed safety assessments have made it increasingly demanding to communicate the safety assessment to persons outside the circle of experts. At the same time, laymen have increasingly become the new "clients" for the safety assessment – particularly politicians and private citizens in the site investigation municipalities. We will return to this problem in the next chapter.

3 Methodology

3.1 Risk and safety – defining the concepts

Risk in everyday speech is the likelihood that something undesirable will occur. However, the concept also includes the consequences of the undesirable event. Some risks have a high probability but small consequences, while with others the reverse is true. For example, you know when you undergo an X-ray examination at the hospital that you get a small dose of radiation that entails a slight additional risk of getting cancer later in life. In this case the probability of getting the dose is 100 percent, but without it the examination would be meaningless. On the other hand, the consequence is negligible for the individual. It is not possible to show that an individual got cancer as a result of one particular examination, even though it makes a small contribution to the risk. When you get in an airplane to go on a vacation the risk profile is the opposite – the probability of being involved in an airplane accident is very small, but if it happens the consequences are often disastrous.

Probability and consequence are thus both important in our risk assessments, and in professional contexts risk is defined as the probability of harmful events multiplied by the average harm or loss (consequence) caused by them. As individuals, we make risk assessments almost purely intuitively. It can also happen that we downgrade the risk more or less deliberately, since we want to do something special or find it hard to resist a habit.

The situation is different when it comes to risks that are forced on us – for example by an industrial facility in our vicinity or global risks such as climate change. Experts often want to compare such risks with the risks we take in our private lives. In such contexts our unwillingness to accept risks imposed from the outside, which may be much smaller mathematically than voluntary risks, may be regarded as irrational. From the individual's viewpoint, however, it may be rational to accept greater risks at the personal level than those that are imposed from the outside. Another factor of importance is whether we can ourselves influence the consequences of an undesirable event or not. A distinction can also be made between risks where we benefit from the advantages ourselves and risks that have no personal advantage for us. In other words, our risk evaluations include not just probability and consequence but also different values. Whether the risk is voluntary or involuntary, whether we believe we can influence the consequences or not, whether the risk arises in the near or far future and what advantages are associated with the activity that gives rise to the risk are just some of the possible evaluation criteria. The decisions to be taken concerning the final repository entail risk evaluation on both the expert and political levels and contain all of these components, i.e. the mathematical definition of risk, values and how the individual perceives the risk from a final repository (risk perception).

The concept of *safety* has to do with the absence of risk, but it can also mean certainty that all reasonable measures have been taken to avoid unnecessary risks. We feel safe when we know that everything possible has been done to avoid the risks and when we have confidence in those who are responsible for this. In the nuclear waste field, safety assessments are done to judge whether the final repository meets, for example, SSI's risk criterion (i.e. the mathematical definition of risk). But it isn't enough that the assessments show this; people must have confidence in the whole safety assessment process. This is where the broader concept of "safety case" enters the picture.

The total safety assessment of a final repository (often termed "safety case"[1]) will be composed of a broad range of arguments. Naturally, the results of the safety assessment will be a central part. However, just as important as the quantitative results is the qualitative assessment of all the work underlying the safety assessment: the quality of the underlying research, the quality assurance of the different steps in the assessment and how the results are presented. In addition there is everything that lies outside the safety assessment, for example the robustness of the

[1] The term "safety case" originally comes from the area of reactor safety. For more information see the report "Post-closure Safety Case for Geological Repositories," OECD/NEA, 2004.

final repository's system of barriers, quality control of the barriers and the safety culture of those who build the repository.

3.2 What is a safety assessment?

Risk assessments are usually based on experience. We know, for example, that the probability of an airplane accident is extremely small. Smoking and road traffic are other areas where reliable statistics exist concerning the risks. When it comes to a final repository for nuclear waste, risk assessment is more difficult since there is so little experience to build on. And not just that – the long periods of time (hundreds of thousands of years) covered by the assessment make it unique. What can be done is to calculate the risk using more or less theoretical methods. But it is not just the lack of experience and the extreme timescale that makes the safety assessment for the final repository unique. The system that must be analyzed is very complex, involving such aspects as geology, hydrology, geochemistry, materials science, seismology, radionuclides and radiation. Knowledge from all of these areas must be integrated in the calculations.

Unfortunately it is not as simple as calculating a single risk figure for the final repository. The problem is that many possible events must be included in the calculation, and each event has its own probability and consequence – in many cases it is very difficult, not to say impossible, to calculate the probabilities of possible events. SKB must nevertheless be able to show that SSI's risk mitigation requirements can be met with high probability. In the *safety assessment*, an attempt is made to systematically analyze all conceivable courses of events. Answers are sought to the following three questions:

- What courses of events are possible?
- What are the consequences?
- How great is the probability of different courses of events?

Possible courses of events in the final repository and its surroundings must first be identified. In the safety assessment, courses of events are called *scenarios*. One scenario is that the final repository functions roughly as intended and that the barriers remain intact for hundreds of thousands of years. Another scenario is that one or more canisters have a defect that results in leakage of radionuclides at an early stage. Yet another scenario is that an earthquake or a future ice age damages parts of the repository – and another is human intrusion into the repository.

