THE SWEDISH PROGRAM HAS ENTERED THE SITE SELECTION PHASE

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ABSTRACT

Facilities for intermediate storage of spent fuel and HLW and for final disposal of ILW and LLW together with a system for sea transportation have been in operation in Sweden for more then 15 years. To complete the "back end system" the remaining parts are to build facilities for encapsulation and final storage of spent fuel and HLW. The Swedish reference method for final disposal of spent fuel, KBS-3, is to encapsulate the fuel elements in copper canisters and dispose them in a deep geological repository.

The Swedish program up to 2001 was focused on the establishment of general acceptance of the reference method for final storage and SKB´s selection of candidate sites for a deep geological repository. In the end of year 2000 SKB presented a report as a base for a Government decision about the siting process. This report gave the background for the selection of three candidate sites. It also presented the program for geological surveys of the candidate sites as well as the background for the choice of the method for final disposal of spent nuclear fuel and HLW.

In the end of 2001 the Swedish government endorsed the plan for the site selection phase and stated that the KBS-3 design of the repository shall be used as the planning base for the work. Permissions were also granted for the fieldwork from the municipalities of Forsmark and Oskarshamn where the candidate sites are located. Site investigations on these two sites started during 2002.

The technical development and demonstration of the KBS 3-method is ongoing at the Äspö Hard Rock Laboratory and the Canister Laboratory. The goal for the coming five years period is to select the site for the repository and apply for licences to construct and operate the facilities for encapsulation and final storage of spent fuel. The encapsulation plant and the repository are planned to be in operation around year 2015.

INTRODUCTION

Today about 50 % of the electricity in Sweden is generated by means of nuclear power from the remaining 11 reactors located at four sites and with a total capacity of 9 600 MW. Eight of the reactors are BWR and three PWR. The Swedish government has decided to start phasing out nuclear power for political reasons. The first reactor at Barsebäck was shut down at the end of 1999 after 25 years of operation. It is planned to also shut down the second reactor at Barsebäck in a few years if the power supply is secured by other means. The first commercial reactor was put in operation in 1972 at Oskarshamn and the latest in 1985. As of now about 4000 tonnes U of fuel have been used in the power production. If all remaining reactors are operated for 40 years, it will result in a total amount of about 9 000 tonnes.

The responsibility for the management of the spent nuclear fuel, as well as for other radioactive residues from nuclear power production, lies with the operators of the nuclear power plants, i.e. the four nuclear utilities. The utilities have jointly formed SKB, the Swedish Nuclear Fuel and Waste Management Company, to safely manage the spent fuel and radioactive waste from the reactors to final disposal. The task of SKB is thus to plan, construct, own and operate the systems and facilities necessary for transportation, interim storage and final disposal.

SKB has developed a system that ensures the safe handling of all kinds of radioactive waste from the Swedish nuclear power plants for a long time period ahead. The keystones of this system are, see Figure 1.

- A transport system with the ship M/S Sigyn which has been in operation since 1983.
- A central interim storage facility for spent nuclear fuel, CLAB, in operation since 1985.
- A final repository for short-lived, low and intermediate level waste, SFR, in operation since 1988.

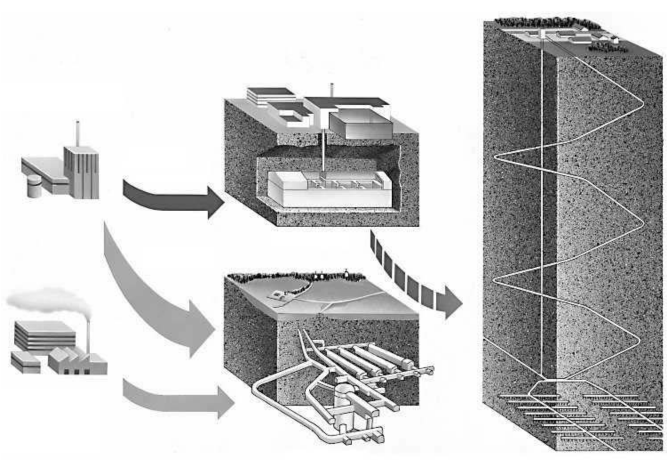

Figure 1. *The Swedish system for handling of radioactive waste*

In CLAB the fuel assemblies and core-components are stored in water pools in a rock cavern. The Government gave permission for the expansion of CLAB in August 1998. Construction of a second storage cavern has started and the work shall be finished in 2004.

