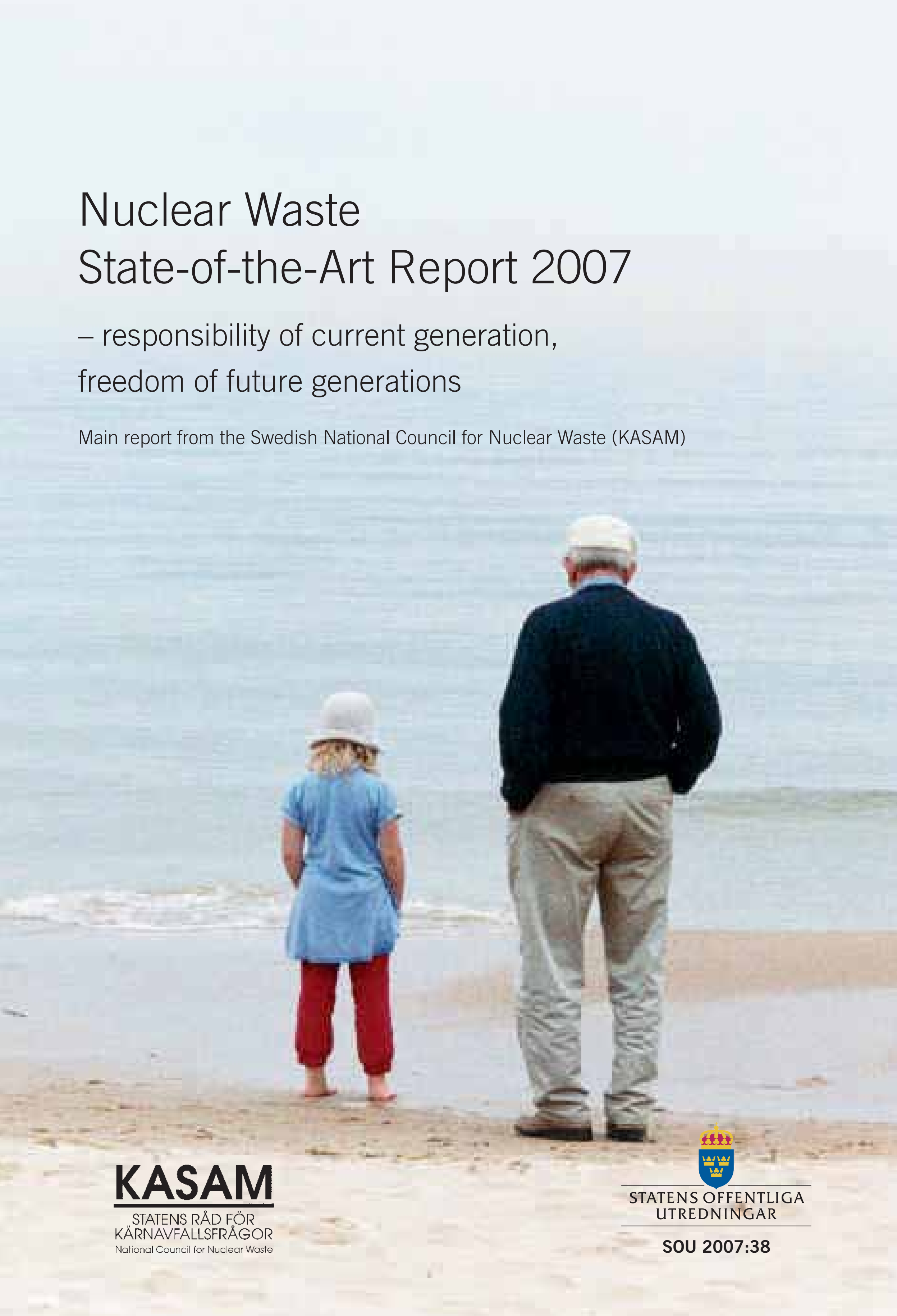

Nuclear Waste State-of-the-Art Report 2007

– responsibility of current generation, freedom of future generations

Main report from the Swedish National Council for Nuclear Waste (KASAM)

KASAM
STATENS RÅD FÖR KÄRNAVFALLSFRÅGOR
National Council for Nuclear Waste

STATENS OFFENTLIGA UTREDNINGAR
SOU 2007:38

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To the minister and head of the Ministry of the Environment

Ever since its establishment in 1985, the Swedish National Council for Nuclear Waste (KASAM) has regularly published reports of its independent review of the state-of-the-art in the nuclear waste field. According to the terms of reference for KASAM issued by the Government in 1992 (Dir 1992:72), such an assessment must be submitted every third year.

KASAM hereby submits its report on the state-of-the-art in the nuclear waste field in 2007, the ninth in this series. This year the report consists of the following 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 fuel – 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).

The main report is endorsed by all members and experts in KASAM. The in-depth reports were produced by different authors, most of whom are closely associated with KASAM.

English versions of the state-of-the-art reports for 1998, 2001 and 2004 are also available.

Stockholm, May 2007

Kristina Glimelius
Chairperson

Preface

The state-of-the-art report presented by the Swedish National Council for Nuclear Waste (KASAM) in 2007 is of a slightly different character than the state-of-the-art reports published previously. This year KASAM felt the need to provide an overall picture in relatively easily accessible form of all its assessments since the first state-of-the-art report in 1986. Some of it has of course been rendered obsolete by subsequent events, but surprisingly much is still relevant.

The 2007 state-of-the-art report should be regarded in the light of the fact that the Government and the relevant regulatory authorities will, within a few years, have to consider applications for permits for final disposal of the spent nuclear fuel from the Swedish nuclear power plants. In the autumn of 2006, the Swedish Nuclear Fuel and Waste Management Co (SKB) submitted an application for a permit to build a so-called encapsulation plant. In 2009 the company plans to submit complete application documents for, among other things, a permit to build a final repository for the spent nuclear fuel. Ultimately it is up to the Government to make a decision on these applications after they have been reviewed in due course by the regulatory authorities and the Environmental Court.

But KASAM does not only wish to present its assessments in collected form. Another purpose has been to describe in general terms the sequence of events whereby these assessments were made. In this way KASAM wishes to contribute to a fundamental understanding of the entire final repository system that has been planned and researched within SKB ever since the late 1970s. By "fundamental understanding" KASAM also means an integrated knowledge of the basic technical and scientific principles of the final repository. These principles must also be integrated and interact with legal, sociological and ethical dimensions in a more comprehensive body of knowledge. Only when our collected knowledge of a future final repository is integrated and harmonized with a broader context of knowledge will we possess a sufficient understanding. The need for such understanding should also be viewed in the light of the vast timespan covered by this project: hundreds of thousands of years.

This means that important decisions must be made on issues associated with the final disposal of Sweden's spent nuclear fuel, including method and site, by national bodies within the very near future. These issues are of national interest. They are nevertheless currently getting only limited attention in the public debate. In both municipalities – Oskarshamn and Östhammar – where SKB is currently conducting site investigations, local politicians and large parts of the populace have a deep engagement and extensive knowledge. But in much of the rest of the country, the nuclear disposal issue is regarded as a "non-issue". KASAM is desirous and anxious to contribute towards strengthening this state of knowledge.

To make it easier for the reader, the 2007 state-of-the-art report has been divided into a general, more accessible and summarizing main report, plus several in-depth reports focusing on special areas. These in-depth reports can be read independently of each other and of the summarizing report. Taken together, they constitute KASAM's report on the state-of-the-art in the nuclear waste field in 2007.

The work of compiling the in-depth reports has been based on the idea that they should reflect the issues relating to the final disposal of the spent nuclear fuel from four different perspectives: decision process, safety, time and risk. Questions concerning the decision process were discussed at a seminar arranged by KASAM in November 2006. The report from the seminar, which was published in early 2007 (Final disposal of spent nuclear fuel – regulatory system and roles of different actors during the decision process, KASAM Report 2007:1e) should also be regarded as an in-depth report to the 2007 state-of-the-art report.

The other in-depth reports are:

- Safety assessment of final disposal of nuclear fuel – role, development and challenge (KASAM Report 2007:2e).
- Time for final disposal of nuclear waste – society, technology and nature (KASAM Report 2007:3e).
- Risk perspective on final disposal of nuclear waste – individual, society and communication (KASAM Report 2007:4e).

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Siv Milton (assistant secretary)

***Consultants*:**
Kjell Andersson, Ph.D. (Transparency programme)
Sören Norrby, M.Sc.
Olof Söderberg, Ph.D.

Contents

1 The nuclear waste

1.1 Energy sources – renewable and non-renewable

Energy sources are usually divided into renewable and non-renewable ones. The renewable sources are replenished at the same rate they are used. They include energy forms such as hydropower, biomass and wind power, which account for about 28% of Sweden's energy supply today. Non-renewable energy sources mainly comprise fossil fuels (coal, oil and natural gas) and nuclear energy.

The non-renewable energy sources were created in the far distant past. The fossil fuels are believed to have originated in tiny marine and aquatic animals and plants that died and settled to the bottom of seas and lakes. Their organic remains were eventually buried under increasingly thick layers of sediment and subjected to increasing pressure and temperature. The most important energy source for nuclear power – uranium – was formed along with other elements even further back in time, before the sun and the solar system emerged from an exploding supernova (see further KASAM Report 2007:3e).

According to an estimate by IAEA-NEA, global uranium resources amount to 16.2 million tonnes. At today's rate of consumption, this amount would last for several hundred years. Furthermore, technical advances towards improved nuclear fuel may enable more energy to be extracted from a given amount of uranium. In addition, there are huge amounts of uranium in sea water, estimated at about 4.5 billion tonnes. Technology for extracting uranium from sea water has been studied, but the costs of large-scale extraction are not known.

1.2 Nuclear fission products

In 1938, physicists Otto Hahn and Fritz Strassman made a remarkable discovery. Following an experiment where they had bombarded uranium with neutrons in order to create a heavier element, they found they had instead obtained atoms with a *lower* atomic number, often radioactive, plus a huge amount of energy. A former Austrian co-worker of Hahn's, Lisa Meitner, who was in Sweden after fleeing from the Nazis, came up with the explanation together with her colleague Otto Frisch during a ski tour outside Kungälv. Instead of forming a heavier element, the neutrons had split the uranium nucleus! In connection with this splitting of the nucleus (fission), mass had been converted to energy in accordance with Albert Einstein's formula $E=mc^2$. The extracted energy was exactly equal to the loss of mass times the speed of light squared. It is this phenomenon that is made use of by nuclear bombs and under more controlled forms and at a slower rate in the roughly 400 nuclear power reactors that are currently in operation all over the world. Three nuclear power plants with a total of 10 reactors are currently in operation in Sweden. They account for roughly half of our production of electricity.

Subsequent research has studied in detail the different products that are formed when the uranium nucleus is split. Besides fission products and lighter atoms, the process also generates neutrons and neutron activation products, of which transuranics (elements with more protons than uranium) are of special interest from a radiation protection point of view. A number of fission products, neutron activation products and transuranics emit *ionizing radiation*, which causes ionizations in the materials it strikes. Some of these radioactive substances (radionuclides) are short-lived, while others decay more slowly and pose a radiation protection problem for a longer time. Fortunately we know how to protect ourselves and other life forms against these radionuclides.

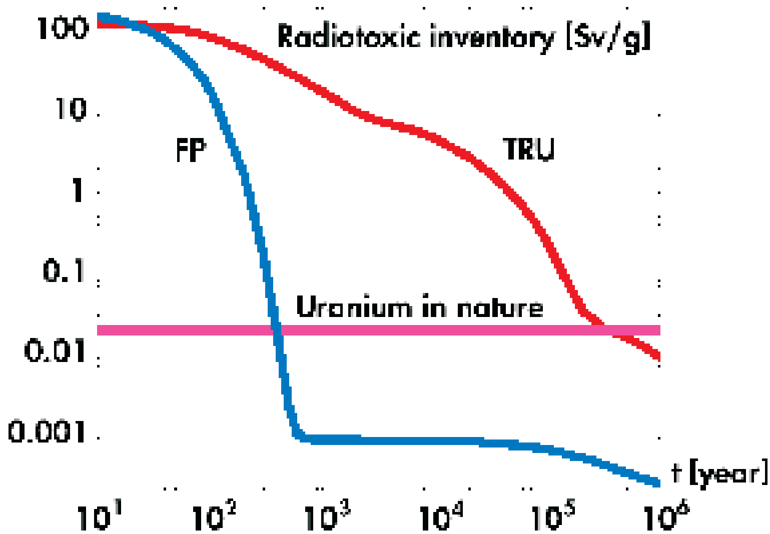
Gamma and neutron radiation from radionuclides penetrate various materials easily and are therefore hazardous even when the radiation source is outside the body. Spent nuclear fuel emits both gamma and neutron radiation with high penetration capacity. The radiation in the vicinity of a bare spent fuel assembly is so powerful that it imparts lethal radiation doses in a short time to an unprotected person even long after being discharged from the reactor.

Other radioactive substances are hazardous if they enter the body via water, food or air and emit their radiation there. Caesium and strontium isotopes dominate this risk during the first few centuries, but gradually transuranics such as plutonium and americium take on increasing importance.

An effective and long-lasting final repository for nuclear waste is achieved by providing engineered and/or natural barriers against the ionizing radiation emitted by the decaying nuclear waste. In Chapter 3 we will return to various alternative methods for designing a final repository with such barriers, as well as other methods for disposing of the waste.

The uranium that is used in a nuclear power plant is loaded into the reactor in the form of fuel rods. Only a very small fraction of the uranium is used up, and when the fuel rods are taken out of the reactor after a few years they still contain about 95% uranium. Only about 4% is fission products and about 1% transuranics. This spent nuclear fuel must be handled with great care. When it is removed from the reactor, it is 10,000 times more radiotoxic than natural uranium. The radiation can cause damage in the form of changes in the DNA molecules in the cells, which can in turn give rise to a higher risk of cancer throughout the person's life and even lead to cell death and tissue damage at high doses. It takes several hundred years for this radiation to decay to the radiation levels in natural uranium. One of these transuranics is plutonium, which has a half-life of about 24,000 years. Figure 1.1 illustrates the radiotoxicity of the spent nuclear fuel and the time it takes to decay.

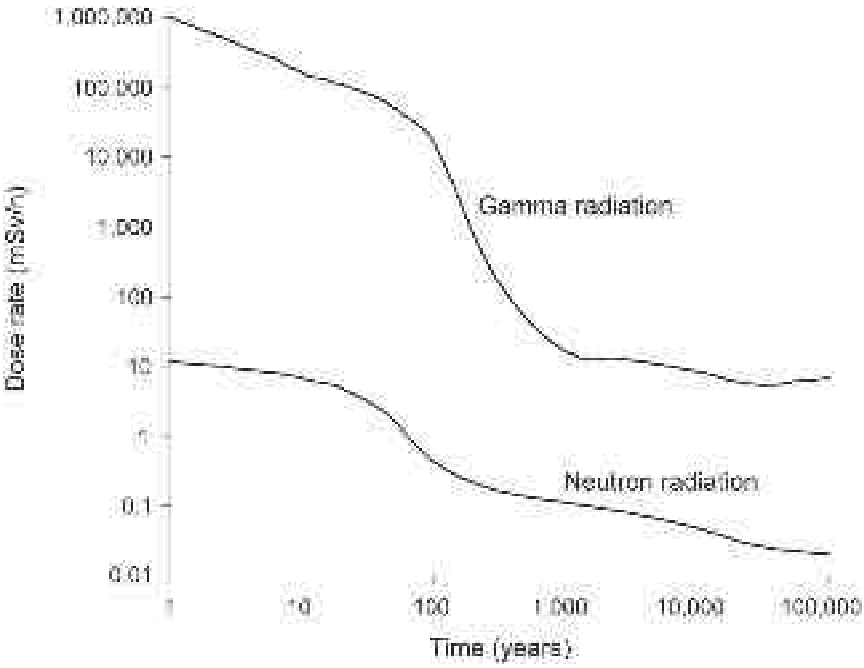
Figure 1.1 Radioactive decay of spent nuclear fuel over time, showing contributions from transuranic elements (TRU) and fission products (FP). The radiotoxicity of the fuel is compared with that of natural uranium ore.



Source: KASAM's state-of-the-art report 2004 (SOU 2004:67, p. 353 of English version).

One point should be made in this context, however. Figure 1.1. cannot be interpreted as implying that the spent nuclear fuel does not pose any radiation protection problems after 100,000 years. Even after this time it continues to emit radiation (see Figure 1.2). At a distance of 1 metre from 1 tonne of unshielded spent nuclear fuel, the gamma dose rate is about 10 mSv per hour (Hedin, 1997). If the cladding is intact, the dose rate is reduced to about 0.1 mSv/h (Håkansson, 2000). By comparison it can be mentioned that the highest permissible level for persons who work with radiation today is 50 mSv over a 5-years period and for private citizens 1 mSv per year.

Figure 1.2 Dose rate (mSv/h) from gamma and neutron radiation at a distance of 1 metre from 1 tonne of unshielded spent nuclear fuel at different times after discharge from the reactor. Note the logarithmic scale. If the cladding is intact, the gamma dose rate is reduced to about 1% of this value (Håkansson, 2000). The gamma radiation level between 300,000 and 1 million years presumably remains at roughly the same level.