The courses of events in different scenarios are described with mathematical models that include groundwater flow, corrosion, radionuclide transport, etc. Carrying out the calculations included in the safety assessment also requires data – both generic data and site-specific data. Site-specific data are obtained from the site investigations that SKB is conducting in Forsmark and Oskarshamn/Laxemar, while generic data are obtained from other studies in the field or laboratory. The safety assessments are becoming increasingly site-specific as SKB's site investigation programme progresses. A site-specific safety assessment – which is required in this case when two sites (Forsmark and Laxemar) will be compared and the most suitable one selected – requires above all site-specific data. To some extent, however, generic data may still be needed if the site investigations have not provided enough data.

The safety assessment is based on a description of current conditions in the geosphere and the biosphere, which are in turn based on the results of the site investigations. The goal, however, is to estimate dose/risk up to a million years after closure. We cannot know with any certainty what the geosphere and especially the biosphere will look like so far in the future. Assumptions must therefore be made. It is also inevitable that the calculations in the safety assessment will contain *uncertainties*. They may be of five kinds:

1. *System uncertainty* describes how well the system has been described, i.e. how complete the defined FEP database is.
2. *Scenario uncertainty* stems from the fact that it is impossible to know whether all important events that should be included in the analyzed scenarios have been taken into account.
3. *Model uncertainty* stems from the fact it cannot be known with certainty whether the models used for evaluation of the scenarios correctly describe all relevant processes (groundwater flow, corrosion, radionuclide transport, etc.). One way to handle model uncertainties is to use different models to describe the system. If different models give the same results, we can have greater confidence that we understand the processes sufficiently well than if they give different results.

4. *Parameter uncertainty* is uncertainty in the values of the individual parameters in the models. Parameter uncertainty is often handled in the calculations by using a wide range of values.
5. *Uncertainty due to the spatial variation* in the parameters used to describe the barrier functions of the rock (for example with regard to water flow).

These uncertainties can be linked to two of the three elements in the safety assessment defined in Chap. 2: system uncertainty, scenario uncertainty and uncertainty due to the spatial variation of the parameter values are associated with the descriptive element, while model uncertainty and parameter uncertainty belong to the calculative element.

3.3 Safety assessment method

Every safety assessment must evaluate the significance of the lack of knowledge that is reflected in these uncertainties. The important thing is showing that all major uncertainties have been dealt with and that their impact on the calculation results has been made clear. Naturally the uncertainties must be minimized, for example by conducting more thorough investigations of the site for a final repository. But it is unavoidable that uncertainties will remain when decisions have to be made. It must therefore be possible to estimate the uncertainties and understand how they can affect the results. When the size of an uncertainty cannot be determined by measurements, various methods for *expert elicitation* must be resorted to. Another method is to make pessimistic or conservative assumptions in the calculations, in other words to use models and parameter values that give a greater calculated risk than more realistic, but uncertain, values. This increases the likelihood of being “on the safe side”.

A distinction must be made between uncertainties that are due to incomplete knowledge and uncertainties that are due to natural variations. The former can be reduced by greater knowledge, but this is not the case with uncertainties due to natural variations. For example, the permeability of the rock to groundwater can vary a great deal over the final repository area. It is therefore necessary to differentiate between variation, whereby the value of a parameter varies from one place to another, and parameter uncertainty, which entails that the parameter has a specific value that has not been established with certainty.

It is important to have systematic methods for identifying and structuring uncertainties and for handling them through the various steps of the safety assessment in a traceable manner. There are two possible approaches for handling uncertainties that arise when the three questions raised in Section 3.2 are to be answered. One way is to try to construct as complete a set of scenarios as possible and calculate the consequence and probability of each scenario. If it were then also possible to estimate all the uncertainties and natural variations included in the calculations, a dose with an uncertainty interval could be calculated for each scenario. Finally, if the probability of each scenario could be specified, the total risk from a final repository could theoretically be calculated. This is called the *probabilistic* method.

The other method, which is called *deterministic*, is based on a smaller number of scenarios whose consequences (radiation doses) can together be judged to cover most eventualities. If all scenarios give acceptable doses, it can be assumed that the final repository will perform safely. Unfortunately, probabilities cannot be neglected with this method either. There will always be improbable, but conceivable, scenarios with great consequences. In order to weigh them into the total safety assessment, the probability of their occurring must be taken into account.

Different importance is given to the probabilistic and the deterministic method in different countries. But the difference between the two methods should not be exaggerated, since reasonability assessments must be made in both cases as to whether the number of scenarios is great enough. There is an element of probability assessment in the deterministic method as well, and in the end the consequences are calculated with the same types of models. In Sweden the emphasis was on the deterministic method for a long time. The farther the nuclear waste programme has progressed, the more data it has been possible to gather for probabilistic calculations, while scenario uncertainty and model uncertainty must still be handled deterministically. In practice, the safety assessment has therefore become increasingly probabilistic, but with considerable deterministic elements.