The goal for the Swedish program up to 2007 is now to investigate and evaluate the candidate sites and to select one site for application of a license to construct a deep repository for spent fuel. At the same time as the technical work proceeds at the two candidate sites the Environmental Impact Assessment work continues with extensive dialogues and discussions with all interested stakeholders (the public, politicians, societies etc). This work will result in an Environmental Impact Statement to be handed in with the application for the deep repository. The encapsulation plant and the deep repository are planned to be in operation around year 2015.

THE KBS-3 METHOD

The Swedish reference method for final disposal of spent fuel, called KBS-3, is to encapsulate the fuel elements in copper canisters and place them in a deep geological repository. The remaining facilities for management of the spent fuel, see Figure 2, will be designed during the site selection phase. The work of adapting the layout and design of the deep repository to site-specific conditions at the chosen municipalities has now started. For each studied site, solutions for sub-systems are combined to form a complete facility. Construction analyses will be performed to evaluate the solutions as regards important construction-related factors, possible construction methods, resource requirements, etc.

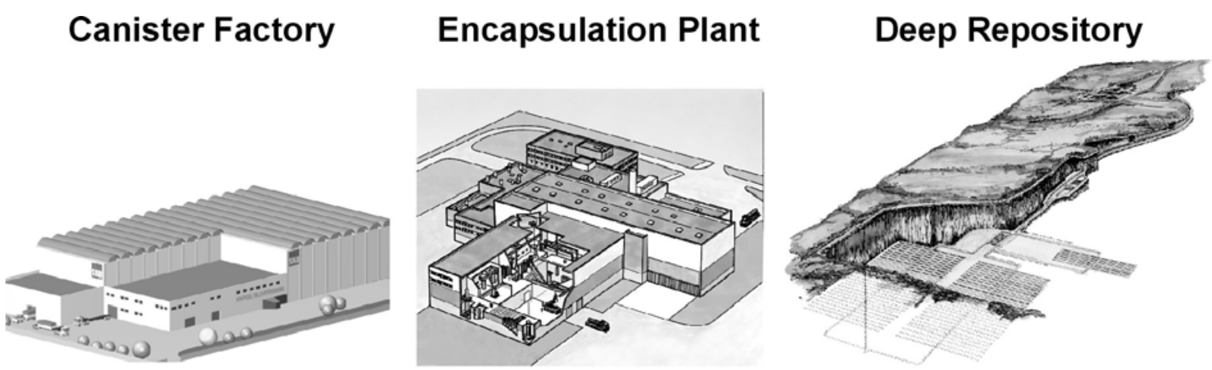

Figure 2. *The planned facilities for encapsulation and final disposal of spent fuel*

The design process includes design of both facilities and equipment above and below ground, as well as planning of the activities during the construction and operation phases. The deep repository is designed in steps that represent a gradually increasing level of detail. In the course of the work, system studies are conducted to investigate layouts and sub-systems. Earlier phases of the design work have resulted in a facility description with examples of how the deep repository can be configured.

The encapsulation is planned to take place in a new plant preferably to be built in connection to the central storage for spent fuel, CLAB. The fuel is today stored in water pools situated in a rock cavern. The storage capacity is 5000 tonnes of uranium. An extension of the storage capacity up to 8000 tonnes is now underway by construction of a new rock cavern. In the encapsulation plant fuel from CLAB’s storage pools will be placed in canisters after having been checked and dried.