Source: Spent nuclear fuel – how dangerous is it? A report from the project "Description of risk" (TR-97-13, p. 23).

Besides the high-level spent nuclear fuel there is also low-level and intermediate-level nuclear waste. The low- and intermediate-level waste is disposed of in a special final repository, SFR, 60 metres beneath the Baltic Sea near the Forsmark Nuclear Power Plant. The intermediate-level waste (water purification filters, protective clothing, tools etc.) is embedded in concrete, while the low-level waste is placed in simpler containers.

The high-level waste differs from the low-level and intermediate-level waste not only in terms of its radiation intensity, but also its heat output. In order to make it easier to handle, the high-level waste requires a cooling-off period so that its temperature declines from about 400°C to below 100°C. This is accomplished by placing the spent nuclear fuel in an interim storage facility. Such a facility (Clab, central interim storage facility for spent nuclear fuel) has been in operation since 1985 at the nuclear power plant on the Simpevarp Peninsula north of Oskarshamn. The high-level spent fuel rods are transported by a special vessel (Sigyn) from the other Swedish nuclear power plants to Clab. Sigyn also transports low- and intermediate-level waste to SFR in Forsmark. About 100 shipments per year are carried by Sigyn.

1.3 Research on the nuclear waste and its effects

The Swedish Radiation Protection Authority (SSI) is responsible for the country's radiation protection and is also responsible for important research in the field. The research is aimed at increasing our knowledge of, for example, the properties of the high-level waste, its effects on humans, animals and plants, and how we can protect ourselves against these harmful effects today and as long as the waste remains hazardous. Another important part of the research is conducted at universities within subjects such as radiophysics, radioecology, physics, chemistry and nuclear chemistry. Research in these fields is also funded by the Swedish Nuclear Power Inspectorate (SKI).

The Swedish Nuclear Fuel and Waste Management Co (Svensk Kärnbränslehantering AB, SKB) was founded by the nuclear power industry, with the primary task to design a final repository system for the spent nuclear fuel. SKB has also carried out various research projects within its field. This research has been reported every third year since 1986 in RD&D programmes (Programme for Research, Development and Demonstration of Methods for the Management and Disposal of Nuclear Waste). Since 2004, SKB's research also includes a special social science research programme. The RD&D programmes, including background reports, have been critically reviewed by the regulatory authorities (SSI and SKI) as well as by KASAM, universities, etc. The most recent RD&D programme was published in 2004 and reviewed by KASAM in a special report to the Government in 2005 (SOU 2005:47).

A central area of importance for our knowledge of the nuclear waste and its effects is radiobiology, i.e. the science of the impact of the ionizing radiation on biological organisms. In this context it can be noted that in the aforementioned report (p. 28, English version), KASAM expressed concern over the current cutbacks in resources disciplines such as radiation physics/radiophysics, radioecology and radiation biology. These resources have been slightly increased by an allocation of an additional SEK 10 million in SSI's 2007 budget for basic research in the field of radiation protection.

As a result of research in radioecology, we now have good and reliable knowledge concerning the cycling of radionuclides in the environment and the effects of ionizing radiation on living organisms. Harmful effects occur only at relatively high radiation doses, and much was learned from the nuclear bombings of Hiroshima and Nagasaki and the nuclear power accident in Chernobyl in 1986. UNSCEAR (the United Nations Committee on the Effects of Atomic Radiation) continuously compiles data on radiation levels and reviews the state of knowledge on the effects of ionizing radiation. The International Commission on Radiological Protection (ICRP) – formed in 1925 – is another important actor in this area, and current radiation protection recommendations rest on a good scientific basis. ICRP's recommendations have been incorporated in relevant Swedish legislation and serve as a point of departure for the requirements and criteria that must be met by a final repository for spent nuclear fuel. We will return with a summary of these requirements and criteria in the next chapter.

There may also be other effects than those due to the ionizing radiation from radionuclides in the final repository which are not included in ICRP's regulations, for example chemically toxic substances in the final repository. KASAM does not address these matters in this report.

1.4 Final disposal in Sweden and internationally

Most countries that have worked with the nuclear waste issue have chosen geological disposal as their main alternative. Examples are Finland, the USA, Germany, France and Japan. Other alternatives have also been discussed, and in recent years there has been some interest in partitioning and transmutation (P&T) (see Chapter 3). But geological disposal – in rock, clay or salt formations – is still the main track. Table 1.1 shows the focus of different countries' final disposal programmes.

Table 1.1 Final disposal of high-level waste (HLW) and spent nuclear fuel (SF) in different countries. All countries are aiming at final disposal with a multiple barrier system at a depth of several hundred metres in different types of geological formations. Different geological formations are being considered in several countries (e.g. France and Germany); the table indicates the main focus.

Country	HLW / SF	Geological formation
Sweden	SF	Rock
Belgium	HLW	Clay
Finland	SF	Rock
France	SF	Clay
Japan	HLW	Rock
Canada	SF	Rock
Switzerland	SF	Clay
UK	HLW	Rock
Germany	SF	Salt
USA	SF	Rock

It is also indicated in the regulations on final disposal issued by the Swedish Nuclear Power Inspectorate (see further Chapter 2) that geological disposal is the main track in the Swedish final disposal programme. According to these regulations, "Safety after the closure of a repository shall be maintained through a system of passive barriers" (SKIFS 2002:1, Section 2). Examples of such barriers are containers for nuclear waste, buffer and the rock formation in which the nuclear waste is deposited. The main function of the barriers is to prevent or delay the escape of radionuclides so that they do not harm man or the environment. This final disposal principle is called the *multiple barrier system*.

Since the 1970s, a widespread international agreement has existed on the fact that geological disposal should be based on a multiple barrier system. In Sweden, the report of the AKA

Committee (see Chapter 3) was of fundamental importance. KBS 1, which was developed in the late 1970s, was based on a geological multiple barrier system[1]. According to sociologist Göran Sundqvist, a contributing factor to the emerging international consensus on a geological multiple barrier system was the risk of nuclear weapons proliferation. This also led to the eventual abandonment of previous plans to reprocess the nuclear waste. Terrorists and "rogue states" would scarcely consider it worth the effort to break into a closed and sealed final repository to retrieve materials to manufacture nuclear weapons or for the purpose of extortion. There are simpler ways.

Man and the biosphere must thus be protected from the radioactive waste by isolating it in the bedrock. Due to the depth of the repository, in combination with the rock formation and other barriers, the travel time for the radionuclides is so long that their radioactivity will have completely or partially decayed on its way from the repository to the biosphere.

1.5 The nuclear waste issue in a societal perspective – decisions under uncertainty

Our knowledge concerning the spent nuclear fuel and its properties and toxicity over a period of hundreds of thousands of years rests on a scientific basis – as does our knowledge of how we can protect humans, other life forms and the environment against the harmful effects of the ionizing radiation. Through its research programme, SKB has come far towards answering the question of how a combination of barriers can prevent or at least delay radionuclides from reaching the ground surface via groundwater flows. But no researcher can with the same certainty say anything about external physical events that could affect the final repository's ability to isolate the spent nuclear fuel from contact with the biosphere. Earthquakes or glaciations are two such possible events. The proposed designs of the final repository that have been discussed in Sweden have naturally taken such courses of events into consideration (see further KASAM Report 2007:2e,).

[1] The KBS-1 system related to the final disposal of reprocessing waste, see further Chapters 3 and 4.

Thus, we can assess and measure the final repository's capacity to prevent, under relatively static conditions, the escape of radionuclides that are hazardous to human beings and other life forms. We cannot assess with the same certainty when earthquakes and other hard-to-predict physical events (comet impacts, major climate changes etc.) will occur, but the final repository can nevertheless be designed so that it can be expected to retain its capacity to contain the spent nuclear fuel despite a wide spectrum of external physical changes.

On the other hand, our ability to predict different kinds of societal changes is much more limited. In recent years we have learned quite a bit about the swings in values that have occurred during the postwar period and what cultural, social and political effects they have had. Certain predictions can be based on this knowledge. However, we know virtually nothing about the living conditions of future generations – not to mention societal conditions hundreds, thousands and even hundreds of thousands of years in the future. Such societal conditions could affect the final repository and its basic function in different ways. In the first place, societal conditions could of course determine whether a future society has the resources and knowledge to prevent or at least limit the harmful effects of radiation leakage. In the second place, societal conditions could also affect the likelihood of an inadvertent intrusion into the final repository. Knowledge of the location and hazardousness of the final repository may have been lost following a serious conflict, after which society may have been rebuilt and, without knowledge or intention, may have inadvertently intruded into a forgotten final repository. The likelihood of such a course of events is perhaps not particularly great; greater is perhaps the likelihood of an intentional intrusion some time in the future in order to recover a resource that is still hazardous.

The risks of leakage and harmful effects are influenced by three factors: (1) internal factors associated with the design of the repository and the natural barriers between the spent nuclear fuel and the biosphere, (2) external factors such as climate and crustal stability, and (3) future intentional or inadvertent intrusion into the repository. (1) can be predicted and controlled with relatively high reliability, (2) with slightly lower reliability, and (3) with very low or no reliability. In other words, a decision regarding a future final repository is in certain respects a "decision under uncertainty". This problem was addressed by KASAM in the early 1990s at different seminars, which were summarized in the 1992 state-of-the-art report. This uncertainty is of particular importance in the nuclear waste issue, but it was also noted in general that only in exceptional cases can societal decisions be made on a completely certain basis – "durability for the future can seldom be determined". Moreover, decisions under uncertainty are not necessarily something negative – particularly if the certainty is made known. Uncertainty can provide an important perspective and entails, for example, a readiness to critically review and to impart another weight to previously "certain" knowledge when the contexts are widened and new factors enter the picture.

It was against this background that the so-called KASAM principle was formulated: "A final repository should be constructed so that it makes inspection and controls unnecessary, without making inspection and controls impossible. In other words, our generation should place the entire responsibility for the final repository on future generations, but neither should we deprive future generations of the option of assuming responsebility" (1987 state-of-the-art report, p. 92; 1992 state-of-the-art report, pp. 15-16; Etical aspects on nuclear waste, 1988, p. 15). The objective is thus two-fold: operational reliability and controllability. Inspection should be unnecessary but at the same time possible. Controllability entails that the final repository should be designed with the aim of achieving the highest possible safety from the start, while at the same time allowing for change and improvement.

1.6 Concluding reflections

The fundamental problem of the spent nuclear fuel is the ionizing radiation. Although it does decline with time, in contrast to the chemical toxicity of stable elements such as mercury and arsenic, it can cause great harm to living organisms if the spent fuel is not kept well contained, especially during the first few centuries after discharge from the reactor. Considerable problems remain after millennia, and the spent nuclear fuel must be kept isolated from life and humans for more than 100,000 years. Humans and other living beings must be kept from being exposed to direct gamma and neutron radiation from the fuel (the radiation levels near the fuel are high even after 100,000 years), while at the same time the fuel must be kept from leaking out of the repository and reaching humans and the environment via the groundwater and food. Awareness of the severity of the problem implies that it is necessary to achieve a workable final repository solution as soon as possible.

Unless it is kept effectively isolated from the biosphere, Sweden's spent nuclear fuel could otherwise cause harm to humans and other life forms – both those living today and those living several hundred thousand years from now.

The residual radiation and its toxicity for the next several hundred thousand years is a measure of the challenge posed by the nuclear waste issue to our generation. Ultimately it is an ethical and a moral challenge. The well-being of generations farther in the future than we can imagine may be affected by our actions today. We will return to these matters later on in this report, but even at this stage there is reason to call to mind a basic rule of thought in such weighty matters. Whatever decision we make in the nuclear waste issue must be characterized by reasonableness. Various circumstances must be weighed against each other, always bearing in mind that alternative courses of action – or the failure to act – also have consequences that entail risks, sometimes greater risks than the main alternative. The enormous timescale involved is a healthy reminder of the enormous challenge of the nuclear waste issue – but in an overall assessment, this factor should also be dealt with in a spirit of reasonableness.

2 The Regulatory framework

In this chapter we will go through the various laws, regulations and recommendations that form the requirements and criteria with which a future final repository in Sweden must comply. We will also provide a description and interpretation of the explicit or implicit moral and ethical principles that are woven into this regulatory framework (and that have in different ways been influenced by international actors, for example in the radiation protection area).

The regulatory framework that has taken shape over the past 30 years has been guided by certain fundamental political standpoints. These standpoints can be summarized as follows:

- The spent nuclear fuel will not be reprocessed.
- The waste from the Swedish nuclear power plants will be managed and disposed of within the country's borders.
- Sweden will not dispose of nuclear waste from other countries.

These different decisions are embodied in international treaties and agreements. Each has its own special background and explanation. The decision not to reprocess the nuclear waste is, for example, linked to the fact that it contains plutonium, which is enriched in the reprocessing process. Plutonium can be used to manufacture nuclear weapons. This is an important reason to refrain from reprocessing, and is in keeping with the international aim of preventing nuclear weapons proliferation.

2.1 Radiation Protection Act, Nuclear Activities Act and Environmental Code

Nuclear power and management of the spent nuclear fuel are legally regulated today mainly through the Nuclear Activities Act (1984:3), the Radiation Protection act (1988:220) and the Environmental Code (1998:808). The basic conditions that must be met by a future final repository are defined in these laws. Section 10 of the Nuclear Activities Act states that “the holder of a licence for nuclear activities shall be responsible for ensuring that all measures are taken that are required for ensuring the safe management and final disposal of nuclear waste arising from the activities or nuclear material arising therein that is not re-used”. A similar formulation is also found in Section 13 of the Radiation Protection Act, which states that “Anyone who conducts, or has conducted, activities involving radiation shall be responsible for ensuring that the radioactive waste arising in the activities is managed and, when necessary, disposed of in a manner that is satisfactory from the viewpoint of radiation protection. The same applies to discharged radiation sources that have been used in such activities.” Of central importance in this context is also the regulatory framework found in the Environmental Code. It contains provisions concerning the preparation of an environmental impact statement (EIS) and how those who are most affected (e.g. landowners) are to be given a say in the decision process. KASAM has on different occasions in seminars and state-of-the-art reports analyzed the EIS as a tool in the decision process (see e.g. KASAM’s state-of-the-art report 1995, SOU 1995:50, Chap. 5).

The question of the Nuclear Activities Act’s relationship to the Environmental Code was dealt with at a seminar arranged by KASAM in the autumn of 2006 (KASAM rapport 2007:1, in Swedish only). We will return to this question in Chapter 6 on the decision process.

2.2 Basic points of departure

In 1993 a number of recommendations and criteria were published by the Nordic regulatory authorities (known as the Flagbook; see also KASAM’s state-of-the-art reports 1989, Chap. 5 and 1995, Chap. 7) concerning the geology of the repository site, the depth and layout of the repository, backfilling and closure of the repository and the design of the waste canisters. These criteria can be regarded as the predecessors of the regulatory authorities' current regulations and general recommendations. SKB has also defined criteria for the different components of the final repository system (see Chapter 4).

The following presentation of the Flagbook's recommendations aims at providing a general background to the current regulations, general recommendations and criteria.

The Flagbook states that a final repository should be designed with basically three kinds of barriers: container, buffer/backfill and rock. The purpose of these different barriers is to prevent or delay the dispersion of radioactive substances (radionuclides). In order to achieve this purpose the barriers must fulfil a number of general criteria.

The containers/canisters shall, according to the Flagbook, have sufficient mechanical and chemical stability to ensure virtually complete isolation of radionuclides for a sufficiently long period of time. The requirements on the canisters are greatest during the first thousand years until most of the radionuclides have decayed. However, the presence of long-lived transuranics necessitates stability and isolation for more than 100,000 years.

Buffer and backfill serve as further barriers to the escape of radionuclides. The buffer surrounds the canister in the deposition hole. The backfill is supposed to stabilize the transport tunnels and keep the buffer around the nuclear waste canisters in place. All in all, the buffer and backfill should contribute to the total stability of the final repository and the long-term containment and isolation of the nuclear waste.

The rock, i.e. the repository site, should, according to the Flagbook, "provide good natural conditions for containing and isolating radioactive substances". The general criteria that are given are, for example, low groundwater flow in the repository, long travel time for the groundwater from the repository to the biosphere, geochemical properties that contribute to a low corrosion rate of the canister material, and siting in a region with low tectonic and seismic activity.

2.3 Regulations and general recommendations

The Swedish Nuclear Power Inspectorate (SKI) and the Swedish Radiation Protection Authority (SSI) are the central authorities for supervision of SKB's work and have clarified the requirements imposed on a final repository for the high-level nuclear waste in various regulations and general recommendations. SKB has been tasked by the nuclear power industry to assume responsibility for ensuring that these requirements are met.

The fundamental requirements on final disposal of the nuclear waste from Swedish nuclear power plants are found in the Nuclear Activities Act. As was stated in section 2.1, the holder of a licence for nuclear activities is also responsible for ensuring that all necessary measures are taken for the final disposal of the nuclear waste (Section 10). The more detailed provisions have been formulated by SKI and SSI in special regulations. Certain guidelines have also been summarized in general recommendations, which are not binding.