An example of how a safety assessment can be carried out is the methodology SKB uses in SR-Can, where ten steps were defined and used:

1. Identification of factors that may be of importance for safety: All factors to be included in the analysis are identified in this step. FEP databases are used here.
2. Description of the final repository's initial state: Description of the final repository's initial state is based on specifications for its design, a site descriptive model and a site-specific layout of the repository.
3. Description of external factors: The external factors are divided into three categories: Climate-related issues, large-scale geological processes and effects, and future human actions.
4. Description of processes: Based on the previous FEP analysis (step 1), the processes to be included in the analysis are identified. For each process, a general description, the time period in which the process is of importance for other coupled processes, and how it is handled in the safety assessment are documented.
5. Definition of safety functions: Here a number of safety functions are defined, along with how these safety functions can be evaluated with the aid of a number of parameters that are in principle measurable or can be calculated.
6. Compilation of data for the calculations.
7. Definition and analysis of the repository's "reference evolution", which comprises a possible evolution of the repository. The reference case is defined and analyzed in this step. Among other things, the isolating and retarding (in the event of leakage from the canisters) functions of the system are analyzed.
8. Selection of scenarios: A main scenario is defined in this step in accordance with SKI's regulations SKIFS 2002:1. A number of additional scenarios are defined that focus on analyzing the safety functions defined in step 4, but also additional scenarios that must be investigated in accordance with SKI's regulations.
9. Analysis of selected scenarios: In this step a risk contribution (to the total estimated risk, which is then compared with SSI's risk criterion) is calculated for each scenario.
10. Conclusions: Here the results of the different analyses are integrated and an assessment is made as to whether the regulatory requirements are satisfied. Here feedback also takes place

to design, continued site investigations and continued research and development activities (the RD&D programme).

These steps can in turn be associated with the three steps/elements described in section 2.1. Steps 1–4 comprise the descriptive element, step 5 belongs to the normative element and steps 6–7 constitute the calculative element. Then the scenario uncertainties are dealt with in SKB's steps 8 and 9.

3.4 The role of the safety assessment in the decision process

The results from the safety assessment are used in the first place to determine whether the selected final disposal method and the selected site meet the regulatory requirements (see Chap. 4), but they also provide feedback to continued site investigations, research and design of the final repository. The safety assessment is a part of the body material that is reviewed by regulatory authorities and other actors. Ultimately it serves as a basis for the political decisions to be made by the Government and the municipal council in the municipality in question. The process can be described in brief with the following steps:

- SKB submits the safety assessment as a part of the supporting material for a decision on the siting of the final repository to show how the final repository meets the safety requirements expressed in the regulatory authorities' regulations.
- The regulatory authorities SKI and SSI review the safety assessment as a part of the application. The regulatory authorities' own experts, their reviewing bodies and various groups of experts and consultants are involved in this review. Tasks in the review include analyzing and evaluating SKB's methodology for the assessment, how data have been used, how the regulatory requirements have been interpreted, etc.
- If SKI (after consulting with SSI) arrives at the conclusion that there are deficiencies in the safety assessment, the Inspectorate can request supplementary material from SKB. If it is found that the results do not warrant the conclusion that the final repository will be sufficiently safe, SKI can reject the application.
- If SKI (after consulting with SSI) finds that SKB's proposal for a final repository complies with the requirements, the matter is

referred to the Government for decision, probably with a proposal for conditions.

- The concerned municipality takes the SKI review report into account, as it is a central factor in the municipality's decision whether or not to support the application (the so-called veto decision in the Environmental Code matter).
- The Government makes a decision in the matter.

This, aside from the next-to-last step, is the decision process under the Nuclear Activities Act. In parallel with this process, the matter is examined under the Environmental Code with requirements on selection of the "best available technology" and an "appropriate" site. SSI makes similar requirements, but while the Environmental Code stipulates separate requirements on "best available technology" and an "appropriate site", site selection is a part of SSI's "best available technology" requirement. In the safety assessment, the selected final disposal method (the technology) is coupled to the specific features of a site and an overall assessment can be made.

The question is now how the safety assessment should be regarded as a basis for a decision. Is it solely an expert product, in which case SKI's decision does not have to be questioned by the political decision-makers, who can instead take other factors into consideration, such as the Environmental Code's general rules of consideration, political conditions in the concerned municipality, etc? Or does the safety assessment, and thereby its review, also comprise part of a body of material that may contain political values? In the latter case, the politicians, as well as private citizens, must be given full insight into the safety assessment.

4 Regulatory criteria and requirements

4.1 Background

General requirements regarding protection of the environment are laid down in the Environmental Code. The Environmental Code also contains requirements on how consultation processes in connection with applications for new facilities and activities should be carried out. These consultation processes will also be applied for consultations under the Nuclear Activities Act. The Environmental Code requires that the best available technology (BAT) must be used and that an account must be given of alternative designs of the facilities included in an application.

More detailed requirements on the nuclear facilities and activeties are made in special legislation via the Radiation Protection Act and the Nuclear Activities Act.

The radiation protection legislation covers all types of ionizing radiation, including natural radiation, and finds application in medical care, industry and research. The radiation protection legislation aims to protect those who work with radiation, but also patients and the public as well as our environment – in short, everyone who may be exposed to radiation.

Nuclear activities are also regulated by the Nuclear Activities Act, a law that focuses on the technical aspects, i.e. how a nuclear activity should be conducted so that facilities and activities do not give rise to accidents or phenomena that might harm man and the environment. The Nuclear Activities Act also regulates matters relating to nuclear material (material that can be used for extraction of nuclear energy) and imposes requirement on safe management.

In addition there are EU directives and international conventions, including the 1997 Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management, that affect Swedish legislation in different ways. Under the Joint Convention, regular reports are made at special conferences on how the Contracting Parties to the Convention are complying with the requirements, including how radioactive waste is managed.