The encapsulation process then is carried out in a number of working stations. Finally the canister is sealed and checked from contamination and placed in a buffer storage before transport to the repository.

RD&D PROGRAMME 2001

In accordance with the Swedish Nuclear Act SKB every third year presents a programme for research, development and demonstration of encapsulation and geological disposal. The latest report was published in 2001, the RD&D Programme 2001.

The methods for pre-investigation of candidate sites have been tested at the Hard Rock Laboratory at the island of Äspö situated close to the Oskarshamn NPP. The Äspö HRL is today also used for development of detailed investigation methodology and tests of models for description of the barrier function of the host rock. Tests of construction methods as well as demonstrations of technology and function of important parts of the repository system are also conducted at Äspö HRL. A special "Prototype Repository" is constructed in the laboratory. Copper canisters, without active material but equipped with heaters, have been placed in deposition holes and embedded in bentonite clay. Also methods of retrieval of canisters embedded in saturated bentonite clay will be tested in full scale at the laboratory.

SKB is also conducting a program for planning and testing methods for the encapsulation of spent nuclear fuel. At the time when the pre-investigations of sites for the repository have started SKB plans to submit an application for construction of an encapsulation plant. The canister is planned to consist of an insert of e.g. iron, which provides mechanical strength, and an outer layer of copper, which provides corrosion protection. Trial fabrications of canisters have been performed during recent years for development of manufacturing methods. Design of a "canister factory" is also a part of the program.

In order to test the methods for sealing and testing of canisters, SKB has built a laboratory for encapsulation techniques in Oskarshamn, the Canister laboratory. Electron beam welding is used for sealing of the copper-lids on the canisters. Ultrasonic- and x-ray-equipment is used for non-destructive testing. The Canister Laboratory will also be used for testing of other parts of the encapsulation process.

Repository Technology

Design and construction of the deep repository is proceeding in a stepwise way. Detailed characterisation of the host rock and initial design of the deep repository will follow the site investigations. The environmental impact of the deep repository was preliminarily studied in conjunction with the feasibility studies. A generic preliminary description of land needs, design of buildings, transportation system was provided as a base for the adoption to the selected sites. The scope of the environment impact depends on the quantity of extracted rock and the scope of new infrastructure, among other things.

The choice of various solutions, such as type of descent (shaft and/or ramp) and the location of the repository's rock caverns and tunnels in relation to each other and to the surface facilities, is dependent on the conditions on the selected site. The choice of descent and its location are determined in the first site investigation phase, while the detailed layout of deposition areas will not be determined until the results of detailed characterisation are available. A detailed environmental impact assessment will be presented when SKB applies for a permit to construct the repository.

The detailed characterisation phase extends in time from approval of the siting permit up until a licence has been obtained for initial operation. During this phase, the deep repository is built to full depth and rock chambers are excavated in parallel with investigations of the rock. The deposition of 200–400 canisters containing spent nuclear fuel is planned during initial operation. According to SKB's long-term plans, the repository will be commissioned around 2015.

The Äspö HRL

One of the fundamental reasons behind SKB's decision to construct the Äspö HRL (Hard Rock Laboratory) was to create an opportunity for research, development and demonstration in a realistic and undisturbed rock environment down to repository depth. Äspö HRL is a generic (not site specific) laboratory. It is a "dress rehearsal" for the coming work with site characterisation, construction, commissioning and operation of the deep repository. Our general experience is that a lot can be learnt and developed in generic laboratory.

According to plans, the activities at the Äspö HRL will continue until the initial operating stage of the deep repository is finished around 2020 -2025. An integrated evaluation of experience from this initial operation and the results from the Äspö HRL will thus provide supporting material for an application for a licence for regular operation of the repository. An important role for the Äspö HRL in this perspective is to conduct long-term experiments where different aspects of importance for the performance of the deep repository are tested over a long time, in some cases up to 15–20 years. The experiments in the "Prototype Repository" focus on monitoring of the function of the repository system and the interaction of the parts of the repository. Certain activities aimed at development and testing of practical solutions for carrying out deposition have also been included. Altogether, six deposition holes have been made in a TBM-bored tunnel, two in an inner section and four in an outer. The tunnel is backfilled with a mixture of bentonite and crushed rock, and a plug will separate the two sections. The Prototype Repository differs from a real repository in that heaters generate the heat instead of spent nuclear fuel. The experiments in the Prototype Repository will continue for about 20 years.