SKI has issued "Regulations concerning Safety in connection with the Disposal of Nuclear Material and Nuclear Waste" (SKIFS 2002:1). These regulations describe with notable clarity not only the objective, but also the design required to achieve safety. According to SKI's general recommendations to the regulations, safety is the ability of a final repository to prevent the dispersion of radioactive substances. This safety shall be ensured by a system of engineered and natural barriers that contain, prevent or at least delay the dispersion of radioactive substances (Section 3). The repository depth shall provide "sufficiently stable and favourable conditions to ensure that the repository barriers perform as intended over a sufficiently long period of time" (General Recommendations, p. 9 of English version). The barrier system shall be able to withstand different types of events and comprise several barriers so that safety is maintained in spite of a single deficiency in a barrier (Section 7). Concrete structures shall, for example, offer effective protection if the actual nuclear waste container begins to leak.

SSI's Regulations on the Protection of Human Health and the Environment in connection with the Final Management of Spent Nuclear Fuel and Nuclear Waste (SSIFS 1998:1) state that "Human health and the environment shall be protected from detrimental effects of ionizing radiation during the time when the various stages of the final management of spent nuclear fuel or nuclear waste are being implemented as well as in the future. The final management may not cause impacts on human health and the environment outside Sweden's borders that are more severe than those accepted inside Sweden" (Section 3). The regulations also clarify that the nuclear waste may not cause any injury as long as the harmful radiation lasts, i.e. for over 100,000 years (cf. Figures 1.1 and 1.2).

SSI also states in its regulations what protective capacity the final repository must have. The probability that a person in the group that is exposed to the greatest risk will be injured by such a leak may not exceed one in a million. This group consists mainly of people living in the vicinity of the repository who are exposed to ionizing radiation that has leaked out from the repository through the engineered and natural barriers, for to example groundwater, lakes and watercourses. How to demonstrate in practice that a final repository does not pose a higher risk than one in a million is of course a complicated matter. A thorough analysis of the concept of risk is provided in KASAM Report 2007:4e.

2.4 Best available technology and optimization

According to SKI's regulations (Section 6 SKIFS 2002:1), each component in the final repository shall be designed taking into account the "best available technique". For a definition of this term, SKI refers to Chapter 2, Section 3 of the Environmental Code. The travaux preparatoires to this provision (Gov. Bill 1997/98:45 Part 2 pp. 16-17, in Swedish only) state that "the technology must, from a technical and economic viewpoint, be possible to use industrially in the sector in question. This means that it must be available and not just exist in the experimental stage. It does not, however, have to exist in Sweden."

In its guidelines from 2005 on the application of its regulations SSIFS 1998:1, SSI emphasizes that the final repository must be designed with the aid of the best available technique, and that this applies to the siting, design, construction and operation of the final repository (p. 2 of English version).

The Environmental Code says, under *General rules of consideration etc.* (Chap. 2) that "the best possible technology shall be used in connection with professional activities to prevent damage. The technology shall be industrially possible to use from a technical and economic viewpoint in the sector in question."

The Swedish legislation uses the expression "best possible technology" or "best available technique", whereas the normal English expression is "Best Available Technology" (BAT). This was pointed out at a seminar about the "alternatives issue" (see Chapter 3) arranged by KASAM in February 2006. There is no difference in meaning between these expressions as they are used in the Swedish legislation. This is evident from the travaux preparatoires to the Environmental Code, where it is stated that the "best possible technology" must be available and industrially possible to use from a technical and economic viewpoint (KASAM rapport 2006:1, p. 19, in Swedish only).

Optimization is, along with BAT, an important requirement on the final repository (Section 4 of SSIFS 1998:1). SSI's guidelines from 2005 on the application of these regulations say that "Optimization and best available technique should be applied in parallel with a view to improving the protective capability of the repository" (p. 2).

Optimization can be described as an application of the ALARA principle. The ionizing radiation to which human beings risk being exposed should not only be less than a given prescribed limit value; it should be "As Low As Reasonably Achievable". A system with threshold doses was abandoned by ICRP back in the 1950s when it was discovered that no doses above the background level could be regarded as safe. According to SSI's regulations, radiation doses to humans shall be kept "as low as reasonably achievable, economic and social factors taken into account" (Section 2). The foremost means for optimization are risk or safety assessments, which are aimed at describing the repository's post-closure protective capability. What is the probability that the engineered barriers will be broken down (e.g. by corrosion)? How great is the risk that different types of climate change will degrade the repository's protective capability? These questions can be answered by studying the final repository's evolution during a series of different – and not entirely improbable – courses of events (scenarios). When it comes to climate change, the consequences of glaciations and permafrost should in particular be studied.

Of central importance in SSI's regulations and guidelines are the requirements and recommendations for assessment of risk for different time periods after closure. This problem complex is dealt with in KASAM Report 2007:3e.

2.5 The ethical premises

Ethical questions related to nuclear waste fall under the concept of "environmental ethics". When studying the ethical premises for the Swedish regulatory framework surrounding the issue of final disposal of spent nuclear fuel, it is important to distinguish between *descriptive* and *normative* environmental ethics (or more generally between descriptive and normative ethics).

Descriptive environmental ethics attempts to discover, describe and classify the environmental values of people, groups or societies. For example, the aim may be to (1) describe and classify the moral values that directly or indirectly guide environmental protection and environmental policy and (2) analyze how people in general respond to environmental policy measures (based on their own fundamental values concerning how man should relate to nature). It is important to emphasize that many other people apart from those engaged in the academic study of ethics are involved in descriptive ethics. Researchers in the social sciences, humanities and ethics conduct research in the area of descriptive ethics. We could talk about "value research" within the environmental area as a more general category of research. Without value research, it is difficult to conduct meaningful normative ethics. We need to acquire knowledge about the basic values that people have with respect to their relation to nature, especially regarding:

- how these fundamental values are conveyed, interpreted or perhaps even ignored by institutions and authorities,
- how these fundamental values are linked to actions and ways of life, and
- how people's moral values etc. can be influenced in a successful and acceptable manner.

Specifically, ethicists are not content with simply describing people's basic values or attitudes to nature. They also want to examine these values critically and constructively. Such a constructive and critical study of environmental issues can be called *normative* ethics. The aim of normative environmental ethics is to critically and constructively evaluate the moral values that directly or indirectly serve as guidelines for environmental protection and environmental policy and people's reactions to these values. Here are some examples of normative environmental ethical questions:

- Should we try to preserve species that are threatened with extinction and, if so, why and to what extent?
- Should we take into account future generations in connection with our use of non-renewable natural resources such as fossil fuels?
- Do we in our generation have the right to use up all oil?
- If so, should future generations be compensated in some way?

Ethical theories concerning the criterion for right action play an important role in normative ethics. A distinction is normally made between *consequential ethics* and *duty ethics*. Consequential ethics assumes that it is the consequences that determine whether an action is right or wrong – duty ethics put more stress on the action itself. An example may serve to illustrate the difference. It is morally wrong to lie. But this can be interpreted in two ways. Either the action of lying itself is wrong. Or the action is wrong because it can lead to consequences that are harmful or destructive.

The following question could be posed in relation to the Swedish regulatory framework surrounding final disposal of spent nuclear fuel summarized above: Which ethical theory is assumed in this regulatory framework? One answer could be inspired by a contribution to an early KASAM seminar on *Ethics and nuclear waste* in 1987 (see SKN-rapport 28, in Swedish only; a summary in English of this report is published as SKN Report 29). There Sven Ove Hansson writes that the dominant form of consequential ethics is utilitarianism, and that this is well-suited for probability analysis. The treatment of risk and uncertainty in economics also has utilitarianism as its philosophical basis. The formalized risk assessment is based almost exclusively on utilitarian models.

The basic principle of utilitarianism can be formulated in different ways, but according to one definition an action is morally right if it will probably lead to – for everyone affected by the action – a greater excess of pleasure over pain than every other action. Applied to the issue of a decision to build a final repository for the Swedish spent nuclear fuel, the fundamental moral and ethical question is thus: Is it probable that this decision – for everyone affected by the decision and its implementation – will lead to a greater excess of pleasure over pain than every other decision?

The utilitarian theory appears to be very relevant for providing an ethical interpretation of the Swedish regulatory framework surrounding final disposal of spent nuclear fuel. The fundamental issue has to do with minimizing the harmful effects of the nuclear waste in the form of pain, disease and death among everyone affected by the action, including future generations. The risk and safety assessment provides us with the answer to the ethical challenge of nuclear waste as well. It is assumed that the best available technology can minimize the risks, and optimization is aimed at ensuring that as little as reasonably possible will escape from the repository in the form of radionuclides that can harm humans and other life forms.

But there are certain features of the Swedish regulatory framework that do not lend themselves as readily to interpretation by utilitarian theory. An example is the fundamental principle of producer responsibility, i.e. “the holder of a licence for nuclear activities shall be responsible for ensuring that all measures are taken that are required for ensuring the safe management and final disposal of nuclear waste arising in the activities or nuclear material arising therein that is not re-used” (Nuclear Activities Act, Section 10). This principle of producer responsibility (also called the “polluter pays principle”) has been of fundamental importance for the management of spent nuclear fuel in Sweden. It is related to a more general principle of responsibility that has been asserted in various national and international contexts. By “polluter” is mainly meant here the nuclear power producers, but the principle can also be interpreted as applying to those who have used the electricity, i.e. the electricity consumer. This means that we in Sweden bear a common responsibility for our country’s radioactive waste. It must not be passed on to future generations, but rather be managed and disposed of today. We can call this the responsibility principle.

The producer responsibility principle, like the responsibility principle in a more general sense, can naturally in turn be justified by reference to utilitarianism. If we observe these principles, the consequences will be better and the harmful effects of the spent nuclear fuel will be smaller. However, it could also be questioned whether the producer responsibility principle and the responsibility principle are really in line with the utilitarian principle. Someone could perhaps give reasons why a different allocation of the responsibility for the spent nuclear fuel has better consequences. In the USA, the federal government is responsible for final disposal. Experience of this model is perhaps not 100% positive, but that may be due to other factors than the allocation of responsibility.

The responsibility principle is clearly embodied in the international regulatory framework for nuclear waste management. In 1995 the IAEA issued *The Principles of Radioactive Waste Management* as a part of its safety series. According to Principle 5, the waste shall be managed "in such a way that will not impose undue burdens on future generations". With reference to these principles, this idea is elaborated on in the IAEA's *Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management* from 1997. Sweden has ratified this convention. According to Article 1, one of the objectives of the convention is:

> to ensure that during all stages of spent fuel and radioactive waste management there are effective defences against potential hazards so that individuals, society and the environment are protected from harmful effects of ionizing radiation, now and in the future, in such a way that the needs and aspirations of the present generation are met without compromising the ability of future generations to meet their needs and aspirations.

This statement embodies a certain type of ethical reasoning which has become common in international environmental contexts. A point of departure is the Bruntland Commission's famous definition of sustainable development from 1988:

> Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs. (Our Common Future, 1988, p. 43).

In other words, if we accept the idea of sustainable development, we also accept that we have a moral obligation towards future human generations. Resources and burdens ought to be distributed fairly between current and future generations. This means that the principle of justice has been extended in time to include not only currently living people, but also future generations. In other words, in our actions and our social planning, we should take into consideration not only human beings currently alive (traditional anthropocentrism) but also future generations (intergenerational anthropocentrism). Here we can talk about new ethics. Never before have we imagined that we could have a moral responsibility that extends more than a generation or two into the future. But the nuclear waste issue extends this responsibility in a dramatic manner further ahead in time than we can imagine, as long as the nuclear waste remains a health hazard, i.e. about 100,000 years into the future. An important question for research and consideration is then what this responsibility or consideration entails more precisely, particularly in situations where our interests may come into conflict with the possible interests of future generations. This "new" environmental ethical mindset (also called "the ethics of sustainable development") dominates the current political debate, both nationally and internationally.

In summary, we can thus discern in the regulatory framework surrounding the management of nuclear waste an ethical theory composed of a utilitarian principle and a responsibility and justice principle. According to the utilitarian principle, we should strive for a decision in the nuclear waste issue which will probably lead to – for everyone affected by the action – a greater excess of pleasure over pain than every other action. BAT and optimization are assumed to be in line with this principle. According to the responsibility and justice principle, the nuclear waste should be managed in a manner that meets the needs of the present without compromising the ability of future generations to meet their own needs.

2.6 Concluding reflections

In this chapter we have summarized the Swedish regulatory framework for management of the spent nuclear fuel from the Swedish nuclear power plants. It is embodied in various statutes, primarily the Nuclear Activities Act and the Environmental Code, as well as SKI's and SSI's regulations and general recommendations. These rules and recommendations are harmonized with various international treaties and agreements. Certain ethical guidelines can also be discerned in this regulatory framework.

The legislation, together with SKI's and SSI's regulations, has provided guidance for the direction of SKB's final repository programme. However, the regulations have to some extent been issued in parallel with the development of SKB's final repository programme. This regulatory framework will in its totality provide guidance for the upcoming licensing process for an encapsulation plant and a final repository. An important democracy question is unavoidable: To what extent will this licensing process be open and accessible to private citizens?

The question is relevant because it is difficult to penetrate the complicated technical and scientific subjects such as welding technology and barrier construction. Furthermore, it isn't easy to understand the implications of the provisions of various statutes – not to mention the decision process in which they will be applied (see further Chapter 6).

Measures to improve transparency and comprehensibility will be of central importance in this context. KASAM commissioned a feasibility study to take a closer look at these values and the methods that promote their realization. In this feasibility study the RISCOM model is of fundamental importance – see further Kjell Andersson, *Genomlysning av beslutsprocess och beslutsunderlag på kärnavfallsområdet - Rapport från förstudie* (Karita research, April 2007; "Making the decision process and basis for decision for nuclear waste management transparent– Report from feasibility study.") It has to do with facts? (is this true?), legitimacy (is this fair?) and authenticity (are you being honest?, what are your values?). "Analysis with the RISCOM model entails giving the participants[1] insight and an opportunity to form an opinion regarding the truthfulness and relevance of the arguments and the actors'[2] authenticity. This is done by subjecting the actors to thorough interrogation from various angles and clarifying the values behind the arguments" (Andersson 2007. p. 16). The RISCOM model was not applied to its full extent in the interrogation concerning "deep boreholes" which KASAM arranged on 14-15 March 2007. This interrogation may be seen as the first example of this approach, but KASAM intends to apply this model in future interrogations in a more systematic fashion so that the subjects are required to provide answers (are "stretched") in questions regarding facts and values as well as legitimacy and authenticity.

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[1] By "participants" is meant here those who participate in the analysis. Who they are depends on what issue is being dealt with, but the requirement on public insight means that the analysis is public.

[2] By "actors" is meant here the organizations that are being consulted in connection with the analysis.

3 The Alternatives

The issue of alternative methods for protecting man and the environment from the harmful effects of the ionizing radiation from nuclear waste has been discussed since the early days of nuclear power. From 1973 until the mid-1980s, nuclear power was the subject of wide-ranging and heated public debate, where one of the main issues was nuclear waste management. The Stipulations Act of 1977 called for an "absolutely safe" method for final disposal of the spent nuclear fuel. The AKA Committee singled out two main alternatives: disposal of the waste after reprocessing of the spent nuclear fuel, or direct disposal of the spent nuclear fuel (Använt kärnbränsle och radioaktivt avfall, SOU 1976:30, 31 and 41; Summary in English, "Spent nuclear fuel and radioactive waste", SOU 1976:32). The reprocessing alternative was eventually dismissed and the KBS-3 method took shape, along with various proposals for alternative methods.

KASAM addressed the alternatives issue in its first state-of-the-art report in 1986. The question comes up again in the state-of-the-art report for 1992, in KASAM's review of SKB's RD&D Programme 98, in a special report on ethical dilemmas surrounding nuclear waste in 1999 (*Responsibility, equity and credibility*), in KASAM's review of SKB's Supplement to RD&D Programme 98 in 2000, in KASAM's review of SKB's RD&D Programme 2001 and in the state-of-the-art reports from 2001 and 2004.

KASAM's review of RD&D Programme 98 dealt with the five different strategies for nuclear waste management that had been considered in the international exchange of ideas (SOU 1999:67):

- Ultimate removal by launching into space (alternative A).
- Disposal in inaccessible areas on Earth, for example beneath the Antarctic ice sheet or in deep sea sediments (alternative B).
- Long-term storage of the spent fuel in a monitored repository – possibly pending the further development of other strategic and

technical alternatives, the so-called zero alternative (alternative C).
- Nuclear transformation, transmutation, of the waste to reduce its radiotoxicity (alternative D).
- Final disposal of the waste deep down in the bedrock (alternative E).

3.1 Alternatives A and B

Alternatives A and B can be dismissed from the discussion quickly and for obvious reasons, since they include launching of the waste to outer space or sub-seabed disposal of the waste in the ocean. These solutions would lead to unacceptable safety risks and/or breaches of international conventions (1972 Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, 1997 Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management).

3.2 Alternative C

Alternative C is usually described as the zero alternative. Such an alternative shall be presented according to the Environmental Code and contain a description of the consequences that arise if the activity or measure is not implemented (Environmental Code Chapter 6, Section 7, paragraph 4; KASAM report 2006:1e; "Nuclear waste. Which alternatives for method and site should be described"). The zero alternative in nuclear waste management might be described in three different ways. The first sub-alternative (C 1) entails continued interim storage in Clab. The second (C 2) entails the erection of some form of dry storage facility on or near the ground surface. Sub-alternative C 3 is similar to C 2, but here the dry repository is intended for interim storage pending a more permanent solution.