By and large, the Swedish regulatory requirements (laws, regulations, general recommendations etc.) appear to be in reasonable agreement with other countries' requirements. This harmonization can be regarded as a consequence of extensive international cooperation on safety and radiation protection, above all within the framework of various international organizations such as the NEA, the IAEA and the EU, but also in other forms.

The competent authority under the Nuclear Activities Act is the Swedish Nuclear Power Inspectorate (SKI), while the competent radiation protection authority is the Swedish Radiation Protection Authority (SSI). The regulatory authorities are entitled to issue regulations and guidelines/general recommendations. The regulations are binding, while the guidelines/general recommenddations only provide guidance. SKI's regulations focus on the technical system and stipulate requirements on the containment of radionuclides and limitation of their dispersion if they should leak. SSI's regulations aim to protect man and the environment by stipulating requirements on optimization of the radiation protecttion and what risk level may not be exceeded.

4.2 Important aspects of regulatory requirements in connection with assessment of the safety of the final repository

How do the regulatory authorities view the utilization of the safety assessment?

SKI and SSI both regard the safety assessment as a very important instrument for focus, control and verification of the programme. As mentioned in Chapter 2, the regulatory authorities have been a driving force behind SKB's development of safety assessment methodology (model development, competence, capacity) and behind international peer review etc.

Are the regulatory requirements consistent and complementary or conflicting and overlapping?

The regulatory authorities have harmonized their regulations so they are consistent and do not conflict. The regulatory requirements are intended to complement each other.

Even though the regulatory requirements are primarily complementary, they are to some extent overlapping, which can create the impression that the regulatory authorities have different views in different questions (one example is the time perspectives, see below). Preferences have been expressed (above all from municipalities) for better coordination of regulatory requirements and for regulatory cooperation.

Do government regulations give preferential right of interpretation to SKB?

It has sometimes been claimed that government regulations give preferential right of interpretation to SKB. It can be asserted that government regulations impose requirements, while guidelines and general recommendations provide information on, for example, how the requirements can be met. But it is possible for applicants (in this case SKB) to show that there may be other ways to meet the requirements than those indicated by the regulatory authorities in their guidelines and general recommendations. SKB is supposed to interpret the regulations and show that the requirements are satisfied, but this should not be regarded as a preferential right of interpretation, but rather as an obligation of interpretation. In any case, SKB's interpretation will be reviewed by the regulatory authorities, who thereby have the last word.

Clarity in the regulatory system necessary

It is naturally desirable that the regulatory system be so clear that there is limited room for interpretation as regards the requirement level for safety and radiation protection. However, the regulations should be worded broadly enough so that they permit different ways of showing that a method satisfies the requirements (see the purpose of the regulatory authorities' general recommendations). The requirements should be defined (wherever possible) *before* an activity is initiated (e.g. site selection and method selection). However, this point of view cannot be carried too far, since national and international knowledge and experience changes with time and must reasonably be reflected in government regulations as well.

Is there too little insight/transparency in the discussions being held between the regulatory authorities and SKB regarding interpretation of regulations?

This question has sometimes been asked in various discussions concerning regulatory requirements. The regulatory authorities and SKB assert that it must be possible for certain discussions between the authorities and SKB to be held without representatives of municipalities and the environmental movement being present. These meetings (which are not part of the consultation process according to the rules of the Environmental Code, but reconciliation meetings within the framework of SKB's RD&D programme) are documented in notes that are made public after the meetings. The expression "consultations" for the contacts that are regularly needed between regulatory authorities and SKB thus have a different meaning than in the Environmental Code, which has led to misunderstandings. KASAM would nevertheless like to point out that it is very important with a high level of insight into the discussions held between regulatory authorities and SKB regarding e.g. the interpretation of regulations.

4.3 Individual issues of importance

SKI and SSI both stipulate requirements on the structure of the safety assessment – How has SKB responded to these requirements in the safety assessment SR-Can (interpretation and compliance)?

In the safety report SR-Can, SKB presents its view of how the safety assessment for the KBS-3 final repository should be structured and carried out. SR-Can was preceded by an interim report published in 2004 (SKB Technical Report TR-04-11). This report was reviewed by both SSI and SKI (see the joint review report SKI Report 2005:40/SSI Report 2005:13), and the viewpoints expressed by the authorities have largely been taken into account by SKB in SR-Can. Whether there are any remaining or new criticisms cannot be answered now. This will be a question for the review of SR-Can that both the regulatory authorities and KASAM will be involved in during the coming year.

SSI's regulations contain above all a health protection criterion in the form of risk – the annual risk may not exceed one in a million. How can this be shown? How far has SKB come?

SSI has in its regulations (SSI FS 1998:1) stated that in order for a final repository to be accepted, it must be designed so that "the annual risk of harmful effects after closure does not exceed 10^{-6} for a representative individual in the group exposed to the greatest risk" (Section 5). This is equivalent to a dose limit of 0.01 mSv/y, i.e. about 1 percent of the natural background radiation.

The SSI regulations further state:

Section 10
An assessment of a repository's protective capability shall be reported for two time periods of orders of magnitude specified in Sections 11-12. The description shall include a case which is based on the assumption that the biospheric conditions which exist at the time when an application for a license to construct the repository is submitted will not change. Uncertainties in the assumptions made shall be described and taken into account in the assessment of the protective capability.