Research on backfilling with mixtures of bentonite and crushed rock is currently being done to a large extent at the Äspö HRL within the framework of the Backfill and Plug Test. In the experiment, a tunnel has been backfilled with crushed rock and with a mixture of 70 percent bentonite and 30 percent crushed rock. The tunnel has been sealed with a plug designed to resist full water pressure and the bentonite's swelling pressure. Drainage mats are used to hasten the wetting of the backfill. During the test, the water flow in the backfill is measured. This is done in the unsaturated state (during the water saturation process) and in the water-saturated state.
In the "Canister Retrieval Test", methodology and equipment are being developed and tested to retrieve the canister from a water-saturated and swelled bentonite buffer and it is being demonstrated how a freed canister can be retrieved under realistic conditions. The project was started in 2000 when bentonite and a canister of natural size with a heater were deposited in a

full-sized deposition hole. The rock is instrumented for monitoring of temperature, rock stresses and rock movements. Furthermore, the deformation of the copper shell and the temperature of the canister are measured. After the bentonite has been water-saturated, which is expected to take between three and five years, SKB will demonstrate how a canister can be freed and retrieved.

Encapsulation of Spent Fuel

SKB is conducting a program for planning and testing methods for the encapsulation of spent nuclear fuel. The canister is planned to consist of an insert of e.g. iron, which provides mechanical strength, and an outer layer of copper, which provides corrosion protection. Trial fabrications of canisters have been performed during resent years for development of manufacturing methods. Design of a “canister factory” is also a part of the program.

The canister consists of a pressure-bearing insert of spheroidal graphite iron (nodular iron) with a steel lid. An outer corrosion barrier of copper is surrounding the insert. There are several different methods for fabricating copper tubes, inserts, lids and bottoms. The final selection of fabrication method should be made as late as possible in order to maintain flexibility and take advantage of technical advances. The selection does not need to be made until the canister factory is designed, which is planned to begin in 2007.

The encapsulation is planned to take place in a new plant preferably to be built in connection with the central storage for spent fuel, CLAB, which has been in operation since 1985. The fuel is today stored in water pools situated in a rock cavern. The storage capacity is 5000 tonnes of uranium. An extension of the storage capacity up to 8000 tonnes is now underway by construction of a new rock cavern. In the encapsulation plant fuel from CLAB’s storage pools will be placed in canisters after having been checked and dried. The encapsulation process then is carried out in a number of working stations. Finally the canister is sealed and checked for contamination and placed in a buffer storage before transport to the repository.

In order to test the methods for sealing and testing of canisters, SKB has built a laboratory for encapsulation techniques in Oskarshamn, the Canister Laboratory, see Figure 3. Electron beam welding is used for sealing of the copper-lids on the canisters. Ultrasonic- and x-ray-equipment is used for non-destructive testing. The Canister Laboratory is also used for testing of other parts of the encapsulation process. Alternative welding methods are also being studied. One method which is under development and which has produced good results in practical trials for several years is Friction Stir Welding. The technology shall be transferred to the Canister Laboratory to continue development there on a full scale during 2003.

The selection of methods for welding and testing influences the design of the encapsulation plant and should therefore be completed by the time for application for a permit to erect the plant. At that time there will also be a programme for qualification of the methods. Qualification of the methods will be done at a later stage, prior to encapsulation of the spent fuel.