Sub-alternative C 1 thus entails that Clab, which now serves as an interim storage facility, is used for a much longer period of time than originally planned. The problem of course is that Clab is designed to store the spent fuel for about 40 years and does not meet the safety requirements that would be made for a longer operating period. This is particularly true if Clab is suddenly left unsupervised. In 2000 – in its supplement to RD&D Programme 98 – SKB described the consequences of prolonging interim storage in Clab up to about 250 years. Continuous renovations could maintain safety, but what happens if the facility has to be suddenly abandoned due to war or environmental disaster? If the cooling pumps stop and this happens while the fuel temperature is still high, the water could evaporate and expose the fuel. The fuel could then suffer serious damage and hazardous radionuclides could escape into the atmosphere after a rather short time. A loss of cooling after the fuel has cooled does not have to have as serious consequences.

Sub-alternative C 2 entails extended (prolonged) interim storage in a dry repository on or near the ground surface. A variant of dry storage, DRD (Dry Rock Deposit), is intended for storage for a very long time, several thousand years. In the DRD concept, containers with fuel are placed in a self-draining rock cavern built in a rock formation that projects up above a surrounding depression. After disposal the rock cavern is closed. No drainage pumping or cooling is required. The idea is to minimize the need for maintenance and monitoring so that storage can take place for a long time. However, high temperatures and the presence of oxygen make it difficult to show that the containers will remain intact for long periods of time (*Background material for consultations under the Environmental code, Chap. 6.* SKB, May 2006, p. 22, in Swedish only).

Sub-alternative C 3 is reminiscent of C 2 with the difference that the dry storage is *only* intended as an interim storage until a new and better technology comes along. In the public debate it has occasionally been suggested that final disposal should be postponed to benefit from the advances in technology that may occur in the next few centuries (KASAM report 2006:1, p. 25, in Swedish only). In the interim the spent nuclear fuel should be deposited in a dry repository on the ground surface and be accessible for final disposal when the appropriate technology becomes available. The argument for this alternative could be taken from utilitarian theory: better final disposal technology increases safety and reduces the risks for future generations. Although the utilitarian principle conflicts with the responsibility and justice principle, which says that our generation is morally obligated to dispose of the hazardous waste, the utilitarian principle should take precedence.

Let us assume that it is probable that better technology in the future could make a final repository safer than the best technology available today. Is this sufficient reason to abandon the responsibility principle and shift the burden of finding a solution to future generations? This is questionable, since it is possible that we already have a sufficiently safe solution for final disposal today and a future solution would only marginally improve safety for future generations. In order to justify setting aside the responsibility principle we must assume that we do not have sufficiently good technology today to build a final repository. But this remains to be determined when SKB has submitted its application for a permit to build a final repository for spent nuclear fuel in 2009.

Furthermore, it is not at all certain that we will have a better technology hundreds of years from now. Instead of progressing, society may regress. The country may be struggling with serious economic, social or medical problems. That will put us in the worst of all worlds: a society in crisis without the resources to dispose of the hazardous waste.

The ethical question could be summarized as follows: Even if it is probable that better technology will be available in the future, this doesn't necessarily mean that today's technology isn't good enough. In this case the responsibility principle takes precedence over the utilitarian principle. The assumption that a better solution will be found in the future can also be challenged. In this case the utilitarian principle does not conflict with the responsibility and justice principle. We have a two-fold moral obligation to deal with the waste as soon as a sufficiently safe method has been demonstrated.

KASAM asserted in its 1999 review of SKB's RD&D Programme 98 that there may be additional reasons against extended interim storage in Clab or another interim storage facility:

> The development of a fruitful idea into a mature, proven technology takes decades when the technology has to satisfy the demands made on management and disposal of high-level waste. In the meantime, the competence in the nuclear waste field currently possessed by regulatory authorities, nuclear power utilities, SKB, universities and consultants will dissipate. If nuclear power has moreover been phased out at the same time and the waste management work has been put on hold, the field will lose its interest and fail to attract new recruits. Enthusiasm, broad expertise and detailed knowledge exist now. To

> risk wasting these resources is not a good alternative. (KASAM's RD&D review 1999, SOU 1999:67, p. 26 ff. of English version).

3.3 Alternative D

Alternative D can be summarized under the heading *transmutation*, or P&T (Partitioning and Transmutation). This method is described in KASAM's 1986 state-of-the-art report (p. 35). The idea is based on transforming long-lived radionuclides into more short-lived ones by irradiating them with neutrons. This can be done in an ordinary nuclear reactor or in a powerful particle accelerator. According to some experts, current technology would make it possible to transform the nuclear waste so that it will decay to natural radiation levels in less than 1,000 years (see Janne Wallenius's contribution to Andrén & Sandberg, p. 108).

In KASAM's state-of-the-art report for 2004, the question of P&T is thoroughly dealt with in a special chapter, in which Professor Henri Condé at Uppsala University participated. The conclusions are not particularly hopeful.

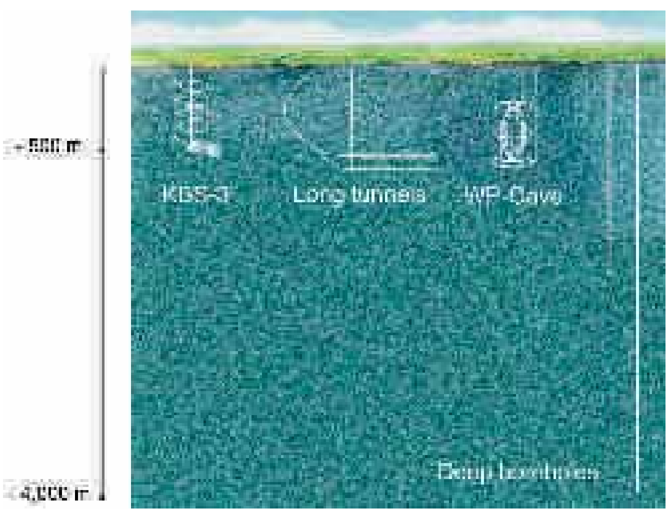
> The application of P&T to Swedish nuclear waste will be a question for future generations. With present-day knowledge of this technology, it is not acceptable to interrupt or to postpone the Swedish nuclear power programme, citing P&T as an alternative. On the other hand, this possible future alternative reinforces the requirement that the repository should be designed so that waste retrieval is possible. According to the ethical principles that KASAM and others have established, each generation should take care of its own waste and not force future generations to develop new technologies to solve the problems. Therefore, it is reasonable for resources to be put aside for further research on P&T. This research could also pay off in ways which are of value for other areas, such as nuclear physics, chemical partitioning technology and materials technology. Swedish P&T research should be coordinated with the research and development being conducted in other countries. To, at this stage, allocate resources for further P&T research is also in line with the view that our generation should give future generations the best possible conditions to decide whether they want to choose P&T as a method for taking care of spent nuclear fuel, instead of direct disposal alone (in accordance with the KBS-3 method, for example). (SOU 2004:67, pp. 408-409 of English version).

It should be added that the method does not result in the transformation of all the nuclear waste into harmless substances. A final repository, albeit a smaller one, would nevertheless be needed.

3.4 Alternative E

Alternative E entails final disposal of the waste deep down in the bedrock or in other geological formations. This is the method that all concerned countries are focusing on. However, the solutions differ depending on the geological formations that are available in each country and on whether they have been judged to be appropriate for the isolation of nuclear waste from the biosphere for very long periods of time. Salt formations have long been studied in the USA and Germany. France is interested in disposal in clay formations. Finland, Switzerland and Sweden have mainly focused on final disposal in rock. Three different methods for such geological disposal have been studied in Sweden and have been the subject of various studies by SKB (see e.g. “Background material for consultations under the Environmental Code”, SKB, May 2006, Chap. 6, in Swedish only).

Figure 3.1 Alternative methods for geological disposal



Source: The figure is taken from “Background material for consultations under the Environmental Code”, SKB, May 2006, p. 10, in Swedish only).

Sub-alternative E 1 – the KBS-3-method – is the most well-developed method and SKB's main alternative. It has been the subject of research and development by SKB in various studies and is presented in greater detail in Chapter 5. The spent nuclear fuel is encapsulated in copper canisters, which are deposited at a depth of about 500 metres in an appropriate geological environment. The canisters are surrounded by a layer of bentonite clay, which comprises a buffer against minor movements in the rock and prevents corrosive substances from coming into contact with the canister. The bentonite also acts as a barrier to prevent radionuclides from the nuclear waste from escaping and reaching the ground surface if the canister is damaged.

Sub-alternative E 2 goes under the designations *long tunnels* or *WP-Cave* (a disposal method that was originally developed by consultants at Widmark & Platzer). Long tunnels is similar to the KBS-3 method in many respects, but the nuclear fuel canisters are spread out in approximately 5-km-long tunnels. Each tunnel is backfilled, and spreading out the canisters is intended to increase safety. Local ruptures and settlements in the bedrock formation could only damage a few individual canisters. WP-Cave is another concept based on more closely spaced canisters than assumed in the KBS-3 method. The canisters would be deposited in a cage-like structure with relatively high heat, surrounded by a bentonite buffer. The whole repository structure would in turn be surrounded by a hydraulic cage to prevent water throughflow.

Long tunnels and WP-Cave have been judged by SKB to contain too many elements of uncertainty to warrant further study.

Sub-alternative E 3 has been summarized under the designation *deep boreholes* and implies that the waste is enclosed in canisters, which are then lowered into boreholes to a depth of 2-4 km in the Swedish crystalline bedrock. The main virtue of this method is that the groundwater flux at this depth is very limited and that it would take such a long time for the groundwater to transport the radioactive substances from the canisters up to the surface that their radiation would have decayed to a harmless level before they reach the biosphere. Knowledge of the properties of the rock at these depths is limited, and SKB calculated a few years ago that R&D on this alternative would take about 30 years and cost at least SEK 4 billion (Clab together with an encapsulation plant and a final repository is estimated by SKI to cost SEK 26 billion). In addition, the method is in practice a single-barrier system since canisters and buffer will very soon be subjected to severe stresses. This also brings up the question of whether the method complies with SKI's regulations and requirements regarding a multiple barrier system. Safety during deposition is another problem. The canisters can get stuck or be damaged on their way down into the rock. It is in practice impossible to retrieve the fuel once it has been deposited.

3.5 Overall evaluation

In order to illustrate an overall evaluation of different system solutions for final disposal of spent nuclear fuel, KASAM presented a table in its review of RD&D Programme 92 rating different methods with respect to five criteria: safety, retrievability, no postclosure monitoring, flexibility and costs (SOU 1993:67, p. 17 of English version). Taking into account advances in knowledge and technology since that time, a similar updated table can be presented for the methods described here: *C 1, C 2, E 1, E 2 and E 3*. We have also added a sixth criterion: controllability.

By *safety* is meant that the repository could probably meet the regulatory requirements on a final repository – even though it might require some development work. Safety must be ensured during both the construction and operating phases.

By *retrievability* is meant that a future generation should be able to retrieve the spent nuclear fuel without too much risk of damage.

By *no postclosure monitoring* is meant the repository should not have to be inspected or maintained for safety's sake after closure.

By *flexibility* is meant the possibility of adapting the layout of the repository to local conditions.

By *costs* is meant costs in comparison with a final repository according to the KBS-3 method together with an interim storage facility and an encapsulation plant (about SEK 26 billion according to SKI). Is it probable that the costs will be less (+), equal (0) or greater (-)?

By *controllability* is meant the possibility of making postclosure improvements in the final repository (that were not foreseen before closure).

A plus sign (+) indicates that the method probably satisfies the criterion. A zero (0) indicates lower criterion satisfaction than with + (even though the method is not unacceptably bad). A minus sign (-) indicates that the method does not satisfy the criterion. A question mark (?) indicates insufficient knowledge of criterion satisfaction.

Table 3.1 The table shows to what extent different methods satisfy the different criteria: safety, retrievability, no postclosure monitoring, flexibility and costs.

	Safety[1]	Retrievability	No postclosure monitoring	Flexibility	Costs	Controllability
Clab	-	+	-	+	+	?
Dry rock caverns[2]	-	+	-	+	+	+
Long tunnels	0	+	+	0	?	0
WP-Cave	0	+	+	0	?	0
KBS-3	+	+	+	+	(ref. alt.)	+
Deep boreholes	0	-	+	+	-	-

Source: Modified after SOU 1993:67 p. 17 of English version.

KASAM has previously concluded that alternatives – which shall be presented in the environmental impact statement according to Chap. 6, Sec. 7 of the Environmental Code – to the KBS-3 method should be sought in the category "repositories built in the uppermost kilometre of the bedrock". This conclusion remains valid according to KASAM's review of RD&D Programme 2004 (SOU 2005:47 p. 143-144 of English version).

[1] The term "safety" includes both long-term safety and operating safety (safety during deposition).
[2] The alternative is not fully comparable to other alternatives, since it generally involves storage of the nuclear waste until a final solution has been found, i.e. for up to about 300 years.

3.6 Concluding reflections

Deep boreholes is the final disposal alternative that has been perceived in the recent Swedish debate as the foremost rival of the KBS-3 method. SKB has addressed the issue in various contexts since the late 1990s, and the environmental NGOs have long urged that the issue be further investigated. In 2006, SKB and the Swedish NGO Office for Nuclear Waste Review (MKG) produced the reports: *Djupa borrhål – status och analys av konsekvenser vid användning i Sverige* ("Deep boreholes – status and analysis of consequences of use in Sweden", SKB Report R-06-58, in Swedish only) and *Slutförvaring av högaktivt avfall i djupa borrhål - En utvärdering baserad på senare års forskning om bergrunden på stora djup* ("Final disposal of high-level waste in deep boreholes – An evaluation based on recent years' research on the bedrock at great depths", MKG report 1, 2006, in Swedish only). These two reports lead to different conclusions. According to the SKB report, deposition in deep boreholes is "a both interesting and difficult-to-implement alternative. The safety advantages that can be expected due to the assumed stagnant groundwater conditions are, however, difficult to demonstrate with the certainty required for final disposal of spent nuclear fuel." (R-06-58 p. 4). The MKG report is more optimistic in its assessment of the possibilities of carrying out a reliable safety assessment and developing an efficient drilling technology. The MKG report emphasizes the big advantage of stagnant groundwater conditions at great depths. This assessment is not challenged in the SKB Report, which instead highlights practical difficulties in the form of investigation costs and delays of the final repository project (see SKB report R-00-28, p. 9).

KASAM has on different occasions (RD&D review 1999, Chap. 2; RD&D supplement review 2001, p. 9; and most recently in a review of SKB's RD&D Programme 2004) judged that disposal of spent nuclear fuel in deep boreholes is not a realistic method (SOU 2005:47, p. 143 of English version). The analysis of the deep boreholes concept in the spring of 2007 confirms KASAM's assessment that there does not appear to be any available technology (in the sense of the Environmental Code) for disposal in deep boreholes, and that such technology cannot be expected to become available within the timespan of the planned decision process. Both drilling technology and sensor technology have, however, advanced during the past 10-15 years, mainly due to R&D in the oil and gas industry. KASAM therefore believes that very good reasons exist for SKB to clearly present and explain its standpoints regarding the "deep boreholes" concept both in RD&D Programme 2007 and in the application for the final repository planned to be submitted in 2009. KASAM also intends to follow developments in the field, above all with regard to technology for drilling and measurement aimed at investigating whether the bedrock possesses the properties that are required for the method to result in safe final disposal.

4 Planning premise

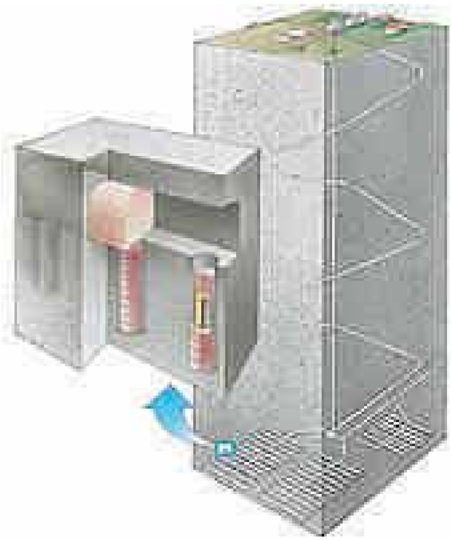
In a decision from 2001, the Government said that SKB should use the KBS-3 method as a "planning premise" for the coming site investigations (Government decision of 1 November 2001). The same decision also underscored "that final approval of a specific method for final disposal cannot be given until 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. SKI has also made a positive evaluation of SKB's system choice on different occasions and says in its review statement to the Government on SKB's RD&D Programme 2004 that "disposal in deep geological formations in accordance with the KBS-3 method is still the most suitable method for the disposal of the spent nuclear fuel".

In November of 2006, SKB submitted an application for a permit under the Nuclear Activities Act to build an encapsulation plant at Clab. In this application, SKB defines the purpose of this plant and the connected final repository.

> 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 (SKB's application for the encapsulation plant, Appendix A, 3.1 Purpose and aims, p. 7, in Swedish only).