Section 11
For the first thousand years following closure, the assessment of the repository's protective capability shall be based on quantitative analyses of the impact on human health and the environment.

> *Section 12*
> For the period after the first thousand years following repository closure, the assessment of the repository's protective capability shall be based on various possible sequences for the development of the repository's properties, its environment and the biosphere.

Time periods: SSI makes a distinction between the time periods before and after the first thousand years when it comes to the risk analysis (it is carried out for all times, but the results shall are used in different ways). On the other hand, all time periods are accorded equal importance in the optimization.

Climate evolution: In the section "Selection of scenarios", SSI's guidelines provide a structure for the risk analysis that will have to affect SKB's work in a tangible fashion, especially with regard to climate evolutions. Among other things, SSI says that the risk analysis should be based on a number of possible climate evolutions – a complete glacial cycle and the effects of glacial earthquakes should be included.

Optimization and BAT: According to SSI, experience from risk analyses and the development work on the final repository should be used for optimization and to take the best available technology into account.

Human impact: In its guidelines, SSI describes how SKB should present scenarios for future inadvertent human impact on the final repository. The scenarios should include a case of direct intrusion in connection with drilling in the repository. Such a scenario was included in SR 97, which received a great deal of criticism.

Risk dilution: Risk dilution has to do with events that have a low annual probability of occurring but which will almost certainly occur at some point during a long time period and that can have great consequences when they do occur. The annual risk can then be low if it is calculated in a normal manner in the safety assessment (same probability of the event every year), even though there will almost certainly be great consequences for individuals at some time. How risk dilution is viewed, or should be viewed, is largely a value question. SSI does not express itself more precisely than to say that the effect "should be taken into account in an evaluation of total risk". Here there is a value question that needs to be clarified.

How these questions should be handled should be studied in the review of SR-Can planned by both the regulatory authorities and KASAM, as well as by other stakeholders.

In its regulations, SKI states:

Section 9
In addition to the provisions of Chapter 4 Section 1 of the Swedish Nuclear Power Inspectorate's Regulations (SKIFS 1998:1) concerning the Safety in Certain Nuclear Facilities, the safety assessments shall also comprise features, events and processes which can lead to the dispersion of radioactive substances after closure, and such analyses shall be made before repository construction, before repository operation and before repository closure.

Section 10
A safety assessment shall comprise as long time as barrier functions are required, but at least ten thousand years.

In its general recommendations to the regulations, SKI stipulates:

On Section 9
The safety of a repository after closure is analyzed quantitatively, primarily by estimating the possible dispersion of radioactive substances and how it is distributed in time for a relevant selection of future possible sequences of events (scenarios). The purpose of the safety assessment is to show, inter alia, that the risks from these scenarios are acceptable in relation to the requirements on the protection of human health and the environment issued by the Swedish Radiation Protection Authority (SSIFS 1998:1). The safety assessment should also aim at providing a basic understanding of the repository performance on different time periods and at identifying requirements regarding the performance and design of different repository components.
……….
Based on an analysis of the probability of occurrence of different types of scenarios in different time periods, scenarios with a significant impact on repository performance should be divided into different categories:

- main scenario,
- less probable scenarios,
- other scenarios or residual scenarios.

……….

The lack of knowledge and other uncertainties in the calculation conditions (assumptions, models, data) is denoted in this context as *uncertainties*. These uncertainties can be classified as follows:

- scenario uncertainty: uncertainty with respect to external and internal conditions in terms of type, degree and time sequence,
- system uncertainty: uncertainty as to the completeness of the description of the system of features, events and processes used in the analysis of both individual barrier performance and the performance of the repository as a whole,
- model uncertainty: uncertainty in the calculation models used in the analysis,
- parameter uncertainty: uncertainty in the parameter values (input data) used in the calculations,
- spatial variation in the parameters used to describe the barrier performance of the rock (primarily with respect to hydraulic, mechanical and chemical conditions).

On section 10

The time period for which safety has to be maintained and demonstrated should be a starting point for the safety assessment. One way of discussing and justifying the establishment of such a time period is to start from a comparison of the hazard of the radioactive inventory of the repository with the hazard of substances occurring in nature. However, it should also be possible to take into consideration the difficulties of conducting meaningful analyses for extremely long time periods, beyond one million years, in any other way than through showing how the hazard of the radioactive substances in the repository declines with time.

In the case of a repository for long-lived waste, the safety assessment may have to include scenarios which take into account greater expected climate changes, primarily in the form of future glaciations. For example, the next complete glacial cycle, which is currently estimated to be on the order of 100,000 years, should be particularly taken into account.

In the case of periods up to 1,000 years after closure, in accordance with the regulations of SSIFS 1998:1, the dose and risk calculated for current conditions in the biosphere constitute the basis for the assessment of repository safety and its protective capabilities.

Furthermore, in the case of longer periods, the assessment can be made using dose as one of several safety indicators. This should be taken into account in connection with the calculations as well as the presentation of analysis results. Examples of such supplementary safety indicators are the concentrations of radioactive substances from the repository which can build up in soils and near-surface groundwater or the calculated flow of radioactive substances to the biosphere.