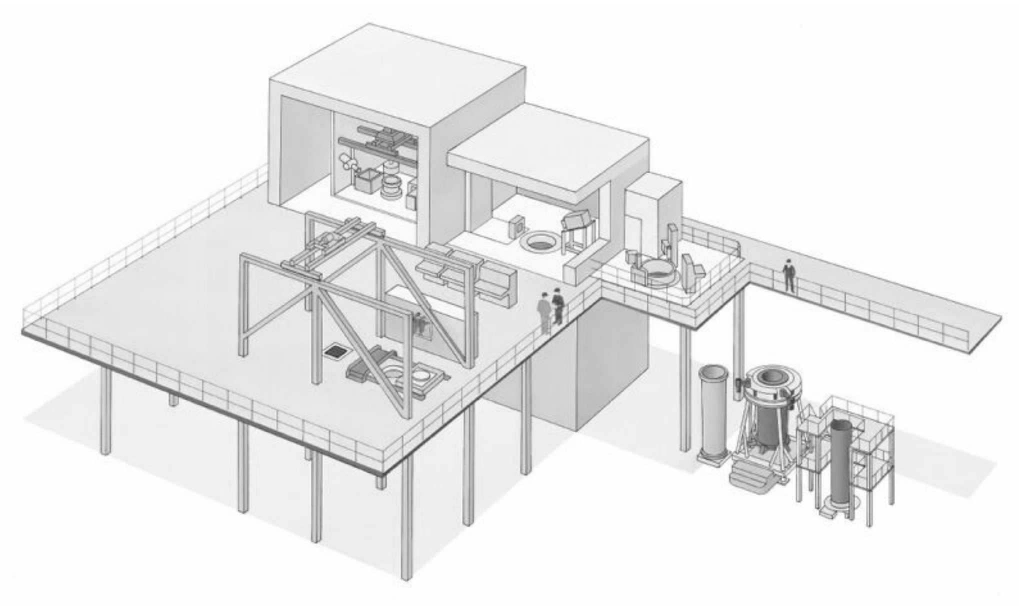

Figure 3. *Interior from SKB´s Canister Laboratory at Oskarshamn*

Development work on electron beam welding (EBW) at the Canister Laboratory is aimed at developing equipment and welding parameters to arrive at a stable process with high reliability where the sealing weld meets the durability and strength requirements. To develop EBW in thick copper, SKB started a project in 1982 at TWI (The former Welding Institute). A machine specially designed for welding of copper canisters was developed for use in the Canister Laboratory.

Development of an alternative method of joining copper by friction stir welding (FSW) was started at TWI in 1996. The fundamental difference from EBW is that the material does not melt when joined. In FSW, a specially designed rotating tool is used. It is equipped with a central probe that is pressed down between the joint surfaces. Because the metal doesn't melt and the temperature can be kept to a relatively low level by controlling the process parameters, a fine-grained, homogeneous structure is obtained in the weld.

Most of the practical work of developing methods for NDT is done at the Canister Laboratory. The weld is tested by several methods. The whole weld is radiographed to detect volume discontinuities (pores). The presence of discontinuities that lack volume, for example incomplete penetration, is investigated by ultrasonic inspection with phased array matrix scanning. The scanner head is applied to the top of the canister lid, which is rotated. Eddy-current testing is being developed to detect near-surface discontinuities. The results of NDT are evaluated by means of destructive tests where the actual size of the discontinuities is compared with the measured results.

SITING

The siting programme of SKB is divided in three major stages, Feasibility studies, Site investigations and Detailed characterisation, see Figure 4.