According to SKB, achieving this purpose requires an encapsulation plant and a final repository. An application for a final repository will be submitted in 2009, but the 2006 application makes it clear that SKB plans to design the final repository in accordance with the KBS-3 method. In SKB's RD&D Programme 2004, this method is presented with the aid of the following illustration (Figure 4.1).

Figure 4-1 The KBS-3 method



All spent nuclear fuel will be disposed of in the crystalline bedrock, 500 metres below the surface. The fuel is enclosed in copper canisters, which are surrounded by bentonite clay. The method is designed so that the waste can be left without supervision and control by future generations.
Source: SKB's RD&D Programme 2004 p. 27.

The KBS-3 method is the main alternative in SKB's planning of a final repository for the Swedish nuclear waste. The exact design will be described in SKB's application in 2009, but the main components in the system have been designed over the period since the late 1970s. KASAM has followed and analyzed this development work over the years, for example in state-of-the-art reports and reviews of SKB's RD&D programmes.

4.1 Historical background

The issue of final disposal of the spent nuclear fuel from the Swedish nuclear power plants attracted little attention when nuclear power was introduced in Sweden in the 1960s. But the issue was politicized during the 1970s and contributed to the change of Government in 1976, when a non-socialist Government under the leadership of then Centre Party leader Thorbjörn Fälldin took office (the runup to this is described by Evert Vedung in Andrén & Sandberg 2004, pp. 33-56, in Swedish only). The nuclear waste issue was at the focus of the political debate, and under the terms of the Stipulations Act of 1977 a nuclear reactor could only be fuelled and put into service under one of two conditions. One was that the reactor owner had a contract for reprocessing of the spent nuclear fuel and could demonstrate how "absolutely safe" final disposal of the reprocessed fuel could take place. The *other* (alternative) prerequisite was that an "absolutely safe" final disposal of spent unreprocessed nuclear fuel could take place. In response to the Stipulations act, the Swedish power producers tasked their jointly owned company *Svensk Kärnbränsleförsörjning AB* (SKBF, renamed in 1983 *Svensk Kärnbränslehantering AB* = the Swedish Nuclear Fuel and Waste Management Co, SKB) with developing a proposal in principle for management and disposal of the spent nuclear fuel from the Swedish nuclear power plants. The proposals KBS (KärnBränsleSäkerhet = Nuclear Fuel Safety) 1 and KBS 2 were based on the Stipulations Act's two main alternatives: final disposal after reprocessing (KBS 1) and direct disposal without reprocessing (KBS 2). The present-day main alternative, the KBS-3 method, eventually emerged from the KBS-2 method. (For a more detailed description of the political and legal history of nuclear waste management, see KASAM's state-of-the-art report 1995 (SOU 1995:50, Chap. 1) and the in-depth report *Tid för slutförvaring av kärnavfall – samhälle, teknik och natur* ("Time for final disposal of nuclear waste – society, technology and nature", in Swedish only, KASAM Rapport 2007:3).

Göran Sundqvist and Jonas Anshelm have, in different publications, taken a closer look at the importance the KBS-3 method has had for the development of Swedish nuclear power (Sundqvist 2002 and Anshelm 2006). Of particular importance is the review that was done in conjunction with the nuclear power industry's applications for permits to fuel the nuclear power reactors Forsmark 3 and Oskarshamn 3. The KBS-3 method was evaluated by international experts and received the go-ahead from both them and SKI, who judged that the KBS-3 method was able to satisfy the requirements on acceptable safety. In the summer of 1984, the Government issued a fuelling permit for Forsmark 3 and Oskarshamn 3 on this basis.

With the passage of time, the issue of selecting a site for the final repository has come increasingly into the foreground, partly obscuring the issue of method. But in 1999, SKB published a safety report, SR 97, which breathed new life into the discussion concerning the KBS-3 method. SR 97 was the response to a Government decision in 1995 regarding a supplement to SKB's RD&D Programme 92. One of the purposes of SR 97 was to "serve as a basis for demonstrating the feasibility of finding a site in Swedish bedrock where the KBS-3 method for deep disposal of spent nuclear fuel meets the requirements on long-term safety and radiation protection that are defined in SSI's and SKI's regulations" (SR 97, p. 18 of English version). SR 97 addresses the issue of long-term post-closure safety. The criteria for an acceptable final repository are SSI's and SKI's regulations, which have been discussed in previous chapters.

The "philosophy" that has guided the assessment of the safety of the KBS-3 method is described in SR 97 in the following manner:

- Long-term safety shall not require future monitoring and maintenance.
- The repository shall be designed to permit possible future measures to modify the repository or retrieve the waste.
- The long-term safety of the repository shall be based on multiple engineered and natural barriers which contribute via different functions to the repository's total safety.

The KBS-3 repository for spent nuclear fuel is designed primarily to isolate the waste. If the isolation function should for any reason fail in any respect, a secondary purpose of the repository is to retard the release of radionuclides. This safety is achieved with a system of barriers that support and complement each other. The safety of the repository must be adequate even if one barrier should be defective or fail to function as intended. This is the essence of the multiple barrier principle.

Another principle is to make the repository "nature-like", i.e. to use natural materials for the engineered barriers. Choosing naturally occurring materials makes it possible to judge and evaluate the materials' long-term stability and behaviour in a deep repository based on knowledge of natural deposits. For the same reason, the repository should cause as little disturbance of the natural conditions in the rock as possible. Above all, an attempt is made to limit the chemical impact of the repository in the rock. (SR 97, p. 92 of English version).

In November of 2006, SKB published another safety assessment of a KBS-3 repository (SR-Can). An integrated safety assessment based on the selected site will be published in 2009 (SR Site). We will return to matters related to safety assessments in section 4.5.

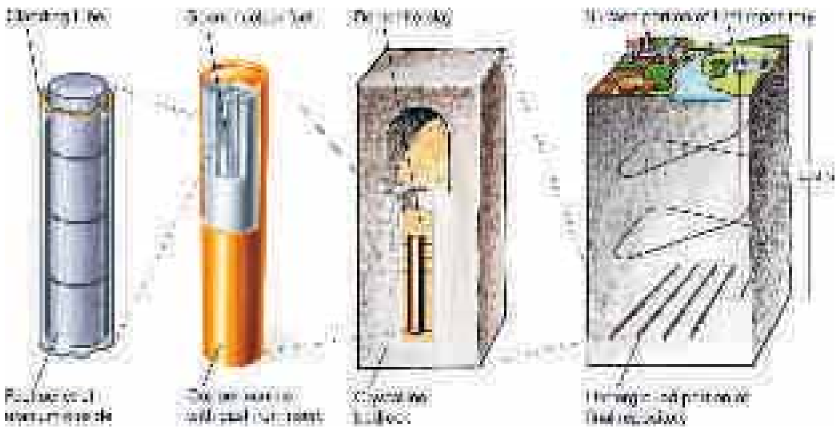
4.2 The KBS-3 method

The KBS-3 method is summarized as follows by SKB in SR 97 (see Main Report 1999, p. 27 of English version):

- The fuel is placed in corrosion-resistant copper canisters. Inside the five-metre-long canisters is a cast iron insert that provides the necessary mechanical strength.
- The canisters are surrounded by a layer of bentonite clay that protects the canister mechanically in the event of small rock movements and prevents groundwater and corrosive substances from reaching the canister. The clay also effectively adsorbs many radionuclides that could be released if the canisters should be damaged.
- The canisters with surrounding bentonite clay are emplaced at a depth of about 500 metres in the crystalline bedrock, where mechanical and chemical conditions are stable in a long-term perspective.
- If any canister should be damaged, the chemical properties of the fuel and the radioactive materials, for example their poor solubility in water, put severe limitations on the transport of radionuclides from the repository to the ground surface. This is particularly true of those elements with the highest long-term radiotoxicity, such as americium and plutonium.

The method is illustrated in Figure 4-2 on the following page.

Figure 4-2 Central components of the KBS-3 method's multiple barrier system



***Source*: SKB: SR 97, Main Report 1999 p. 28 of English version.**

SKB has pursued a thorough programme of research and development on this system choice since the KBS-3 method was first introduced in 1983. Every third year since 1986, SKB has submitted a programme for research, development and demonstration of methods for the management and disposal of nuclear waste

4.3 KASAM's assessment of the KBS-3 method

The KBS-3 method contains the following four fundamental barriers for preventing or retarding the dispersion of radionuclides from the nuclear waste:

- the canister,
- the buffer,
- the backfill,
- the geosphere.

KASAM has on different occasions commented on SKB's proposal for the design of these barriers and how they can prevent or at least retard the dispersion of toxic radionuclides from the nuclear waste.

The canister is the most important barrier for isolating the spent nuclear fuel. Three fundamental requirements are imposed on such a canister. It must (1) be leaktight so that no radionuclides get out and no groundwater gets in, (2) provide mechanical stability, i.e. withstand the mechanical stresses that can reasonably be expected to occur. Furthermore the canister must be (3) corrosion-resistant. "The premise is that the canister must be able to withstand corrosion attack for at least 100,000 years" (KASAM's review of SKB's RD&D Programme 2004, SOU 2005:47, p. 43 of English version).

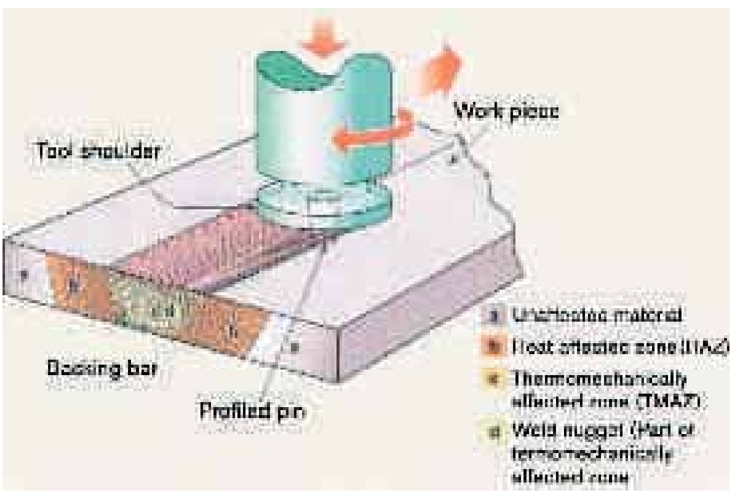
SKB's "reference canister" consists of an inner container of cast iron and an outer shell of copper. The cast iron insert provides mechanical stability and the copper shell protects against corrosion. KASAM and other authorities have been positive to the choice of materials (see e.g. KASAM's review of RD&D Programme 2001, SOU 2002:63, p. 49 of English version), but have emphasized that "acceptance criteria must be developed for all parts of the canister". SKB asserts that they have demonstrated in their research programme that the reference canister can satisfy the requirements on mechanical stability and corrosion resistance that will ensure that the spent nuclear fuel can be contained for at least 100,000 years during a series of different scenarios (possible sequences of events). The canister must be able to withstand both earthquakes and ice ages as well as more "normal" stresses down in the final repository. The copper canister must, for example, withstand shear movements and prevent groundwater from running into the gap between the canister shell and the cast iron insert.

Safety assessments must be conducted in order to predict possible sequences of events if the canister fails to satisfy the established criteria (SOU 2004:67 p. 323 of English version). In its licence application for the encapsulation plant in 2006, SKB established certain acceptance criteria and carried out such consequence analyses.

The establishment of acceptance criteria is also aimed at assuring the quality of the individual canisters, i.e. that the copper shell and cast iron insert do not have any flaws in the form of material defects or structural faults (e.g. defective weld joints). The fabrication process must guarantee that such flaws are detected and corrected. Of particular importance is access to an efficient welding method for reliably sealing the canister. A copper lid will be welded onto the canister after the spent nuclear fuel has been lowered into the cast iron insert. SKB has developed different methods for sealing of the copper canister. The reference method is currently a welding method that bonds the materials together with frictional heat without the material melting. This method was thoroughly described and evaluated in SKB's RD&D Programme 2004.

In May 2005, SKB announced in a press release that a "safe method for encapsulation of spent nuclear fuel is ready". This technology for sealing of the canister is called "friction stir welding" and is illustrated in Figure 4.3. SKB's encapsulation method has been positively assessed in KASAM's review of RD&D Programme 2005 (SOU 2005:47 p. 56 of English version). But it remains for SKB to show that the welding procedures can routinely give results that meet stipulated requirements (SOU 2005:47, p. 22 of English version).

Figure 4-3 Principle of friction stir welding



***Source*: Development of fabrication technology for copper canisters with cast inserts. Status report in August 2001 by Claes-Göran Andersson, SKB report TR-02-07.**

The buffer is supposed to keep the canisters in place and, in the event the canister starts to leak, retard the dispersion of the radioactive material, for example via the groundwater. Its main function is to prevent flowing water in the rock from coming into contact with the canister and its nuclear waste. In order to perform this function, the buffer must, according to SKB, meet a series of requirements (see RD&D Programme 2004 or KASAM's summary in review report SOU 2005:47 p. 81-82 of English version), for example:

- conduct decay heat away from the nuclear waste,
- have low hydraulic conductivity in order to retard the transport of radioactive material from a damaged canister,
- have a sufficient swelling pressure to ensure contact with the surrounding rock, but not higher than what the rock and the canister can take,
- be self-healing so that no permanent cracks form,
- have other properties that are stable for at least 100,000 years.

Furthermore, the buffer must comply with a number of preferences, such as:

- prevent microorganisms from coming into contact with the canister and causing corrosion,
- be able to absorb gas from a damaged or corroding canister without deterioration of other buffer properties,
- not contain impurities that are harmful to the copper canister or the backfill material,
- be able to filter out colloidal particles.[1]

SKB's reference material for the buffer is bentonite clay (MX-80), which SKB judges can satisfy the above requirements and preferences. The question of alternative buffer materials has, however, not been finally answered and is discussed, for example, in KASAM's review of RD&D Programme 2004 (SOU 2005:47 p. 83 of English version). Another important question concerns gas transport and how, for example, hydrogen from a damaged canister is transported through the bentonite buffer. KASAM has questioned why this issue isn't prioritized in SKB's research programme.

[1] Colloids are tiny particles around 1 nm to 1 µ in size that can remain suspended in water and that can affect radionuclide transport from a final repository with radioactive waste.

The backfill in the deposition tunnels is, claims SKB, not a barrier in itself. It is rather a prerequisite for the buffer and the rock to function as effective barriers. In other words, the function of the backfill is to stabilize the final repository. Furthermore, SKB has set up a number of other requirements. The backfill must (cf. SOU 2005:47 p. 93 of English version):

- have a stiffness that minimizes the upward expansion of the buffer,
- have a hydraulic conductivity that is comparable to that of the surrounding rock,
- exert a certain swelling pressure against the roof to counteract piping.

In its review of RD&D Programme 2004, KASAM states that the question of radionuclide transport through the backfill and how it can be retarded is a more important part of the requirement specification than is made evident in SKB's RD&D programme. The density of the backfill material will presumably be lower than that of the buffer. Radionuclides from a damaged copper canister will travel faster through the backfill than through the buffer. This has not been given sufficient attention by SKB. Nor has the increasing microbiological activity in the backfill that could result from its lower density.

In contrast to the buffer, SKB does not specify any particular reference material for the backfill in its most recent RD&D programme (2004). In its review of RD&D Programme 2001, KASAM has pointed out the advantages of swelling clay that is compacted in place in the tunnel. The clay creates a maximum seal against walls and roof. Furthermore, KASAM has asserted that different materials may be needed in different spaces. The deposition tunnels may require a different material than transport tunnels shafts and ramps to the ground surface (SOU 2002:63, p. 65 of English version).

The geosphere provides natural protection for the canisters. Furthermore, rock with mechanical stability, limited fracturing and the right chemical composition can significantly retard the dispersion of radioactive material from damaged and leaking canisters. It is therefore of crucial importance that both probable and less probable courses of events in and around the final repository are distinguished and the consequences of these scenarios are studied and evaluated. Reliable knowledge of groundwater transport along different fractures is of crucial importance. Such knowledge has been obtained from, for example, the Äspö HRL.

A central question in this context is the occurrence and properties of fractures and fracture zones. This question was given thorough attention in KASAM's state-of-the-art report for 1998. The objective previously was to locate the final repository in a sufficiently large volume of "fracture-free" bedrock. This objective was eventually modified. Moderately fractured rock became the ideal. The "slab model" emerged, where the goal was to find a homogeneous slab of bedrock, protected by surrounding zones of weakness which can absorb any future movements in connection with earthquakes and ice ages (SOU 1998:68 p. 121 of English version).

In its RD&D Programme 2004, SKB writes that the final repository will be built in crystalline rock of granitic composition (p. 243 of English version). This point of departure has repeatedly been questioned by KASAM in reviews of previous RD&D programmes. The point of departure should instead be a comparison between different rock types and how they can meet the requirements that must be met by the rock barrier (Review of RD&D 98 Supplement, p. 2, in Swedish only; SOU 2002:63, p. 70 of English version, and SOU 2005:47, p. 100 of English version). Additional observations concerning the rock barrier are expressed in Chapter 7 about the site selection process.