SKI and SSI do not have exactly the same view of the time periods. SKI requires safety assessment for the time periods 10,000 years and 100,000 years (a glacial cycle). SKI's regulations are focused on safety assessment methodology (scenario selection, model verification, uncertainty analysis, etc.). But SKI's regulations do not conflict with SSI's regulations. Nevertheless, it is apparent that there is a strong overlap and that a collaboration between SKI and SSI is necessary. The regulatory authorities therefore plan to conduct a joint review of SR-Can.

4.4 Conclusions

The government regulations provide for the most part a good and comprehensible regulatory framework (even by international comparison). General recommendations and guidelines, regulatory reviews of SKB's safety assessments and international peer reviews of both SKB's and SKI's safety assessments have been driving forces in the development of safety assessment methodology and of government regulations.

The assessment of the long-term safety (for 100,000 years or more) of a final repository is a complex problem. The safety assessment methodology is and will always need to be detailed and complicated. This advanced methodology can be supplemented, but not replaced, by less complicated assessments. There will always be a need for good communication of how basic data have been defined, how the safety assessment has been conducted, what uncertainties exist, how government requirements have been satisfied, etc.

5 Reflections and conclusions

5.1 Elements of the safety assessment

Who owns the safety assessment and its different parts? In Chapter 2, the term *ownership* was used to distinguish between the roles of industry and the regulatory authorities in relation to the different elements of the safety assessment. Ownership gives the right to change and use an element, but it also carries obligations and responsibilities for quality, changes and use. The situation during the developmental phases of the safety assessment can be said to be characterized by co-ownership between SKI, SSI and SKB of the descriptive and calculative parts. This has driven method development and competence building and has promoted international cooperation. However, it is extremely important that this co-ownership should cease when applications have been submitted for the final repository so that the division of roles in the review process is clear and unambiguous. In applications the descriptive and calculative parts are owned exclusively by SKB – with the rights and obligations that accompany ownership. This means that SKB assumes full and undivided responsibility for design, documentation, quality and use of the FEP database and the calculation models that are used in the safety assessment that serves as a basis for applications, regardless of how and by whom these tools have been developed during the co-ownership period.

The normative part of the safety assessment is owned by society and administered during the development phase and during the review process by SKI and SSI. The regulatory authorities issue regulations and guidelines/general recommendations based partly on science and proven experience and partly on their interpretation of the risks society is willing to accept. The normative part and the expertise which the regulatory authorities have accumulated during the development phase constitute the platform from which the review work is conducted. The task of administering the normative part gives SKI and SSI the authority to request supplements to the application if there is any doubt as to whether norms and criteria are satisfied. A supplement may entail that SKB has to modify a description or a calculative part.

Scenarios are constructed from components from the descriptive part, while consequences are calculated with models from the calculative part and are checked against the normative part to determine whether they are acceptable. It is not meaningful to talk about "ownership" of scenarios, since they comprise the common ground where arguments originate and the risks associated with the final repository are discussed.

In a previous report on the decision process, KASAM dealt with the roles of different actors and pointed out the need to clarify how the preparation of the matters by the regulatory authorities (SKI and SSI), the environmental court and the Government Offices should be coordinated[1]. Responsibility for review of the safety assessments rests primarily with the regulatory authorities. But since the matter is subjected to permissibility assessment under the Environmental Code, the role of the environmental court may need to be defined more precisely when it comes to the safety assessment. How does the environmental court intend to review the safety assessment, and how will this assessment be used to examine the matter under the Environmental Code? To what extent do the expert authorities share the administration of the normative part with the court? Can the court have a different valuation of the risks society is willing to accept?

After review, the application is turned over for processing and decision to the political system, consisting in this case of the concerned municipalities and the Swedish Government. They are in principle free to modify the normative part. It is scarcely likely that the municipalities and the Government will alter the assessment of science and proven experience that is made by the expert authorities, but they may make other interpretations of risks society is willing to accept.

[1] KASAM Report 2007:1e.

5.2 Regulatory requirements

Estimating the risk from a final repository is naturally largely a question of science and technology, but in the end it is a question of values and political decisions. The critical phase in terms of how values enter into the assessment, consciously or unconsciously, is in the initial phase, when the questions which the assessment is supposed to answer are formulated. This is done largely by the safety and radiation protection authorities when they issue criteria and other requirements on the final repository, i.e. before SKB does its safety assessment.

The power industry is responsible via SKB for safe management and disposal of nuclear waste, and the regulatory authorities "set the bar" through their regulations. The regulatory authorities act here as interpreters of the prevailing values in society. This is of course not a unique phenomenon for nuclear waste. All of society's norms in the form of laws (acts and ordinances) are based on the ethical and moral values of its citizens. SKI and SSI get their mandates from the Government, but ultimately they are also answerable to the citizens.

SSI's risk criterion was issued by an expert authority and is aimed at other experts who will apply for a permit for a final repository, i.e. SKB. SKI and SSI are expert authorities, but their regulations and guidelines/general recommendations (explaining how the regulations are to be interpreted) must harmonize with the values that exist in society. They must also be explained and communicated to the public. The practical interpretation of SSI's risk regulation incorporates values as well as technology and science. If the public's risk perceptions rest on fundamental values more than feelings, as new research indicates, there should be good possibilities for a fruitful dialogue in society regarding how the concept of risk should be used for a final repository.