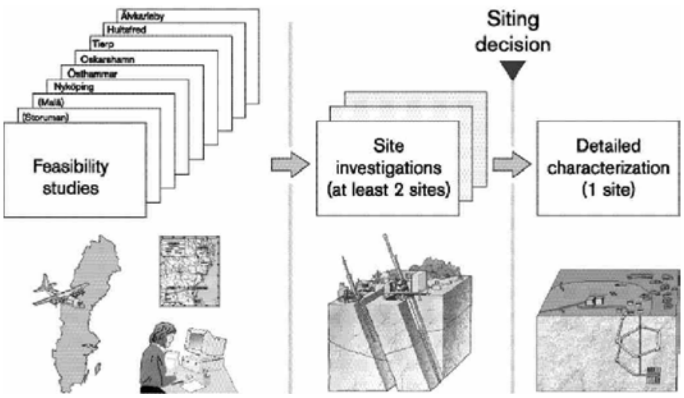

Figure 4. *Siting stages in the Swedish programme*

Since 1992, when the current siting programme for the deep repository for spent nuclear fuel in Sweden started, feasibility studies have been conducted in eight municipalities. In two of these municipalities, Storuman and Malå, feasibility studies were followed by referendums in 1995 and 1997, regarding the question on further participation in the siting process. The inhabitants in both of these municipalities rejected further participation.

In the other six municipalities - Oskarshamn, Östhammar, Nyköping, Hultsfred, Tierp and Älvkarleby feasibility studies were conducted between 1995 and 2001, see Figure 5.

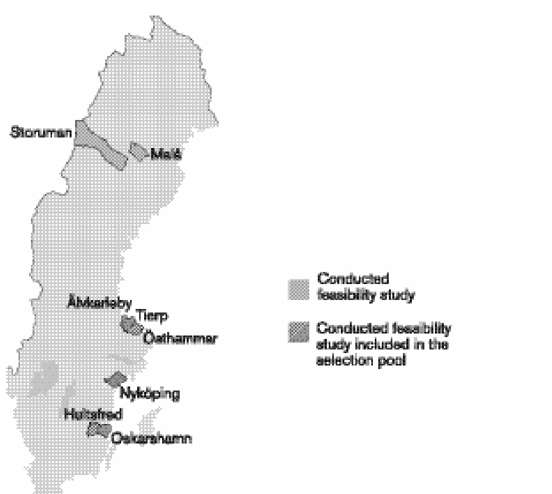

Figure 5. *Municipalities where feasibility studies have been performed*

Stakeholder participation

The feasibility studies contained a lot of technical study work and also set the consultation processes in motion for the municipalities and their inhabitants , the affected county administrative boards, neighbouring municipalities and the safety authorities.

The Swedish Environmental code calls for an Environmental Impact Assessment (EIA) process to be started as early as possible when a project is launched. The whole consultation process, as carried out during the feasibility study period, has formed the actual EIA process in Sweden even if some of the actors claim that the formal legal process (according to the Environmental code) then had not begun. What has been done already though are, as we believe, directly according to what was intended in the law - very early consultations with all interested stakeholders. This also means that a lot of important and interesting questions have been raised and addressed at a very early stage in the Swedish siting process.

The organisation set up by the municipalities to follow the SKB work during the feasibility studies has varied in complexity and strength. In Oskarshamn the whole Community council acted as a reference group for the work. This meant that all the politicians became very knowledgeable about the nuclear waste issues in general and the work in the feasibility studies in particular. Special working groups acted towards specific questions and towards different target groups (including neighbouring municipalities). A key part of the organisation was the so-called EIA-forum - a group consisting of representatives from the municipality staff, the safety authorities, SKB and the Kalmar County Board (chair of the EIA-forum group).

All principal questions in the SKB siting programme has been discussed in the Kalmar EIA-forum group as well as many site specific ones relating to the Oskarshamn municipality. Notes from these meetings are available for any interested stakeholder (also on Internet).

In both Östhammar and Tierp the municipalities formed special project groups to follow the SKB work but the majority of the politicians in these municipalities did not follow the work as closely as the politicians in Oskarshamn did. In Tierp there was also a rather forceful opposition group formed which also had members belonging to political parties represented in the community council. Both Östhammar and Tierp belong to the Uppsala County, which also formed an EIA-forum in the same way as in the Kalmar County. The meetings in the Uppsala EIA-forum can be described as information meetings where all actors explained the current situation.