The biosphere is defined as "all living organisms in the environment, including man, as well as the part of the environment with which man and the other organisms interact" (SOU 2005:47 p. 117 of English version). If radionuclides from damaged canisters reach the biosphere, this can have more or less harmful effects on man and other living organisms. These harmful effects have been described in Chapter 1, and the ethical challenge for the final repository project is to predict and reduce the probability that such harmful effects will occur as much as reasonably possible.

Harmful radioactive substances from leaking canisters can reach the biosphere in essentially three different ways (with the exception of an intentional or inadvertent human intrusion into the final repository). In the first place, these substances can reach the ground surface with groundwater flows that pass through a final repository with broken or corroding canisters. The outflow for the contaminated groundwater may be wells, springs, mires and wetlands, lakes, streams, and coastal and sea water. Furthermore, such groundwater can contaminate arable soil with radioactive substances and be absorbed by various types of grain which are then eaten by animals and man. In the second place, harmful radionuclides can reach man and animals by sedimentation on seafloors and lake beds. If the sediments are then exposed after future land uplift, they may be cultivated to produce food, which will be contaminated. In the third place, leaking canisters could be freed by erosion, where the rock is worn down to the level of the final repository, or by severe faulting that brings the canisters up to ground level. Such courses of events may be unlikely, but they cannot be ruled out entirely.

It is the dilution volume that determines what consequences a release of radionuclides from the final repository will have for plants, animals and humans. Through the site investigations near the nuclear power plants in Forsmark and Oskarshamn, SKB has learned where different outflow points are located and can thereby also calculate the dilution factor. The Safe project in Forsmark has shown that that water flowing out of the rock is to a great extent diluted by the groundwater in the Quaternary deposits by a factor of about 100 (SKB 's RD&D Programme 2004, p. 279 of English version). The results of additional research in this area can be expected to be reported along with SKB's application in 2009.

In the concluding chapter (6) we will return to the question of whether there isn't another barrier in the form of the social decision process. In this chapter we will now examine two additional questions: retrievability and safety assessment.

4.4 Retrievability

By retrieval is meant freeing one or more canisters and then bringing them back for possible reuse. The question has been given limited attention by SKB, justified by the fact that there is no formal requirement in Sweden that retrieval of a deposited canister must be possible (SKB's RD&D Programme 2004, p. 126 of English version). KASAM has, however, addressed the question on numerous occasions, not least at an international seminar arranged by KASAM jointly with the IAEA in 1999. The seminar was documented in a detailed report (*Retrievability of High Level Waste* *and Spent Nuclear Fuel*, IAEA-Tecdoc-1187, 2000). Three possible reasons are given initially for retrievability (at different points in time):

- it must be possible to take remedial actions if it would appear that the repository does not perform according to expectations,
- new technologies or new economic conditions may lead part of the waste, particularly spent fuel, to be considered a useful resource,
- new technologies may be developed which can make the radioactive waste less dangerous or even harmless.

These arguments in favour of retrievability must, however, be weighed against the disadvantages. They include the extra costs for adapting a final repository so that future retrieval is possible, as well as the costs of retrieval itself. Another problem that was discussed at the seminar concerns the consequences for long-term safety. Does the adaptation of the final repository for possible retrieval necessitate certain compromises with regard to long-term safety? The question is an ethical one. What should be prioritized? The freedom of choice of future generations or their safety? In KASAM's most recent state-of-the-art report, an argument is made for the standpoint that if there is a conflict between freedom of choice and safety, the choice should fall on safety (SOU 2004:67 p. 451-452 of English version).

In its review of RD&D Programme 2004, KASAM pointed out the necessity of analyzing safety in connection with a retrieval of fuel canisters from the final repository. No such analysis has yet been reported by SKB, but has been anticipated as a system variant in a future system analysis (RD&D Programme 2004, p. 370 of English version).

4.5 Role and development of the safety assessment

The main role of the safety assessment is to demonstrate the long-term safety of a final repository in Swedish bedrock for spent nuclear fuel and high-level reactor waste. Method development has been pursued for over three decades both in Sweden and internationally, by both government authorities and industry. Sweden has constantly been in the forefront and occasionally a leader in the development of safety assessment methods.

The safety assessment is a tool for systematically analyzing all conceivable courses of events (scenarios) that can affect a final repository. The goal is to find out what scenarios are possible, what the consequences are and how high the probability is for the different scenarios.

The following presentation is based on KASAM Report 2007:2e on safety assessment of final disposal of nuclear fuel – role, development and challenge.

4.5.1 Role

With the passage of the Stipulations Act in 1977, the reactor owners were given clear responsibility for final disposal of the nuclear waste. The regulatory authorities SKI and SSI were supposed to issue requirements and examine applications for permits. The requirement that was made in the Stipulations Act on an “absolutely safe” final disposal led to an early start of the safety assessment work in Sweden, with the involvement of both industry and the regulatory authorities.

Even though estimating the risk posed by a final repository mainly involves scientific and technical judgements, it is ultimately a question of values. And these values are expressed in political decisions. When SKI and SSI decide what requirements and criteria are to apply to the final repository, they are acting as interpreters of society’s values and norms. 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.

Both SKI’s and SSI’s regulations make requirements on what should be included in a safety assessment. The safety assessment is a component in both method selection and site selection. The purpose of the safety assessment is to determine the long-term safety of a given final disposal method on a specific site. Many site-specific factors are weighed into the safety assessment to achieve an overall judgement of the suitability of the site to host a given final repository. The safety assessment can also be used to investigate the effect on long-term safety of the different designs of the components included in the final repository, for example the backfill and the copper canister.

4.5.2 Development

The specific questions which the safety assessment is supposed to answer have varied over the three decades that have passed since the mid-1970s from questions concerning the possibility of building a safe final repository somewhere in the Swedish crystalline bedrock to a prioritization of R&D and designing a final repository on a selected site. The division of responsibility between government and industry has remained the same during these three decades (industry has total responsibility for the nuclear fuel cycle from uranium mining to final repository with SKI and SSI as the regulatory authorities), but the roles of the actors in the safety assessment process have varied. Besides national politicians and decision-makers in regulatory authorities and industry, municipal authorities and local citizens, as well as various non-governmental organizations, are now also considered to be important stakeholders.

In the early years, the nuclear power industry took the initiative in the development of safety assessment methodology with a focus on identifying the processes and properties of the Swedish bedrock that determine the safety of the repository. During the 1980s and 1990s, much methodology development was pursued by the regulatory authorities, for example through a series of international projects including HYDROCOIN, INTRAVAL and BIOMOVS. SKI's "own" safety assessments started with Project-90 and culminated in SITE 94, which is the most recent safety assessment published by the regulatory authorities. Through these projects, SKI in particular built up its own capacity in the area through its own efforts combined with those of Swedish and foreign consultants and other international experts. In the latter part of the 1990s, the nuclear power industry resumed the initiative and SKB conducted extensive development 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 – planned for 2009. An important step towards SR-Site is SKB's most recently published (2006) safety assessment SR-Can (SKB report TR-06-09), which is the first site-specific safety assessment where it is possible to compare properties at different sites and their effect on the calculation results.

For the sake of simplicity, it could be said that a safety assessment basically contains three elements, and that it is around these elements that the development work is concentrated. A *normative part* defines the norms and criteria that are to be satisfied. A *descriptive part* identifies features, events and processes that control the post-closure evolution of the repository. The third element is a *calculative part* that ties together the normative and descriptive parts (by showing that a repository that is controlled by the identified processes, events and properties either satisfies or fails to satisfy the defined norms and criteria).

As mentioned previously, development of the descriptive and calculative parts of the safety assessment has taken place within SKI, SSI and SKB.

But it is the role of the regulatory authorities to define and develop the normative part of the safety assessment. They do this by establishing criteria and norms (regulations and general recommendations). 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.

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.

4.5.3 Challenges

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 safety assessment must – based on the properties of the barriers and the processes and events that can affect these properties – identify all relevant pathways over which radionuclides can be transported. The safety assessment also includes subsequently 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 radionuclides, but also concentrate them, so that even a small leakage from the final repository can have consequences for life and health.

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. The connections between barrier properties, processes and events during the long period of time are very complex, however. Even after three decades of extensive research and development, considerable uncertainties will 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 SKB's responsibility to identify these uncertainties and show that, taken together, they do not affect the assessment of the repository's safety.

Responsibility for the decision to build or not to build a proposed repository ultimately rests with the country's political bodies, in the last instance 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. Since the safety assessment is part of the body of material which the politicians must consider, it must be presented in a way that can be understood by a layman. This is another of the safety assessment's challenges.

4.6 Concluding reflections

Regarding the alternatives question, KASAM said in summary in its review of RD&D Programme 98 (SOU 1999:67 pp. 34-35 of English version) that when it comes to a built repository in the bedrock, the KBS-3 method has several advantages. The method is the best in terms of its adaptability to the conditions in the host rock as they are established during excavation. Furthermore, the method is based on encapsulating the fuel in a space-saving, compact module – the canister with the surrounding bentonite buffer. The small dimensions are favourable when it comes to depositing the modules in a homogeneous portion of the host rock. Since the fuel is distributed among many canisters, a smaller quantity of fuel will be exposed to groundwater if and when the canister is breached. Each deposition module is positioned in radiological isolation from all other modules, which facilitates the emplacement of canisters in adjacent holes and makes it simpler to retrieve an already deposited canister if necessary.

In its review of RD&D Programme 2001, KASAM repeated this assessment (SOU 2002:63, p. 100 of English version) and added that disposal in deep boreholes is not a realistic alternative method in accordance with the requirements of the Environmental Code. In this context, KASAM stated that "The possibility of retrieving the spent nuclear fuel is likely to be virtually non-existent and there could, thereby, also be considerable difficulties in implementing a meaningful demonstration phase for such a repository". In the same review, KASAM also stated that "In KASAM's opinion, there are considerable reasons in favour of the present focus of the Swedish nuclear waste management programme, namely, further development work on direct disposal in accordance with the KBS-3 method. This development work must be conducted in a goal-oriented manner."

In its review of RD&D Programme 2004, KASAM saw no reason to comment further on the choice of the KBS-3 method as a planning premise for the site investigations. The issue of the choice of method was once again re-opened in 2006 by public demands to take a closer look at the deep boreholes alternative. This issue has already been dealt with in Chapter 3.

5 Site selection

One of the main problems in the nuclear waste issue is site selection, i.e. arriving at a well-founded decision on the siting of a final repository. The Environmental Code provides that “Sites for activities and measures shall always be chosen in such a way as to make it possible to achieve their purpose with a minimum of damage or detriment to human health and the environment” (Chap. 2, Sec. 4). A phrase that has often been used in discussing site selection has been “best possible site”. But the implications of this expression are unclear, and it does not occur in the text of the law or in the relevant travaux preparatoires. In KASAM’s opinion it is more relevant to speak of *site selection criteria*, meaning a set of requirements which a site for the establishment of a final repository should satisfy. Such criteria have also been established by SKB, for example in its RD&D Programme 1995. There SKB defined four site selection factors: safety, technology, land and environment, and societal aspects. SKB judged that this subdivision suited the purpose of the studies. In TR-01-03 (known in Swedish as Fud-K), SKB presents a revised structure for siting factors in the following three categories: bedrock, industrial establishment and societal aspects (see TR-01-03[1], p. 116).

In the present report it has previously been stated that a distinction should be made between the criteria for the *geographic* siting and the criteria for the *geological* siting. The geographic siting has to do with where in the country the final repository should be located. The geological siting refers to the rock formation. In what type of rock should the final repository be located – and at what depth? Geographic and geological siting are naturally dependent on each other. Certain geographic sites in the country can be excluded because they do not meet the criteria for geological siting.

[1] Integrated account of method, site selection and programme prior to the site investigation phase.

5.1 General points of departure

The question of a best possible site has been the subject of lively discussion in connection with the Environmental Code's requirement of a minimum of damage or detriment to human health and the environment. The more precise implications of this criterion were discussed at a KASAM seminar in February 2006 on method and site selection (KASAM report 2006:1e, in Swedish only). Different interpretations were made as far as site selection is concerned. According to one view, the Environmental Code only requires a *sufficiently* good site. According to another, stricter interpretation, the applicant for a permit to build a final repository must be able to show that the site is the geologically best site in a stricter and more absolute sense. KASAM asserted the following in its conclusions from the alternatives seminar in February 2006:

> The term "Best possible site" lacks meaning if what is meant and under what conditions the term should be applied are not defined. Nor is there any explicit requirement in the Environmental Code for a best site from a geological viewpoint. But it may be difficult for applicants – as well as for the Government – to justify why the site that is "best" from a geological viewpoint should not be selected in an overall assessment of the concrete alternatives presented in the EIS. (KASAM report 2006:1e, p. 34, in Swedish only).

KASAM has previously underscored the relationship between geological conditions and the stability and long-term safety of the final repository. There are unstable areas in the boundary zones between the continental plates where a final repository for spent nuclear fuel should not be located. "It should instead be located inside the actual shields, far from the boundary zones with active geology" (SOU 2004:120, p. 29, in Swedish only). The continental shields, such as Africa and Europe, are billions of years old. One of these shields is the Baltic Shield.

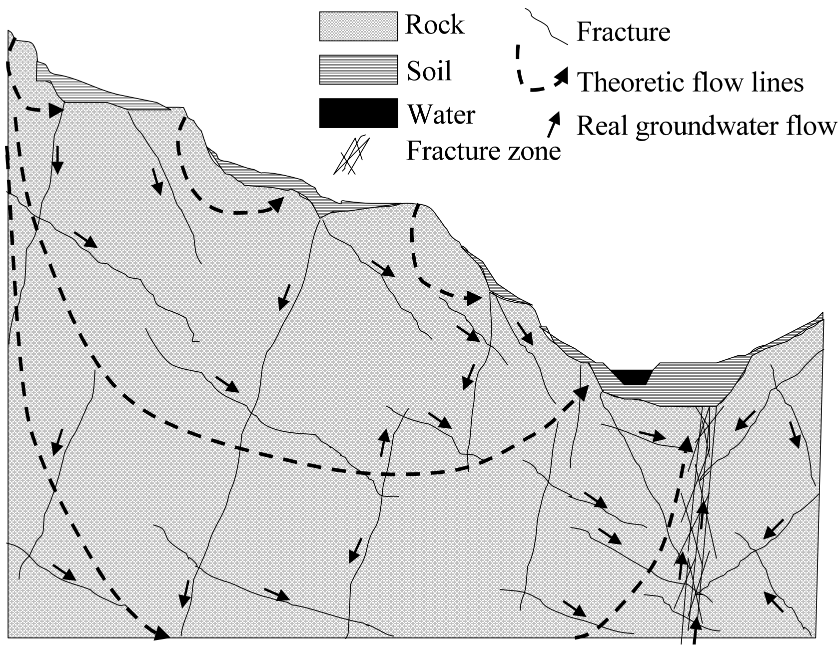
The bedrock for a final repository should guarantee its mechanical stability for up to a million years. Compared with the age of the Baltic Shield, 100,000 years – and even a million years – is a brief span of time. The rock types in this shield have not changed in a very long time. Earthquakes and the like can happen here, but they are not characteristic for this geological formation. The Baltic Shield therefore offers good prospects for hosting a final repository. Then there are better or poorer areas within this shield, depending on rock types, fracture frequencies, deformation zones etc. Good conditions should exist in formations that take the form of large lenses or “slabs”. The deformation takes place around the lens or slab, not within it. They have not been, nor are they likely to be, affected by ice ages either.

The most probable pathway over which radionuclides from the nuclear waste can reach the ground surface is the groundwater flow through the fracture system in the rock. The question of the groundwater flows in the rock and how they are affected by the final repository will therefore be fundamental in the safety assessment (see KASAM Report 2007:2e).

The study of groundwater flow is called hydrogeology, which examines the physical and chemical processes that control the occurrence and flow of the water in rock and bedrock and how they can be formulated mathematically in flow calculations. The radionuclides decay and are retained as they pass through the rock in a more or less predictable way. It is also possible to calculate how the engineered and natural barriers have to be designed in order to retard the transport of radionuclides with the groundwater. Since it is possible to some extent to calculate how different courses of events such as ice ages, faults or earthquakes affect a given final repository, it is also possible to some extent to judge how such events affect groundwater flows in the rock. There is good scientific knowledge here, but also unanswered questions. Many studies have been made of future ice ages, but it is also necessary to take into account periods of warmer climate, for example due to the greenhouse effect (see KASAM Report 2007:3e).

KASAM has also addressed the issue of inland versus near-coastal siting of a final repository (KASAM 2005, pp. 98-101, in Swedish only). It has, for example, been claimed that an inland siting would be more appropriate – for example on the highland in the interior of Småland (Holmstrand, O. et al. (2002) “The worst sites have been selected”. Dagens Nyheter, 4 Jan. 2002). There the transport distances for the groundwater are longer, which would delay the outflow of radionuclides from a leaking final repository. But in reality, hilly landscape (such as is found in Småland) is divided into a large number of recharge and discharge areas, where geological structures of various kinds such as fracture zones and hypabyssal rocks control the groundwater’s flow paths (see Figure 5.1). These questions have subsequently been illuminated by a large model study of eastern Småland (SKB rapport R-06-64).

Figure 5.1 Recharge and discharge areas as well as groundwater flow patterns in a valley with varying topography and thin soil cover on fractured, hard rock. The actual flow pattern deviates considerably from the theoretical depending on fractures and fracture zones



Source: SOU 2004:67, p. 238 of English version.