It appears as if SKI's and SSI's regulations are harmonized with each other. However, SSI's regulations are based on the need to protect man and the environment, while SKI's regulations have a more technical background and focus on the function of the final repository and the ability of the barriers to contain radionuclides and retard their transport from the repository. This means that there is a possibility of both overlap and conflict between the regulatory requirements. It would appear necessary that the regulatory authorities cooperate not only in the formulation of regulations and guidelines/general recommendations, but also in reviewing how SKB applies the regulations, e.g. in the safety reports published by SKB.

The issue of regulations and general recommendations for safety and radiation protection for a final repository for spent nuclear fuel is very complex. Many types of questions (science and technology, health and the environment, ethics and jurisprudence etc.) must be weighed in the balance so that the regulations and recommendations reflect a requirement level that is sufficiently rigorous for activity operators and regulatory authorities, while at the same time comprehensible to decision-makers, politicians, environmental groups and the general public. This is not an easy balance to strike. The regulatory authorities have tried to do this by issuing explanatory publications and presenting their views at seminars. Nevertheless, SKI and SSI must try even harder to explain, for example by publishing joint pedagogical descriptions of their regulations and general recommendations, and how they intend to judge the safety assessments submitted by SKB for review. KASAM is considering arranging a special hearing session on government regulations and general recommendations.

5.3 The role of the safety assessment under the Radiation Protection Act, the Nuclear Activities Act and the Environmental Code

Are there conflicts with regard to requirements (laws, regulations, general recommendations) between the Environmental Code, the Nuclear Activities Act and the Radiation Protection Act?

The question was taken up at KASAM's seminar on the decision process in November 2006[2]. Good coordination of the decision process will be needed. There is a certain risk of "conflict" due to the fact that the Environmental Code deals with issues of technology (e.g. BAT, "alternative designs") while also dealing with protection against ionizing radiation.

The safety assessment is a component in the site selection. A large number of site-specific factors are weighed into the safety assessment so that an overall assessment of the suitability of the site for a final repository is obtained.

[2] See KASAM Report 2007:1e.

The safety assessment may conclude that several sites satisfy the regulatory requirements so that a comparison between them can be made (based on the margin by which they satisfy SSI's risk criterion). According to the legislative commentary on the Environmental Code (Gov. Bill 1997/98:45, Part 1, p. 220), the most suitable of these sites shall then be chosen (taking into account factors outside the safety assessment as well). But the Nuclear Activities Act makes no such requirement; it is sufficient that the selected site complies with the stipulated requirements.

5.4 Communication of the safety assessment

It is our opinion that the safety assessment is a document which the politicians must consider – and not just accept SKB's safety assessment and SKI's review of it as a set of factual data that cannot be questioned. It is therefore necessary to make the safety assessment transparent so it can be understood by laymen. KASAM pointed out in its review of RD&D-Programme 2004 that "both SKB and the authorities must explain and publish pedagogical descriptions of the safety assessments that have been carried out and the models upon which the assessments are based"[3].

Against this background, the position of the safety assessment today, not least after the publication of SR-Can, is something of a paradox. On the one hand, SR-Can is a very heavy technical report (as it must be) with a large number of technical background reports comprehensible only to specialists. On the other hand, the safety assessment is the most important supporting document for the political decision whether or not to issue a permit for construction of the final repository. If awareness of the nuclear waste issue is not raised among laymen, the political decision process will be susceptible to various manoeuvres and fragmentations[4].

Naturally it is not reasonable to expect politicians in general or other laymen to fully comprehend FEP analysis, groundwater modelling or models for corrosion of the copper canister. But it should be possible to discuss certain fundamental assumptions

[3] Nuclear waste – Barriers, Biosphere and Society (p. 78, SOU 2005:47, English version).

[4] By "fragmentation" we mean that the focus is put on certain isolated parts of the whole issue at the cost of the whole picture.

about the time aspect, what can (and cannot) be predicted over very long timespans, how to regard different scenarios for human intrusion, how to compare the risks from a final repository with other risks, what the safety assessment says about comparisons between sites, etc.

A prerequisite for an effective decision process is that SKB and the regulatory authorities can communicate such matters in a way that inspires confidence. This has a lot to do with government regulations and general recommendations, how SKB chooses to interpret them and on what grounds the regulatory authorities can accept SKB's interpretation.

It is important that this be communicated in the best possible way to decision-makers and the public. The goal of the dialogue is to make the safety evaluation *transparent*, which means making both technical issues and values visible and comprehensible. Good decisions require clarity in both parts, which makes special demands on the decision process. If the experts alone set the agenda, values can easily be overlooked. On the other hand, the technical issues can easily be brushed aside if the decision process is dominated by values. In both cases there is a risk that the supporting material will not cover all aspects of the question.

We in Sweden have a tradition of openness in public life and the public sector. Openness is a necessary, but not sufficient, prerequisite for transparency. Openness means that all reports and other information must be made accessible for public insight via the Internet or by other means. Often, however, the amount of information is too great for the individual citizen to fully grasp what is important. True transparency entails something more: active efforts to promote public insight. KASAM is trying to accomplish this with its transparency programme. SKB, as well as SKI and SSI, have to make an effort to explain the safety assessments that are carried out. It is not simplified assessments that are needed, but pedagogical explanations of the complex assessments. SKI and SSI must see themselves as experts on whom the municipalities and private citizens can rely in the examination process.