In what ways have stakeholders then had a chance to get their voices heard during the feasibility study period? Well, everyone could influence this early EIA process and the corresponding decisions in many ways:

1) At direct meetings and hearings set up by the main actors (the municipality in question, the authorities and also SKB).
2) In discussions at the SKB information offices in the municipalities with feasibility studies.
3) Through their representatives in the municipality and the EIA-forum groups.
4) Through the debate in mass media.

Lessons learned from the siting procedure

Some experiences from the feasibility study period regarding the early EIA-process are the following:

- The process itself must be well known and clear to get acceptance. The actors/stakeholders must also see the possibilities for how or in what way the process can be affected or changed and what is fixed.
- Openness and clarity in statements from all actors is absolutely essential.
- All actors in the process must be prepared to answer questions.
- All actors must be prepared to listen to (and learn by) the arguments brought up during the process.
- Discussion in small groups and with the potentially really affected people is the most valuable parts of the process to build trust and to learn about key questions.
- There will never be consensus regarding all questions. The fact that you have a consultation process does not mean that consensus will or have to be reached.
- The attitudes among those working in the process must be reflecting their belief that dialogue and discussion of these questions will create a better repository - both technically and socially. There must be a respect of all stakeholders and their arguments and a willingness to listen and learn.

Selection and decision on sites

In December 2000 SKB reported to the authorities that the preferable selection of municipalities for further Site investigations are Östhammar, Oskarshamn and Tierp. In a report SKB gave the background for the selection of the three candidate sites. It also presented the program for geological surveys of the candidate sites as well as the background for the choice of the method for final disposal of spent nuclear fuel and HLW.

In the end of 2001 the Swedish government endorsed the plan for the site selection phase and stated that the KBS-3 design of the repository shall be used as the planning base for the work. It was also needed to have permissions from the three municipalities where the candidate sites are located. The municipality of Östhammar decided in December 2001 to accept a Site investigation in their municipality. The corresponding positive decision was taken in Oskarshamn in February 2002. In Tierp the community council voted no to further investigations in April 2002.

SITE INVESTIGATIONS

The goal of the site investigation phase is to obtain a permit to build the deep repository for spent nuclear fuel. The permit applications will be based on broad supporting documentation. The investigations of the rock serve as a basis for configuring the underground parts of the deep repository, but will also influence the positioning and layout of the surface parts of the repository. In parallel with the site investigations, consultations will be held with county administrative boards, regulatory authorities and municipalities, as well as with members of the public and organisations that can be expected to be affected, in keeping with the requirements and intentions of the Environmental Code.

The Swedish Government has quired that SKB present a clear programme for site investigations before site investigations commence. Such a programme has been prepared /4/ based on SKB's experience of rock investigations, e.g., from the study site investigations, the Stripa mine and the Äspö Hard Rock Laboratory. The programme describes the scope of the geoscientific information which SKB intends to collect on a site and how the information is to be used in evaluating the suitability of the site for a deep repository. The general programme was supplemented in 2001 by more detailed descriptions, so-called discipline-specific investigation programmes.

A large number of activities are conducted with different purposes during a site investigation. The activities aimed at ascertaining the technical and safety-related suitability of the site for the deep repository can be divided into investigations, design and safety assessment. Each of these activities results in a main report.

The site investigations are divided into two main phases; initial and complete investigations. Initial site investigations are performed to identify the site within a specified area that is deemed to be most suitable for a deep repository and to determine whether the feasibility study's judgement of the suitability of the area holds up in the light of borehole data from repository depth. The initial site investigations are expected to take 2-3 years. If the assessment shows that the site has good potential to host a repository, complete site investigations will follow for an expected duration of 3-4 years.

The number of boreholes in the drilling programmes and the scope of the measurements cannot be specified in advance, since they are dependent on the conditions on the site. A reasonable estimate is that 10–20 cored holes and roughly 20–40 percussion holes are required.
Drilling is carried out in campaigns, where 3–4 holes are drilled. This is followed by measurements and evaluation of the results.