In summary, KASAM has in its state-of-the-art reports and FUD reviews been able to conclude that knowledge of groundwater conditions in Swedish rock has increased as a result of SKB's research. Whether or not the calculations that have been done are reliable and adequate and verify that geological formations exist in Sweden that meet the requirement of "an effective and reliable isolation of the waste from the environment" for hundreds of thousands of years can really only be credibly answered by the regulatory review of SKB's application in 2009.

5.2 Flexible or systematic site selection strategy?

A fundamental difference of opinion on the whole site selection procedure emerged and became a topic of discussion in the early 1990s. Göran Sundqvist describes this in his book *The Bedrock of Opinion. Science, Technology and Society in the Siting of High-Level Nuclear Waste* (2002) and distinguishes between two site selection strategies. He says that SKB's site selection strategy is *flexible*. The goal is to arrive at the site selection decision without being burdened by overly detailed requirements and regulations. SKB assumes that there are many sites in the country that are suitable from a geological perspective. This enables them to allow the municipalities to decide whether or not they want a final repository. One part of this strategy is the invitation that was sent out in 1992 to the country's 286 municipalities with the offer of a feasibility study. According to Sundqvist, this flexible site selection strategy, based on voluntary participation and local acceptance, differs from the more *systematic strategy* which the regulatory authorities and KASAM have recommended. A fundamental aspect of this strategy is clear and well-defined site selection criteria, a more overall assessment in the form of a general siting study, and against this background a systematic selection process.

The systematic strategy came to expression in the previously mentioned Flagbook, where Nordic regulatory authorities have harmonized their principles in a collection of criteria for acceptable nuclear waste management. According to the Flagbook, the site selection process should be carried out in three stages.

The *first* stage should be an area survey to identify the regions within which suitable sites for the establishment of a final repository might be found. The main goal is to rule out those regions that are unsuitable from a hydrological, tectonic or demographic standpoint. A final repository should not, for example, be deliberately located in a densely populated area with porous rocks. Furthermore, sites near valuable mineral deposits are avoided.

The *second* stage should involve identifying a number of sites within the regions that have been deemed suitable. Here, tougher demands are made on the investigation methods and their rigorous execution. Site-specific analyses must be carried out with a view to the specific layout of the final repository and in order to be able to compare different sites with each other.

Finally, the *third* stage should be to select a site, where an even more rigorous detailed characterization is performed. A shaft is sunk down to the planned level of the final repository and measurements are performed from tunnels at this level. This provides more detailed knowledge of the geological properties of the rock than those obtained in the second stage. The final examination of the suitability of the site for a final repository is done when these results have been compiled and evaluated.

In its RD&D Programme 1998, SKB defended its flexible strategy against the criticism that had been levelled by advocates of the systematic strategy in the following manner:

> Those who believe another systematics is needed for the site selection process imagine that the best site can be identified by screening on increasingly detailed scales. No consideration should be given to public opinion, at least not in the initial stages; instead, bedrock conditions should determine the choice of site.
>
> We believe that such a process has poor prospects of success. The reason is that site-specific knowledge of the most important safety-related factors (groundwater flow, groundwater chemistry, conditions for radionuclide transport and rock mechanical conditions) is lacking on most sites. Generalized appraisals can be made, but only when boreholes and borehole measurements are available does it become possible to evaluate safety and compare areas from this aspect. It is furthermore highly uncertain whether municipal residents would accept a "best" site that has been identified in a centralized process without local participation. Foreign experience supports this view. (SKB's RD&D Programme 1998, p. 80 of English version).

It should, however, be emphasized that the flexible and systematic site selection strategies have never been applied in practice in their pure forms. The regulatory authorities, and not least KASAM, often returned to the question of local acceptance and a municipally rooted decision process (see Chapter 6). SKB's flexible strategy was manifested in the aforementioned invitation to the country's municipalities to submit an expression of interest for investigations relating to a final repository. Feasibility studies were started in eight municipalities, but completed in only six. Of these, Forsmark and Oskarshamn were selected for site investigations. But it should be noted that during the course of this process, SKB simultaneously published clarifications of the site selection criteria (1994), a general siting study (1995) and a comparison between North/South and coast/interior (1998). The latter study was an important complement and indicated SKB's growing understanding for a more systematic strategy. At the same time, KASAM had some critical viewpoints regarding SKB's site selection strategy in its review of SKB's RD&D Programme 1998:

> Even though a valuable discussion is presented in the report, the result is that neither the northern nor the southern parts of Sweden can be prioritized in terms of siting prospects. The same conclusion applies to comparative evaluations of the siting prospects in the coastal and interior regions. It is easy to understand that SKB does not wish to draw definitive conclusions in a report such as this. However, SKB could have highlighted some issues which have a bearing on the selection of sites for site investigations. The report discusses important areas such as the bedrock, groundwater, climate changes (e.g. permafrost and glaciation) as well as shoreline displacement. The report could have presented, for example, a table showing which factors might be better in a coastal siting and which factors might be better in an inland siting. The grounds for evaluation proposed by SKB include the possibility that a coastal siting could be advantageous e.g. in terms of a reduced need for transport by road or railway. The critical reader wonders if any other factors may exist which would indicate that an inland siting would be more advantageous. SKB itself specifies a couple of such factors in the North-south/Coast-interior report, namely comparatively more changeable groundwater conditions (as an effect of shoreline displacement) and a possible occurrence of saline groundwater in near-coastal locations. KASAM does not find these to be examples of decisive factors, but believes that it is important that SKB, in connection with the preparation of the body of siting data for the choice of at least two sites for site investigations, should try to arrive at more comprehensive and well-defined grounds for evaluation, based for example on the line of reasoning in the North-south/Coast-interior report. (SOU 1999:67, pp. 48-49 of English version.)

5.3 Site selection process

In 1993 and 2000, SKB carried out *feasibility studies* in eight municipalities: Storuman, Malå, Östhammar, Nyköping, Oskarshamn, Tierp, Älvkarleby and Hultsfred. In 1995, SKB published a *national general siting study*, and in the late 1990s county-specific general siting studies of the bedrock.

After municipal referendums in 1995 and 1997, the municipal councils in Storuman and Malå said no to further investigations. SKB reported its conclusions from the feasibility studies at the end of 2000 (see also section 5.4). According to SKB, areas existed in five of six municipalities which were geologically suitable for further studies. SKB wanted to conduct *site investigations* on three areas, situated in the municipalities of Östhammar, Oskarshamn and Tierp. SKB also wanted to study an area situated in the municipality of Nyköping, but in the spring of 2001 the municipal council in Nyköping voted against continued participation in SKB's site selection process. The municipal council in Tierp voted with a narrow majority to decline further cooperation with SKB, while clear majorities in Östhammar and Oskarshamn spoke in favour of the proposed site investigations.

After agreements were reached with the two remaining municipalities, site investigations were commenced in 2002 in Forsmark and in the vicinity of the Oskarshamn nuclear power plant. Very extensive investigations have since been conducted in the two areas, including a large number of boreholes (600–800 m deep) intended to provide information on such parameters as rock strength, fracture zones, water flow and water pressure, as well as the chemical composition of the groundwater. With the support of these investigations, SKB will make its choice of site for a future final repository and subsequently submit its application. According to SKB's calculations, the final repository will be ready to receive the first canister in 2018 and the last in about 2050. Approximately 4,500 canisters will then have been deposited in the final repository. Then the repository will be closed and sealed. SKB estimates that this will take place in around 2060.

5.4 KASAM's assessment of feasibility studies and site investigations

In December 2000, SKB submitted a supplement to its RD&D Programme 1998 entitled *Integrated account of method, site selection and programme prior to the site investigation phase* (known as Fud-K in Swedish, translated to English and published as SKB report TR-01-03) in which the considerations for selection outlined in section 5.2 were presented. The programme also included some aspects relating to the choice of method that have been touched upon previously in this report (see for example Chapter 3). In this context we wish to focus on site selection (TR-01-03, Part III) and the preliminary investigation programme (TR-01-03, Part IV).

SKB's fundamental conclusion was that all sites except the investigated areas in Älvkarleby Municipality have a bedrock that is judged to be potentially suitable for a final repository. The technical and environmental prospects are also good. After a closer analysis, SKB decided to prioritize "Forsmark, Simpevarp and Tierp north for test drilling and further study, along with additional studies of the prospects for the Skavsta/Fjällveden alternative." According to SKB, this alternative offers "a reasonable balance between the preference of a robust programme on the one hand and a reasonable level of cost and effort on the part of society on the other" (TR-01-03, p. 18).

KASAM published its review of Fud-K 2000 in June 2001. The overall assessment was positive. The feasibility studies were, according to KASAM, well done within the framework of their purposes and limitations. Since the information on geology, fractures, hydrogeology and hydrogeochemistry is incomplete, KASAM said that it cannot be assumed that the coming site investigations will produce positive results. It is therefore important to maintain the breadth in the site investigation programme for some time to come.

During the period of circulation for comment, SKB also published a report (TR-01-29) with a special focus on the upcoming site investigations. This report was highly praised in KASAM's review and was considered to be a model for investigations that will serve as a basis for environmental impact assessments in other contexts. This report, as well as in the previous one from 2000 (TR-01-03), addressed the central issue of the location of fracture zones, for example. The importance of the fracture zones for site selection was emphasized, and the following was quoted from TR-01-03:

> If the repository cannot be positioned in a reasonable manner ... in relation to regional ductile shear zones, regional fracture zones or local major fracture zones, the site is not suitable for a final repository. (TR-01-03, p. 137)

5.5 Social science research

In its 2002 review of SKB's RD&D Programme 2001, KASAM found that SKB's site investigation programme was too narrowly focused on scientific and technical issues. These issues are of course essential, but should be complemented by social science studies of the affected population and affected communities. "Examples of such issues are the effects of the site investigation phase on information and democracy requirements, including work and decision processes in the political arena. Other examples are possible effects in the legislative area, changes in regional conditions with respect to the labour market and the municipal economy, and the development of opinions on a local and national level with respect to the further work on a repository. In particular, it may be of interest to investigate issues relating to the role of the mass media in forming public opinion." (SOU 2002:63 p. 116 of English version). Similar viewpoints were expressed by others, such as affected municipalities.

In view of these wishes it is gratifying to note that SKB has, since 2004, pursued a special social science research programme aimed at broadening the perspective on the societal aspects of the nuclear fuel programme, raise the quality of the background material and the EISs, and contribute to the research on the societal aspects of large industrial and infrastructure projects.

SKB has concentrated its social science research programme on four areas:

- Socioeconomic impact – Macroeconomic effects (2 sub-projects).
- Decision processes (2 sub-projects).
- Opinions and attitudes – psychosocial effects (3 sub-projects).
- Global changes (1 sub-project).

A total of eight different projects in these four areas were thus funded in an initial phase. In its review of SKB's RD&D Programme 2004, KASAM perceived it as a shortcoming that the area "Global changes" was only being investigated to a limited extent in this phase. This is particularly true in view of the fact that SKB, in its master plan in Appendix A talks about fast, far-reaching and unpredictable societal changes that should be considered in conjunction with the safety of the final repository (RD&D Programme 2004, p. 371 of English version). The social science research programme currently (January 2007) comprises twelve different projects. Four projects have been added, but none of them are within the area “Global changes”. They are rather more closely related to the third area, “Opinions and attitudes – psychosocial effects”. On this point there is thus reason to reiterate the criticism expressed by KASAM in its RD&D review in 2005. It therefore remains unclear to what extent the social science research programme is related to existing gaps in knowledge of relevance to the EIA process and the fundamental safety issues that are associated with the future construction of a final repository for spent nuclear fuel.

For a number of years now, KASAM has pointed out the need for social science research as a complement to technical and scientific research. This need has now also been recognized by the nuclear power industry. As of 2004, SKB is funding a programme for social science research whose various sub-projects are being conducted by a number of departments at several Swedish universities. However, KASAM has considered it important for the credibility of the research that some of it should also be funded by someone other than the activity operators and SSI and SKI.

A report has been compiled for KASAM by the Department of Economic History at Umeå University providing an overview of the social science research and the literature on the nuclear waste issue in Sweden, with a focus on research of current relevance. The purpose has been to examine the scope and thrust of the independent social science research on the issue of nuclear waste in Sweden in comparison with the research that has been initiated and funded by the actors who participate in the decision process in the nuclear waste issue.

The report shows that the social science research on the issue of nuclear waste is currently being funded for the most part by the actors in the sector, mainly SKB, but to some extent also by SSI and SKI. Only one research project with foundation funding and one project with EU funding have been identified (these funds have furthermore been granted to the same researchers). For natural reasons, SKB’s social science research programme has the character of applied research, with a focus on the siting issue. A number of research issues regarded as urgent are addressed in the report, such as environmental issues and energy policy, international and global contexts, the vulnerable position of the municipalities and ethical-philosophical aspects.

5.6 Concluding reflections

The site selection process that has been described and assessed in this chapter appears to be more of historical interest. Forsmark in Östhammar Municipality and Laxemar in Oskarshamn Municipality are currently the subject of site investigations. A future final repository will be located on one of these sites – provided the Government approves SKB's application for a permit to build a final repository.

The previous site selection process is not solely of historical interest, however. It casts its shadow as far into the future as the future final repository is designed to protect us and future generations against the harmful effects of the nuclear waste. The credibility of the final repository project is dependent on this process being perceived as scientifically tenable. The conflict between the systematic and flexible site selection models can therefore not be dismissed. A selection process that ends with site selection being reduced to a choice between two areas close to existing nuclear power plants may attract many critical questions. Has local acceptance been allowed to play too prominent a role in comparison with geological aspects? Has an inland alternative been dismissed without sufficient reasons? The dismissal of an inland alternative means that it is not possible to make a closer comparison between e.g. groundwater flows in a near-coastal alternative and an inland alternative. At all events it appears urgent that SKB should clearly explain its standpoint and how it has proceeded.

The results of the site investigations in Forsmark and Laxemar will be of central importance in SKB's coming application (2009) for a permit to build a final repository.

In conclusion, there is reason to return to the question of the need for research in the social sciences and the humanities in conjunction with the planning and execution of large, technical advanced projects such as the nuclear waste project. KASAM has in various contexts underscored the value of SKB's social science research programme, while at the same time advocating the need for independent research on the social, economic, legal and ethical aspects of nuclear waste. These aspects should be studied to as great an extent as possible outside the organizations whose main concern is the nuclear power issue. This increases the chances of obtaining knowledge that can serve as a reliable basis for future decisions.

In summary, KASAM would therefore like to underscore the need for strategic independent long-range social science research on the nuclear waste issue, which may also be of benefit to other large-scale projects of national interest.

6 The decision process

6.1 The decision process – a social barrier?

SKI's general recommendations concerning the application of the regulations SKIFS 2002:1 state (p. 8) that the physical barriers in a final repository can be of two kinds: engineered (e.g. the copper canister containing the nuclear fuel) or natural (rock formations). A third category can be added to these two kinds of barriers: a social barrier. The importance of such an *expanded* multiple barrier system has been pointed out by sociologist Göran Sundqvist, cf. Figure 6.1 (see Sundqvist 2001 pp. 203-219 and Sundqvist 2002 p. 14-18). Society – in the sense of well-informed and critical public opinion and a democratic decision process – can constitute such a barrier. Sundqvist writes (Sundqvist 2001 p. 204, in Swedish only):

> In the first place, the local community has been a barrier – in the sense of an obstacle – for nuclear power utilities and authorities by repeatedly obstructing waste shipments of waste and efforts (investigations of the bedrock) to find a site for the final repository. In this sense, society is a barrier that prevents disposal of the waste on specially selected sites. In Sweden, the action group "Rädda Kynnefjäll" ("Save Kynnefjäll") is the best example of a social barrier in this sense. In the second place, society can, in the same way as the other barriers, act as a protective barrier that prevents the waste from leaking into the biosphere. Competent and responsible people can "guard" the repository, today and in the distant future, by preserving it in society's collective memory and thereby preventing human intrusions, both intentional (plutonium thieves) and unintentional (the search for desirable natural resources).

This social barrier is naturally an analogy – it is of a different nature than the natural and engineered barriers. But analogously to these, the social barrier has its protective function, its limitations and its control systems. And the social decision process can indirectly affect the protective capacity of the final repository system.

Figure 6.1 The expanded multiple barrier principle

The natural barrier	**The engineered barrier**	**The social barrier**
Bedrock	Encapsulation	Decision process, attitude, collective memory
Protection	*Protection*	*Protection*
Good rock	Functioning encapsulation	Participation, preservation of information
Opposition	*Opposition*	*Opposition*
Poor rock	Poor containment	Opinion: acceptance or rejection
Control	*Control*	*Control*
Geologists	SKB	Many actors, ultimately the Government

Source: After Sundqvist 2001 p. 207, in Swedish only.

The table in Figure 6.1 tries to show that society contributes in different ways ("the social barrier") to preventing the spent nuclear fuel from harming man and the environment. The table provides a simplified picture of the situation, but KASAM considers it valuable as a point of departure for a discussion of the decision process for the final repository for spent nuclear fuel.

In this chapter we will concentrate on the process that will lead to a decision on SKB's upcoming application for a permit to build a final repository for spent nuclear fuel.