5.5 KASAM's role

SKI and SSI are the government authorities who are responsible for the development and execution of safety assessments. KASAM's role in the safety assessment work has primarily been that of communicator, but also reviewer. SKB's triennial RD&D reports give KASAM an opportunity to review and comment on SKB's progress and completed safety assessments. Description and evaluation of the safety assessment work has been an important recurrent theme in KASAM's state-of-the-art reports and exemplifies KASAM's role as a critical communicator of knowledge about the safety assessment. This in-depth report is an example of this part of KASAM's work. KASAM's recently started transparency programme is one way of fulfilling this role. Clarifying the role of the safety assessment in the decision process is one aspect of this work.

6 References

Guidelines on the application of the regulations (SSI FS 1998:1) concerning protection of human health and the environment in connection with the final management of spent nuclear fuel and nuclear waste (SSI FS 2005:5).

Regulations on the Protection of Human Health and the Environment in connection with the Final Management of Spent Nuclear Fuel and Nuclear Waste (SSI FS 1998:1).

IAEA 1997. Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management.

Nuclear waste – Barriers, Biosphere and Society, KASAM's Review of SKB's RD&D-Programme 2004, SOU 2005:47.

Nuclear Activities Act (SFS 1984:3).

Environmental Code (SFS 1998:808).

The Act (1997:140) concerning special permission to load a nuclear nuclear with nuclear fuel etc. (the Stipulations Act).

SKBF/KBS. 1977. Final storage of spent nuclear fuel – Vitrified waste from reprocessing.

SKBF/KBS. 1983. Final storage of spent nuclear fuel. KBS-3 – Spent nuclear fuel.

SKB, 1992. SKB 91 – Final disposal of spent nuclear fuel. Importance of the bedrock for safety. SKB TR-92-20, Svensk Kärnbränslehantering AB.

SKB, 1996. SR 95 – Template for safety reports with descriptive example. SKB TR-96-05, Svensk Kärnbränslehantering AB.

SKB, 1999. SR 97 – Deep repository for spent nuclear fuel. SR 97 – Post closure safety. Main report – Vol. I, Vol. II and Summary, SKB TR-99-06, Svensk Kärnbränslehantering AB.

SKB, 2004. Interim main report of the safety assessment SR-Can. SKB TR-04-11, Svensk Kärnbränslehantering AB.

SKB, 2006. Long-term safety for KBS-3 repositories at Forsmark and Laxemar – a first evaluation. Main report of the SR-Can project. SKB TR-06-09, Svensk Kärnbränslehantering AB.

SKI, 1991, SKI Project-90 , SKI TR 91:23. Swedish Nuclear Power Inspectorate.

SKI, 1996. SKI Site 94. Deep Repository Performance Assessment Project. Volume I. Volume II. SKI 96:36. Swedish Nuclear Power Inspectorate.

SKI/SSI, 2001. SKI's and SSI's Joint Review of SKB's Safety Assessment Report, SR 97, Summary, SKI Report 01:3, Swedish Nuclear Power Inspectorate; SSI Report 2001:02, Swedish Radiation Protection Authority.

SKI/SSI, 2005. Granskning av SKB:s SR-Can interimsrapport: SKI:s och SSI:s bedömning av SKB:s uppdaterade metoder för säkerhetsanalys, SKI Rapport 2005:06, SSI Rapport 2005:03, Statens kärnkraftinspektion, Statens strålskyddsinstitut, Stockholm, Mars 2005.

SKI/SSI, 2005. Review of SKB's interim report of SR-Can: SKI's and SSI's evaluation of SKB's up-dated methodology for safety assessment, SKI Report 2005:40, SSI report 2005:13, Swedish Nuclear Power Inspectorate, Swedish Radiation Protection Authority, Stockholm, July 2005.

The Swedish Nuclear Power Inspectorate's Regulations and General Recommendations concerning Safety in connection with the Disposal of Nuclear Material and Nuclear Waste (SKIFS 2002:1).

Radiation Protection Act (SFS 1988:220).

Stipulations Act (SFS 1977:140).

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

The Swedish National Council for Nuclear Waste – KASAM – is an independent scientific committee within the Ministry of the Environment. Its mandate is to advise the Government in matters relating to nuclear waste and the decommissioning of nuclear installations. KASAM's members are independent 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.

KASAM's activities include describing the state of knowledge in the nuclear waste field every third year in a so-called state-of-the-art report. The 2007 report on the state-of-the-art in the nuclear waste field is the ninth in this series. This year the report consists of a main report entitled *"Nuclear Waste, State-of-the-Art Report 2007 – responsibility of those now living, freedom of future generations"* (SOU 2007:38), plus four in-depth reports. These are:

- *Final disposal of spent nuclear fuel – regulatory system and roles of different actors during the decision process* (KASAM Report 2007:1e),
- *Safety assessment of final disposal of nuclear waste – role, development and challenge* (KASAM Report 2007:2e),
- *Time for final disposal of nuclear waste – society, technology and nature* (KASAM Report 2007:3e) and
- *Risk perspective on final disposal of nuclear waste – individual, society and communication* (KASAM Report 2007:4e).

This report on safety assessment of final disposal of nuclear waste is thus one of the in-depth reports. The purpose is to give the reader a deeper understanding of the role and development of the safety assessment and the challenges facing us.

All reports are available at www.karnavfallsradet.se.

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