After each drilling campaign the rock models, the layout, and the evaluation of long-term safety are updated. The analysis of the uncertainties in the model descriptions is used to plan the next drilling campaign. The boreholes are positioned and aimed in order, for example, to verify the occurrence, location, orientation and properties of deformation zones and rock type boundaries. A number of holes are drilled to obtain data from potentially suitable repository volumes between the deformation zones. It is the properties and conditions in this bedrock that are most essential for the safety assessment. The results are evaluated in relation to the requirements and criteria and with respect to remaining uncertainties in the description of the site.

Investigations at Forsmark

The area in Forsmark being considered for site investigations is approximately 10 square kilometres in size and extends from the Forsmark industrial area to the southeast.

The bedrock in the Forsmark area is composed mainly of homogenous gneiss-granite with judged normal conditions regarding fracture frequency and local fracture zones. Based on geological mapping of the area and experiences from the investigation and construction of the nuclear power plant and the SFR facility some important site-specific questions that must be addressed are:

- The three dimensional shape of the potential host rock (the tectonic lens).
- Potential for metal-ore occurrence at depth.
- The possible occurrence of gently-dipping fracture zones.
- The occurrence of high rock stresses.

Besides these site-specific questions, other general questions must also be considered. These are concerned for example with the occurrence and frequency of dikes and fracture zones, the hydraulic conductivity of the fracture zones and the surrounding bedrock, flow paths for groundwater and the chemical, thermal and rock-mechanical conditions. Long-term changes in surface runoff, groundwater flow and groundwater chemistry must also be assessed.
The initial site investigation will take place over a period of about 3 years and includes the following main tasks:

- The properties of the bedrock will be investigated with three deep cored boreholes which will be drilled along the centre-line of the area.
- Fracture zones in the area and its surroundings will be studied by means of geological mapping, geophysical measurements from a helicopter and from the ground surface, and by means of percussion boreholes.
- The boundary zones of the area in the Northeast and Southwest will be investigated with two deep cored boreholes (the position of the boreholes can be decided first when the investigations in the previous point have been completed).
- The initial site investigation phase concludes with an overall evaluation and a decision whether to commence with complete site investigations or to terminate further work on the site.

Investigations are currently in progress and the first deep borehole has reached its final depth of 1000 m (November 2002), see Figure 6.

Figure 6. *Drillcore from the first borehole at Forsmark.*

Investigations at Simpevarp

Well-preserved granites formed 1900-1650 million years ago dominates the bedrock in the municipality of Oskarshamn . The feasibility study showed that most of the northern part of the municipality has bedrock that is judged to be of interest for further studies from a geological viewpoint. The choice of the Simpevarp area is based on the fact that the deep repository's industrial operation can be co-sited with the existing facilities on the Simpevarp Peninsula and that the repository can be built in suitable bedrock at as close a distance as possible.
In the initial phase the site investigation will be focused on investigating the conditions at depth on the Simpevarp Peninsula and on identifying a site further west that is suitable for test drilling. The main question for the Simpevarp Peninsula is whether the area is big enough for a deep repository, given the existing fracture zones. Moreover, information is lacking on those properties of the bedrock at depth within the peninsula that are generally of great importance for long-term safety and constructability. A few deep boreholes, together with data from surface investigations and existing rock caverns and tunnels, should suffice to determine whether it is worthwhile to proceed with complete site investigations on the peninsula. The existing facilities limit the opportunities for carrying out some of the geophysical ground and airborne measurements that are included in the general programme, mainly with electrical methods.

For the area west of the Simpevarp Peninsula, the main question for the investigations is to find out the location and properties of fracture zones and thereby where bedrock blocks are located within which a deep repository can be built.

Investigations are currently in progress and the first 1000 m deep borehole on the Simpevarp Peninsula has been completed.

Selection of a final site

The investigations at the two potential sites have started with surface investigations and drilling. SKB expects to proceed the current program of investigations and consultations with authorities and the public in order to submit a licence application for one of the investigated sites in 5 to 6 years time.

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