6.2 The decision process so far

KASAM has on different occasions highlighted issues associated with the decision process. In the late 1980s, KASAM organized three seminars in cooperation with the National Board for Spent Nuclear Fuel (SKN). These seminars dealt with the unavoidable uncertainty associated with every decision concerning nuclear waste. The long time perspective compounds this uncertainty, even though considerable uncertainty is also associated with shorter-term decisions. The seminars used a simple model for well-founded decision-making that deserves to be reiterated. On the one hand, well-founded decision-making requires awareness of the goals society wishes to achieve and the values that should guide the activity to which the decisions apply. On the other hand, knowledge of the relevant facts is also required. The problem with decisions in the nuclear waste issue is that the knowledge base is incomplete and that certain knowledge is not available at the time the decision has to be made. A decision regarding a given solution must therefore be made with the awareness that other solutions may present themselves in the future. This openness to future developments are expressed in the KASAM principle, which has been mentioned previously in this state-of-the-art report: "A final repository should be constructed so that it makes inspection and controls unnecessary, without making inspection and controls impossible. In other words, our generation should not place the entire responsibility for the final repository on future generations, but neither should we deprive future generations of the option of assuming responsibility" (1992 state-of-the-art report, pp. 15-16). According to the quote, the objective is two-fold: operational reliability and controllability, inspection unnecessary but at the same time possible, disposal under the safest possible forms while allowing for change.

At subsequent seminars and in state-of-the-art reports, KASAM has on different occasions addressed the issue of the content of the environmental impact statement (EIS) that must be appended to an application for a permit to build a final repository for spent nuclear fuel. An international conference held in 1994 was presented in KASAM's state-of-the-art report for 1995 (Chap. 5). The issue recurred in the 1998 state-of-the-art report, where a seminar held in 1997 was presented. Besides the EIA process, the seminar dealt with questions such as: How are the municipal permit applications processed? What laws apply? What does the municipal veto entail? But the seminar concentrated largely on the imminent site selection process (see Chap. 5).

6.3 The future decision process

The spent nuclear fuel issue has been the subject of a decision process going back more than 30 years that has included many decisions both by SKB and by public legal bodies. The public decision process entered a new phase in November 2006 when SKB submitted an application under the Nuclear Activities Act for a permit to build an encapsulation plant for spent nuclear fuel immediately adjacent to Clab in Oskarshamn and announced that it will submit an application in 2009 for a permit to build a final repository for spent nuclear fuel.

On 15 November 2006, KASAM held a seminar entitled "Slutförvaring av använt kärnbränsle – regelsystem och olika aktörers roller under beslutsprocessen" ("Final disposal of spent nuclear fuel – regulatory system and roles of different actors during the decision process", KASAM Report 2007:1e). The purpose of the seminar was to describe the regulatory system and the roles of different actors during the decision process. Another goal of the seminar was to identify any unclear points during this decision process. Another question of interest was the way in which the background material for a future decision is gathered.

The following presentation is based on the recently mentioned report from KASAM's seminar in November 2006.

The decision process is mainly regulated by three laws: the Environmental Code, the Nuclear Activities Act, and the Planning and Building Act. These three laws are central in three different decision processes with certain common points of contact.

The decision process under the Nuclear Activities Act

As mentioned above, SKB submitted an application under the Nuclear Activities Act in the autumn of 2006 for the encapsulation plant and intends to submit an application under the Nuclear Activities Act in 2009 for a permit to build a final repository for spent nuclear fuel. These applications are being processed by SKI (in close cooperation with SSI), which will submit a statement of comment to the Government. It is already clear that SKI will not submit a statement of comment to the Government on the former application until a decision has been made on an application for a final repository and that this decision process will somehow be coordinated with the decision process under the Environmental Code (see below). The Government will then make a decision to grant or reject the two applications under the Nuclear Activities Act. If permits are granted, SKI and SSI will issue special conditions.

The decision process under the Environmental Code

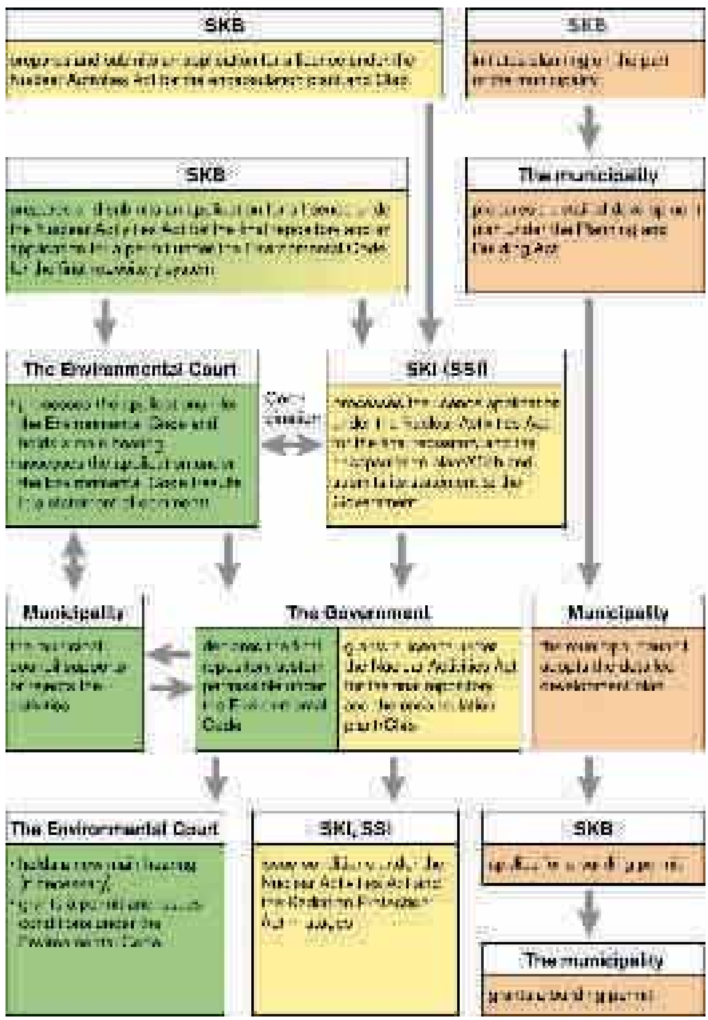
In 2009 SKB plans to submit an application for a permit under the Environmental Code for the entire final repository system. This application is being processed by the Environmental Court, which will submit a statement of comment to the Government. During its processing of the matter, the Environmental Court will solicit viewpoints from SKI and SSI, among others. A Government decision on permissibility under the Environmental Code assumes in principle that the municipal council of the concerned municipality supports the application. If the municipal council opposes the application, the Government may not allow the activity (municipal veto). If the Government finds that the activity is permissible, the Environmental Court will probably hold a new hearing and announce a decision on a permit and conditions under the Environmental Code.

The planning process

When SKB submits applications for permits for the encapsulation plant and the final repository, the concerned municipality also initiates the planning process. The municipality prepares a detailed development plan in accordance with the Planning and Building Act. If the Government gives its permission for the facility, the municipal council adopts a detailed development plan, which then serves as a basis for SKB's application for a building permit.

Figure 6.2 illustrates the different steps, the different laws and the different actors in the licensing process, i.e. the basic structure of the future decision process. It contains many details, which are examined in KASAM rapport 2007:1 (in Swedish only). In conjunction with the seminar, some unclear points were identified in the decision process that may need to be clarified. These unclear points manifest themselves in three different areas.

Figure 6-2 Main features of the process up to a decision in the nuclear waste issue (from KASAM Report 2007:1e, p. 17)



Source: SKB Rapport R-06-50 p. 20 (in Swedish only).

Unclear points when it comes to coordination of the processing of the applications within and between administrative and licensing authorities, the Environmental Court and the Government Offices
An important prerequisite for a democratic decision process is that the processing of different matters by the authorities takes place in an open and transparent manner. How will the Environmental Court examine SKB's applications, and how does SKI determine whether SKB complies with the requirements of the Nuclear Activities Act? How does SSI determine whether SKB complies with SSI's regulations? How will this be done in practice when the Government and its offices examine the matters under the Nuclear Activities Act and the Environmental Code?

6.3.1 Unclear points in the use of certain essential terms and concepts

Different terms or normative principles are sometimes used in the public discussion about final disposal without stipulation as to whether they are taken from acts, ordinances, regulations or recommendations. Furthermore, the terms are often used in different senses and sometimes in an unclear manner. Examples of such terms are:

- Alternative methods, alternative designs and best available technology.
- Alternative sites, suitable site and best site.
- Optimization.

KASAM considers it urgent in future discussions that these terms be clarified and that their normative status be established.

6.3.2 Unclear points regarding the underlying purpose of the final repository

In connection with the permissibility assessment under the Environmental Code, the determination of the purpose of the proposed facility is of central importance.

Purpose formulations answer the question "why?" What is the reason for wanting to build a final repository for spent nuclear fuel? The answer to this question is fundamental to answering the next logical question, namely how should a final repository be realized, in other words the method, design and site issues. These different steps in the reasoning process must be observed by the applicant.

The purpose of a final repository is not local acceptance or to apply a given method (for example the KBS-3 method). The purpose of a final repository for spent nuclear fuel has ultimately been formulated by society at the political level (parliament or Government). In this case a general statement of purpose can be found in the Nuclear Activities Act. Section 10 states that "the holder of a licence for nuclear activities shall be responsible for ensuring that all measures are taken that are required for ensuring the safe management and final disposal of nuclear waste arising in the activities...".

SKB described the purpose of the final repository for spent nuclear fuel in the following manner in its application in November 2006 for a permit to build an encapsulation plant:

> SKB's purpose is to create a final repository for spent nuclear fuel from the Swedish nuclear reactors 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.
>
> 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…

KASAM considers it urgent to establish to what extent this purpose is supported by various statutes and other statements of a policy character that have been adopted by the Government, the Riksdag (parliament) and the regulatory authorities.

6.4 Concluding reflections

The decision process in the nuclear waste issue involves a number of legal problems, several of which were examined in the autumn of 2006 at KASAM's seminar on regulatory systems and the roles of different actors during the decision process (see KASAM Report 2007:1e). One special problem has already been discussed. SKB has chosen to divide the application process into two steps where they will first apply for a permit under the Nuclear Activities Act to build an encapsulation plant and three years later submit an application under the Environmental Code to build the encapsulation plant and applications under both the Nuclear Activities Act and the Environmental Code to build a final repository.

Some criticism was levelled at this division during the seminar. The application for the encapsulation plant binds the application for the final repository to a given method, the KBS-3 method. The critics said that the discussion of alternatives in the application for the final repository would be rendered irrelevant by the fact that that the application to build an encapsulation plant assumes that the KBS-3 method will be used. This would make it very difficult to take a step back and take an objective look at alternatives in 2009. The regulatory authorities said that they did not intend to rule on the application for the encapsulation plant submitted in the autumn of 2006 before they had seen the complete environmental impact statement in the application for the final repository in 2009. According to the regulatory authorities, one reason for this standpoint was that they cannot assess the KBS-3 method until they have a complete body of material, which means in practice not until 2009, according to SKB's timetable.

Representatives of SKB responded to this criticism at the seminar. In the first place, it is important to get going with the actual review process as early as possible. "It is an advantage that SKI and SSI have an opportunity to become acquainted with the process of encapsulation" (KASAM Report 2007:1e p. 41). But the authorities are not expected to arrive at any decisions until all the background material is available. In the second place, the work with encapsulation has come so far that the time was (November 2006) considered ripe to submit an application.

During the course of the process and at critical decision occasions, it is likely that decision-makers and citizens in general will be faced with the fact that experts disagree on various issues. An example of such an issue is that there is no scientific consensus regarding the suitability of the Baltic Shield to host a final repository. Sweden has a bedrock that has been stable for hundreds of millions of years and can therefore be expected to remain stable

– barring any disasters with global consequences (such as gigantic meteorite impacts) – until the radioactivity of the nuclear waste has declined to a harmless level in several million years. This is naturally not 100% certain, but it is nevertheless a claim that gives us some ground to stand on. However, dissenting opinions have been expressed claiming that the crystalline bedrock is neither stable nor predictable.

We can distinguish the contours of a well-known dilemma: how can private citizens make a well-founded choice in a question where even well-informed experts cannot agree? The currently topical issue of global warming illustrates the same dilemma. There is broad, but not total, scientific consensus that man is contributing significantly, through greenhouse gas emissions, to the warming of the Earth's atmosphere. The UN Intergovernmental Panel on Climate Change (IPCC) has shed light on the destructive consequences such as drought and floods for the world's populations, particularly in less developed countries. But there are dissenters who challenge these claims.

The previously described RISCOM model is a method that can be used to resolve the dilemma in the democratic decision-making process caused by the failure of experts to agree. How can transparency in the nuclear waste issue be achieved in practice? "A key to ensuring that different opinions are heard is involving different groups in society – it should not just be the traditional group of experts who participate. Only then do we get different slants on the issue. In other words, broad participation is vital. Furthermore, this transparency programme must be fully public. Only then can private citizens obtain the full insight that is required in a democratic society. Another prerequisite is that the body that organizes the transparency programme must be perceived as neutral, i.e. as not having any particular bias or preference. There should be a force that has transparency as its identity" (Andersson 2007, p. 12, in Swedish only).

The decision that we will soon have to face is whether the KBS-3 method should be implemented or whether we should wait for better solutions that might become available in the next few decades or even further in the future (better solutions may of course come to light during the time up until the KBS-3 repository is closed). The spent nuclear fuel is being stored in Clab, and the quantity there will grow for as long as we continue to operate the Swedish nuclear power plants. In our attempts to achieve full transparency and consider all arguments, the arguments that are put forward not to implement KBS-3 must also be challenged, and problems that may have to do with, for example, monitored storage and long-term financing must be addressed.

In conclusion, we would once again like to reiterate the guiding principle formulated by KASAM in the late 1980s for the management of nuclear waste: "A final repository should be constructed so that it makes inspection and controls unnecessary, without making inspection and controls impossible. In other words, our generation should not place the entire responsibility for the final repository on future generations, but neither should we deprive future generations of the option of assuming responsibility" (1992 state-of-the-art report, pp. 15-16). This principle attempts to balance the responsibility of the current generation against the freedom of choice of future generations.

Achieving such a balance is easier said than done, however. This question also came up at the seminar in November 2006. What does the law say about the possibility of future generations to retrieve the nuclear waste from the final repository? It was made clear at the seminar that retrievability is not mentioned at all in the relevant laws. There is, however, a formulation in SKI's regulations about final disposal of spent nuclear fuel (SKIFS 2002:1) that should be noted. There it says in Section 8:

> The impact on safety of such measures that are adopted to facilitate the monitoring or retrieval of disposed nuclear material or nuclear waste from the repository, or to make access to the repository difficult, shall be analyzed and reported to the Swedish Nuclear Power Inspectorate.

This regulation can be interpreted as saying that a special reason is required to facilitate retrieval and possibly also that safety may not be compromised for the sake of retrievability or inspectability. SKB's president expressed a similar opinion at the seminar in November 2006. The fundamental requirement is long-term safety. But he added at the same time that "we also see it as an advantage that there is a technical possibility to retrieve canisters after closure, should future generations wish to do so" (KASAM Report 2007:1e, pp. 41-42) and that KASAM had previously stated that there is a value in combining long-term safety with freedom of choice (for future generations). KASAM still has the same basic attitude, something which should be noted in every comment on the KASAM principle. The current generation has a responsibility for the safety of future generations – and for their freedom of choice. But whether these two values – safety and freedom of choice – can be realized without one encroaching on the other is a question that is still unanswered. Perhaps it will be answered in SKB's application in 2009 for a permit to build a facility for the final disposal of spent nuclear fuel.

7 References

This report is largely based on a survey of committee reports, parliamentary publications and statutes during the period in question. A survey has also been made of the eight programmes for research, development and demonstration of methods for the management and disposal of nuclear waste presented by the Swedish Nuclear Fuel and Waste Management Co (SKB) during the period 1986-2004, the review statements on these programmes published by KASAM and the Government decisions that have been made in response to these RD&D programmes. KASAM's state-of-the-art reports, which are published every third year, have also served as a basis for this report, along with the in-depth reports for this year's state-of-the-art report. Another background document is SKB's application in November 2006 for a permit under the Nuclear Activities Act for an "encapsulation plant and a central interim storage facility for spent nuclear fuel at Simpevarp in Oskarshamn Municipality". Other documents referred to in this report are listed below.

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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 the following main report entitled *Nuclear Waste, State-of-the-Art Report 2007 – responsibility of current generation, 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 fuel – 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).

The purpose of this main report to provide an overall picture in relatively easily accessible form of all our assessments since the first state-of-the-art report in 1986. Some of it has of course been rendered obsolete by subsequent events, but surprisingly much is still relevant. Another purpose is to describe in general terms the course of events within which these assessments were made in order to contribute to a fundamental understanding of the complexity of managing the nuclear waste issue.

The report is available on www.kasam.org. It can also be ordered at kasam@environment.ministry.se.

Fritzes
ett Wolters Kluwer-företag

106 47 Stockholm Tel 08-690 91 90 Fax 08-690 91 91 order.fritzes@nj.se www.fritzes.se

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